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THE CONSERVATION OF HEARING IN INDUSTRY

by

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ABSTRACT

THE CONSERVATION OF HEARING IN INDUSTRY

A discussion of the need for a technique which would reduce the incidence of industrial hearing loss by increasing the use of hearing protection suggested that Industrial Audiometry could act in this manner and a research programme was accordingly designed to investigate this hypothesis.

Following a general survey of hearing conservation problems on a large industrial site and the consequent development of the specification for a comfortable earmuff, a controlled study was conducted in 8 plants, employing 1716 individuals. The power of audiometry to increase hearing protector usage and change attitudes towards the conservation of the hearing was compared with that of a programme of education, and that of a programme which contained both audiometry and education. The effectiveness of each of these three treatments was measured using specially developed attitude questionnaires and objective measurements of the change in hearing protector usage with time.

The results showed that industrial audiometry produced signficant and positive long term changes in hearing protector usage and attitudes towards the conservation of the hearing. Additionally audiometry was shown to be a more successful method of changing these attitudes and increasing hearing protector usage than a programme of standard education. However, the efficiency with which industrial audiometry could change attitudes was shown to be reduced when it was added to the education to produce a mixed programme. Moreover, such a mixed programme could not be said to be more effective in increasing hearing protector usage than audiometry used alone.

As a consequence of these findings, recommendations are made as to the optimum balance between audiometry and education in a hearing conservation programme. It is suggested that more use should be made of audiometry as a motivational tool in hearing conservation than has hitherto been the case.

An analysis was also completed of 954 audiograms obtained during the research programme. Amongst other conclusions it was shown that the link suggested in the literature to exist between eye colour and noise induced hearing loss had no basis in fact, and that the main audiogram analysis procedure presently recommended for use in the UK was not the optimum method.

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"My mother's deafness is very trifling you see, just nothing at all. By only raising my voice and saying anything two or three times over she is sure to hear" - Miss Bates in Emma, Chapter 19 by Jane Austen.

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CHAPTER 1

PREVENTING NOISE INDUCED HEARING LOSS IN INDUSTRY

1.0 Introduction

The main sections of this thesis describe a study of the power of industrial audiometry to protect the hearing of the noise exposed workforce by increasing the usage of ear protection and changing certain attitudes held by employees.

The field work was completed at the ICI site in Middlesbrough, subsequent to the publication in 1975 of a Health and Safety Executive Discussion Document entitled "Framing Noise Legislation" (Health and Safety Executive 1975) in which the position of industrial audiometry in a hearing conservation programme was described as being of relatively little importance. It was intended that the investigation described in this thesis should serve to evaluate the manner in which industrial audiometry could be of benefit in a hearing conservation programme, other than of providing a surveillance of hearing levels.

Work at ICI culminated in a short presentation to a meeting of the Works Managers of ICI Middlesbrough early in 1981. A complete analysis of the data has been reserved for this volume and the results are discussed in the light of the body of current literature with particular reference to the issues raised by the conflicting requirements for industrial audiometry given in the 1981 Draft UK Regulations on industrial noise, and the 1986 European Directive on the same topic. (Health and Safety Commission 1981, Commission of the European Communities 1986). This conflict must be resolved by 1990, when the UK is required to have enacted full noise laws under the Health and Safety at Work Act (1974).

Efforts have been made over the last 2-3 decades in the UK to reduce the risk of employees sustaining a noise induced hearing loss through exposure to excessive levels of industrial noise. Publication of the documents "Noise and the Worker" (Ministry of Labour 1963) and the 1972 "Code of Practice for Reducing the Exposure of Employed Persons to Noise"

(Department of Labour 1972) are evidence of these efforts. Under the 1972 Code hazard is deemed to commence in the UK at levels of noise which cause an employee to receive more noise energy than that resulting from an 8 hour exposure to a noise level of 90 dB(A), an exposure otherwise known as 90 dB L_{Aeq}. (Health and Safety Commission 1981).

Despite the publication of the 1972 Code of Practice, and the later draft UK noise regulations in 1981, referenced earlier, approximately one million employees in the manufacturing industry alone were shown still to be exposed to hazardous levels of industrial noise in 1983 (Health and Safety Commission 1984, British Standards Institute 1983). Employment statistics permit an extrapolation of this figure to 1.75 million employees from all segments of the working population still exposed in 1985. (Central Office of Information 1985). Mr Selwyn Gummer, during his term as Under Secretary of State for Employment, stated that "deafness is the second most common industrial disease, the first being back pain, the incidence of which is more widely spread". Burlison, Regional Secretary of the General Municipal and Boilermakers Union is quoted as claiming that "already the lives of half a million workers have been ruined by industrial deafness in the North East of England alone" (Guardian 1983). He generated an interesting analogy, placing the problem into an accurate perspective; "If we were talking about half a million people losing their sight because of an industrial process there would have been a public outcry years ago".

It is apparent, therefore, that those social and instinctive personal reactions which serve to protect the sight do not appear to operate in the same way to protect the hearing. Substitute mechanisms, or pressures, must be found. That legislation is not one such pressure was suggested in 1974 when the Chief Inspector of Factories concluded in his annual report of that year that despite the introduction in 1972 of the UK Code of Practice on Noise, a recent survey conducted by his organisation had shown "no significant evidence of a general improvement" (Chief Factor Inspector 1974).

Certainly the Health and Safety Executive do not need new noise legislation to enhance their powers of prosecution, for actions can already be started under the 1974 Health and Safety at Work Act. This is exemplified by the prosecution brought against John Haggas Ltd, a weaving company in Keighley, West Yorkshire. The company was fined an "exemplary" £1000 for taking insufficient steps to ensure that the workforce used hearing protectors in a industrial environment in which the noise levels reached sound pressures levels of 101 dB(A). (Times 1984). In the previous year the Health and Safety Executive (HSE) had also succeeded in a case brought against Michael Carr, a 27 year-old labourer at Bottoms Mills, Todmorden. Carr had persistently refused to wear the hearing protection provided in direct contravention of the 1974 Health and Safety at Work Act (Health and Safety at Work 1983).

Gummer, during the debate in the House of Commons referenced above, reinforced the concept that new noise legislation would not automatically solve the problem of workplace exposure to hazardous levels of noise, and that other methods of increasing awareness of the hazard represented by noise should be sought. He stated "there is a tendency to suggest that if the government makes a series of regulations they have solved the problem, but that may well be the last stage in solving the problem ... awareness is the key to the (industrial noise) issue. I want the Commission to examine ways to raised the public consciousness of its seriousness".

Section 1.1 of this chapter discusses those forces acting to decrease the auditory hazard in the workplace, whilst section 1.2 develops the argument that the issue of hearing protection is a widely adopted economic solution to the problem of noise exposure, but the usage of this protection by employees is poor. Section 1.2.4.2 discusses, in particular, the concept that industrial audiometry may offer a potent mechanism for increasing hearing protector usage. The main study described in this thesis addresses the hypotheses described in detail in section 1.3.1 which postulate in general that audiometry has the power to increase hearing protector usage, defined herein as behavioural change, and that in addition industrial audiometry can change certain attitudes towards conservation of the hearing. The efficiency of industrial audiometry to function in this way is compared and contrasted with that of standard programmes of education in hearing conservation, and programmes consisting of both audiometry and the standard education element.

The following section examines the three main forces acting to reduce the hazard to the hearing represented by industrial noise. The objective of this examination is to identify the most cost effective mechanism for reducing the incidence of noise induced hearing loss, and to evaluate any potential for increasing the efficiency of this mechanism.

1.1 Forces acting to decrease the auditory hazard in the work place

The three main forces can be defined as moral forces, legislative forces, and forces generated directly or indirectly by the employee and focussed upon the employer. These are discussed in turn below.

1.1.1 Moral forces.

Unfortunately the first of these forces can be discussed and discounted relatively swiftly. Moral forces are those that should motivate good employers and often cause the initiation of altruistic activities. However, in commercial practice a balance has to be struck between the morality of allowing employees to become affected by noise, and the arguably greater morality in the eyes of the employer of ensuring by the generation of profit that employees continue in work. Although the decision to commence hearing conservation activities is often initiated on moral grounds, in the majority of cases the final clearance to proceed with the programme is given by higher management after a cost benefit analysis has been completed, balancing the expenditure necessary against the penalties accruing as a consequence of disregarding the remaining two forces discussed below. At this juncture the motivation is no longer a moral one but financial in nature.

A moral obligation also exists on the employee to comply with the efforts of his employer to ensure a safe place of work. In the experience of the author, however, this force is not particularly strong at the present time in the majority of UK industries, possibly due to the long tradition of management/workforce conflict in which the two appear to believe that they are on different sides of a battle to improve standards of living.

1.1.2 Legislation.

The second force is that generated by legislation and Codes of Practice.

The 1972 "Codes of Practice for reducing the exposure of employed persons to noise" discussed earlier, was followed in 1975 by a document entitled "Framing Noise Legislation" (Health and Safety Executive, 1975). This outlined the proposed legislation on industrial noise, but the form of the legislation was not published until 1981, and then still in the format of a draft document for discussion and comment (Health and Safety Commission, 1981). This proposed legislation expanded upon the duties and requirements described within the 1972 Code of Practice, with some minor modifications to the hazard criteria, and some expansion upon the duties of employers, employees, and the manufacturers of noisy machinery. Additionally industrial audiometry was shown as a mandatory requirement above a noise exposure level of 105 dB(A) L_{Aeq}, together with the monitoring of personal noise dose.

Unfortunately, prior to clarification and promulgation, these proposals were followed approximately one year later by the publication of proposals from the Commission of the European Communities, containing criteria and action levels radically different from those put forward by the United Kingdom. As a member of the European Community the United Kingdom would come under the jurisdiction of these regulations upon ratification. The natural consequence of the introduction of the European draft was the generation of fierce debate upon the merits of the two proposals causing a temporary halt in the progression of the UK draft legislation into law.

The European Directive passed into European law on 12th May 1986. It is discussed further in chapter 12, where it is shown that the results of the work described in this thesis have a profound implication upon the manner in which the UK HSE intend this Directive to be enacted in Britain.

The major differences between the European and United Kingdom proposals lie in the choice of a lower hazard level of 85 dB(A) L_{Aeq} in the European document, compared to the 90 dB(A) found in the UK draft regulation, and a requirement which translates to a direction that any employees exposed to noise in excess of the hazard level need regular screening audiometry.

Debate as to whether the European or the UK criteria are the more appropriate is robust and revolves around the cost effectiveness of each of the proposed hazard levels.

Van Atta (1973) contends that it is not scientifically possible to set a realistic standard for material or energy that will protect the whole of any exposed population. However, the lower the exposure level the smaller is the number of individuals that will sustain the industrial disease, in this case noise induced hearing loss, but the greater the expenditure necessary. The latter can be seen in the findings of a report produced by Concawe (1981), which reveals that the number of employees exposed in Europe to noise above an 85 dB(A) L_{Aeq} is approximately twice that number exposed to noise above 90 dB(A) L_{Aeq}.

Some of the arguments for and against these two possible hazard levels are given by Sutton (1983), Tempest (1978), and Dear (1979), and revolve around an International Standardisation Organisation document 1999. This correlates lifetime noise exposure levels with the resulting severity of deafness occurring in the population (International Standardisation Organisation 1982). However, the technical quality of this document is open to question (Robinson 1983) and it is not entirely clear as to whether or not the ISO 1999 predictions can be accepted without qualification, or whether reliance should be placed in the parallel United Kingdom document British Standard 5330 (British Standards Institution, 1976), which produces somewhat different predictions. Accordingly it is difficult to assess the number of individuals that will benefit if the hazard level is lowered from an L_{Aeq} of 90 dB(A) to one of 85 dB(A), except to state that the improvement would be small, probably in the region of 10% less individuals reaching a hearing loss of 30 dB averaged over 1, 2, and 3 kHz at age 60 years after a 40 year noise exposure.

Both the European and draft United Kingdom proposals are designed to embrace all noisy industries, but four industry specific items of legislation have already been promulgated into the body of UK law. These are: the Woodworking Machines Regulations 1974 (SI 1974 No 903), the Agriculture (Tractor Cabs) Regulations 1974 (SI 1974 No 2034), the Offshore Installations (Construction and Survey) Regulations 1974 (SI 1974 No 289) and the Offshore Installations (Operational Safety, Health and Welfare) Regulations 1976 (SI 1976 No 1019). All embrace in some form the rationale of the 1972 Code of Practice discussed earlier.

A more general Act, the Health and Safety at Work Act (1974), also exists under which it is possible to bring a prosecution against an employer or employee who has failed to take adequate steps to protect the hearing either by not following the guidelines set down in the 1972 code, or by ignoring the general safety duties explained within the 1974 Act and applied to noise at work. A circular from the HSE to its Factory Inspectors explains how this Act may be used to bring an action for industrial noise as a risk to health (Health and Safety at Work, 1984).

Although this body of legislative activity holds promise, it should be remembered that arguments have already been presented in section 1.0 to suggest that "legislation-led" safety procedures are unlikely to be successful. Awareness of the hazard must be generated first, at the factory floor level. Furthermore, problems of enforcement present a second factor limiting the power of legislation to increase the level of protection of the hearing.

Legislation relies for its effect upon enforcement, which in turn relies upon the existance of a sufficiently large policing force. If the force is relatively small, as is the number of UK Factory Inspectors, then the issue must be unequivocable before manpower can be expended to bring the case to court, or ensure that other statutory penalties are invoked. Examination of the number of prohibition or improvement notices issued by Health and Safety Executive Inspectors arising from excessive noise at work shows that only 272 were issued over a six year period from 1975 to 1980, (Dove 1982), a rate essentially unchanged in 1982 when it was reported that 59 improvement notices were issued, (Works Management, 1984). Two thirds of the 1975 to 1980 notices were issued to obtain compliance with the Woodworking Machines Regulations, and the remainder to obtain compliance with the general duties section of the Health and Safety at Work Act. Although gradually increasing with time, this rate only averages 45-50, per year over the whole of the United Kingdom. The overall effectiveness can thus be judged. A possibly unfair but interesting comparison is that over the same period, 1975-1980, Factory Inspectors made approximately 1.25 million visits to factory premises (Gummer, 1984). Although this number appears large in fact each factory in the UK will receive only one visit from a Factory Inspector every seven years, on average, with the worst 10% being visited once every three years (Gummer, 1984). Such a low level of policing will reduce the effectiveness of the proposed legislation unless the will for the legislation to succeed already exists on the factory floor. Moreover, apparent compliance with any noise legislation as noted by a Factory Inspector, would not necessarily indicate that all noise hazard had been eradicated from that particular factory. The reasoning is given below.

It is very often the case that engineering noise control at the source or between the source and the employee is not feasible, and reliance has to be placed upon secondary noise control measures, such as issuing the employee with hearing protection, reducing the time worked in the noise, or requesting the employee to comply with procedures designed to reduce the noise emitted. Such procedures could be as simple as requiring a certain flow of oil to be maintained to a bearing, keeping a circular saw blade sharp, or even remembering to shut the door of a noise enclosure. Discussion in section 1.2.1 will show that these secondary methods of noise control prevail at the present time. The time and intensity trade off relationship which describes noise hazard is such that the permitted exposure time is surprisingly short even at relatively moderate levels of industrial noise, as shown by Else (1973). For example, a level of 105 dB(A) can be tolerated for only 15 minutes per working day if hazard to the hearing is to be avoided. A level of 108 dB(A) could only be tolerated for 7.5 minutes and so on. Short periods of non usage of hearing protection, erroneously extended periods of work unprotected in a hazardous noise environment, or failure to comply with procedures designed to reduce the noise generated, can all cause the employee to sustain a hazardous noise dose. In human terms, if not legally, it is understandable if a factory manager or an infrequent visitor such as the Factory Inspector misses the fact that short term over-exposures are occurring, nullifying a potentially successful hearing conservation programme which appears to comply with the noise legislation in force.

Therefore, even if legislation could be adequately policed, it could still be unsuccessful at the factory floor level unless additional motivational activities are undertaken, a theme addressed by this thesis. Legislation would appear to be a strong force at the managerial level but one which becomes dissipated as it passes down the management chain to the employee.

1.1.3 Indirect forces generated by the employee.

The third force which acts to increase the protection of hearing in industry, is that generated by the employee. Direct action on this issue is relatively rare on any large scale but does occur more routinely through such bodies as site safety committees. Pressure on a much larger scale is channelled through indirect employee action such as cases brought by employees in the Civil Courts against employers, in which damages are claimed for a noise induced hearing loss sustained during a working lifetime. These civil claims cause insurance companies to increase pressure on employers to instigate good hearing conservation measures, as do the out-of-court settlements paid by employers to avoid lengthy court cases which they do not feel confident of winning.

Between 1972 and February 1984 approximately 24 successful noise induced hearing loss cases have been brought in the Civil Courts within mainland United Kingdom by employees alleging negligence on the part of their employers. Further cases have been heard in Northern Ireland, where levels of damages are generally much higher, and reflect a judicial attitude and system not existing in the mainland. Wherever the cases are heard, however, the expenses involved in defending a claim are large. Stone (1974) indicates that the costs involved in defending the Berry versus Stone Manganese Marine Ltd case described below were six times higher than the amount of charges awarded. This must be considered to be a conservative estimate.

Certain points of law have emerged from both the successful and unsuccessful cases which are relevant to the present discussion. Describing these points permits an evaluation to be made of the influence of actions in the Civil Courts on hearing conservation activity at factory floor level.

The judgement made in the Berry versus Stone Manganese Marine Ltd case showed that it was insuffícent for employers to simply issue hearing protection, but that they must also motivate the employees to use the protection provided (Ashworth, J., Royal Courts of Justice, 6 December 1971). McGuiness versus Kirkstall Force and Engineering Co Ltd, an unsuccessful case for the employee, resulted in a finding given within the judgement that 1963 was the date by which the reasonable and prudent employer should have known of the deleterious effect of noise on the hearing, (Hodgson, J., Leeds. Judgement 22 February 1979, Liverpool).

This judgement was used by Justice Mustill in 1983 to minimise the level of damages paid to six employees of three Tyneside shipyards in a single case funded by the General Municipal and Boilermakers Union (GMBU) (The Guardian 1983; Mustill, J., Newcastle upon Tyne, 14th November 1983). Most of the observed noise induced hearing loss was caused prior to 1963. In turn this latter case caused awards made under the out of court settlement scheme agreed between the GMBU and the Iron Trades Employers Insurance Association Ltd to be maintained essentially at their pre 1983 levels, and not increased as had been the intention. This scheme is discussed further later in this section.

Mr Justice Mustill decreed in 1981 that he would accept that a plaintiff might have suffered a noise induced hearing loss during previous employment with another company but that he would also be willing to accept that the claimant had noted no disability at the termination of this prior employment, and that the additional hearing loss even if minor, occasioned by the present company, had finally caused the claimant to exhibit a loss which represented a perceptible handicap, (Heslop versus Metalock (Britain) Ltd 1981. Mustill, J., Newcastle upon Tyne, 24 November 1981). In terms of company policy this judgement must strengthen greatly the argument for pre-employment audiometry, as the data obtained would enable a defending company to put forward cogent counter arguments.

The level of individual damages awarded in these 24 cases ranged from £600 (Mustill, J., Newcastle upon Tyne 14 November 1983, Weekly Law Reports 1, 522, 1984) in Nicholson et al versus Swan Hunter Shipbuilders Ltd to

£21,675 in Abramovicz versus Carborundum Co Ltd (Forbes, J., Manchester 22 July 1981).

The average level of damages is probably not high compared to company turnover, although as described earlier, the out of court costs are more substantial, as is the large scale expenditure of managerial time. However, the two former costs are met by insurers whilst the latter disappears into company overheads, thus largely negating the apparent effect of the financial penalty. However, a loss in the civil courts will cause the company to lose status in the commercial community, and will also cause employees to lose confidence in other safety policies operated by the company and increase the level of claims for industrial hearing loss. However, these penalties are unlikely to be considered by a company prior to action in the Courts.

The prospect of an action in the Civil Courts is unlikely to be a potent direct force on employers to increase the level of protection for employees against industrial noise for the following reasons. Firstly the direct financial penalties are low. Secondly the number of cases reaching the civil courts over the last decade has been low. Thirdly, these cases do not receive extensive media coverage and thus their potential value to the hearing conservationist is reduced. Fourthly, unless the company safety officer raises the problem, the managerial level tends to think that the safety officer has the problem under control, which is not always the case. Finally, a company normally has confidence in its own negotiators, and would assume that these company officers could ensure that the company did not appear in the Civil Courts.

However, insurance companies do monitor action in the civil courts closely, and are now starting to form a robust pressure group operating on employers, encouraging them strongly to review industrial noise as a hazard on their premises. Certain insurers are now informing clients that they will no longer underwrite the risk of a claim arising from a noise induced hearing loss, unless the company takes further steps to reduce the hazard, (Calverly, 1983). Some insurance companies are specifying audiometry as a compulsory component of any hearing conservation programme.

The threat of action in the Civil Courts is not the major stimulus acting on the insurance companies; this is provided by the level of out of court settlements made to employees to forestall court action. The average settlement size has been reported as approximately £1,500 with the large majority lying between £1,000 and £10,000 (Health and Safety, 1980). Details of two major out-of-court compensation scales have been published, these being, The Ministry of Defence (Civilian Employees) Deafness Compensation Scheme (1978) and the Agreement between the Iron Trades Employers Insurance Association Ltd and the Amalgamated Society of Boilermakers, Shipwrights, Blacksmiths and Structural Workers (Health and Safety 1980). The Ministry of Defence scheme is more generous that that of the Iron Trades Company. An employee aged 60, with a hearing loss of 30 dBHL averaged over 500 Hz, 1 kHz and 2 kHz would attract a payment of £2000 from the Ministry of Defence but only £750 from the Iron Trades Employers Insurance Association Ltd. Other schemes are known to operate, but these are of a confidential nature. The numbers of claims outstanding on these schemes exceeds 20,000. British Rail alone set aside £5 million with which to pay compensation for noise induced deafness in 1983 (Young, 1983). The accounts for the year ending December 31, 1979, indicated that Harland and Wolff Ltd in Northern Ireland had made a provision for industrial deafness claims of £4 million, bringing their total since 1975 to £11 million (International Management, 1980). The glass industry could be liable for claims totalling £10 million (Works Management, 1982). The Iron Trades Employers Insurance Association Ltd is believed to have set aside a fund totalling £50 million to meet the expected level of industrial claims under its own scheme (Morning Telegraph, 1983).

Pressure from insurers on employers has been belated, but is now quickly becoming one of the most powerful forces for reform of hearing conservation measures. However, this pressure can appear to bring success in terms of reaction from the factory manager or safety officer, but still fail at the level of the employee through an inadequate knowledge of how to motivate him. This problem was discussed earlier, and forms the emerging theme of this chapter.

The final force for change to be considered in this section is that exerted by the Industrial Injuries Scheme administered by the Department of Health and Social Security under the Industrial Provision of the Social Security Act 1975.

Occupational deafness was first prescribed as an industrial disease in 1974 and pensions under the scheme have been available since 3 February 1975. The criteria for eligibility were strict in order to keep the number of required audiological examinations to less than 10,000 a year. This was believed to be the maximum spare capacity that the National Health Service could offer (Industrial Injuries Advisory Council, 1982). In the event, this limit of 10,000 examinations per year was not reached, although the loading of case work on regional audiological centres was not even, with a greater load being borne by those centres in highly industrialised locations.

Accordingly, the minimum requirements for entry into the scheme were relaxed in September 1979, and again in 1983 (Rossi, 1983). The various recommendations extended the number of occupations and range of employees covered, reduced to 10 the number of years that it was necessary to have worked in these occupations in order to qualify for benefit, and increased to 5 years the period in which it is possible to make a claim after cessation of qualifying employment. A substantial sensori-neural hearing loss equalling at least 50 dB in each ear averaged over 1, 2, and 3 kHz is required for a successful claim, and in at least one ear the loss must be ascribed to occupational noise.

In 1983 in a written answer to a Parliamentary Question asked by Mr Greville Janner (Labour: Leicester West) Mr Hugh Rossi stated: "It is estimated that the average level of disablement of people receiving industrial disablement benefit on 30th September 1981, the latest date for which statistics are available for the prescribed disease occupational deafness (PD 48) was 40 per cent, which currently attracts a benefit of £21.44 per week, which will be increased in November" (Rossi, 1983(b)). As a guideline, disablement is assessed at the lower limit of 20% where the average hearing loss in each year equals 50 dB, and at an upper limit of 100% where the average hearing loss reaches 90 dB over the stated frequency range.

The significance of this scheme as a force for change in hearing conservation procedures can be evaluated by assessing the number of individuals submitting successful claims under the scheme.

Figures produced by the Industrial Injuries Advisory Committee (1982) indicate that approximately 27450 employees have lodged claims under this scheme between 30th October 1974 and 30th April 1982. Only approximately 16,150 of these were examined audiologically, representing 59% of the total. Examination of figures presented by Mr John Selwyn Gummer (1983) in a further reply to a written question from Mr Grevill Janner (Janner, 1983 (b)) indicated that 624 cases of occupational deafness were confirmed in 1982. Consideration of the Industrial Advisory Council report referenced above suggests that of the number of claims lodged that year, approximately 1900 were examined, and of these the 624, or 33% were successful. Therefore, of the estimated 4000 submitting claims in that period, only 16% received benefit. This represents a drop from 25% between 1975 and 1979 as suggested by examination of the Industrial Injuries Advisory Council Report, and that published by the Health and Safety Commission (1981). 17.6% of claimants were successful in the 25 months up to 1981 (Welsh, 1981).

It is apparent, therefore, that only a relatively small number of claimants were successful in 1982. Although the pressure for increased hearing conservation activity caused by the success of claimants is cumulative over the years, a counter pressure must also exist caused by the presence of the large number of unsuccessful claimants. This latter number would suggest to a workforce that noise induced hearing loss could not be as serious or as prevalent as they had first thought.

For this reason it is felt that the existence of the Disability Pension can only be considered a weak force acting to improve hearing conservation procedures on the factory floor. It is further weakened in reality by the fact that few employees know of the existence of the scheme, and those who do, rarely feel that they would ever become eligible for a pension. If this were not the case, then it is reasonable to assume that they would take steps to ensure that their hearing did not become damaged, for it would be a very atypical individual who would allow himself to be deafened thinking that the Disability Pension would completely compensate him for his loss.

The arguments presented would suggest that Disablement Benefit, compensation in the Civil Courts and out of court settlements are all unlikely to represent strong direct forces causing a long term change in attitudes or safety habits. They act as indirect forces in that they cause government and insurance companies to increase their pressure on employers, who in turn should increase their own efforts to find methods of reducing the auditory hazard and encouraging employees to co-operate with any safety procedures instigated.

At this point, the employer is left with the problem of motivating the employee in the most cost effective manner possible, to take a positive attitude towards conservation of hearing. As all three of the forces discussed in section 1.1 have been shown to be effective only through this focal point it would valuable at this stage to examine a hearing conservation programme in industry.

1.2 Hearing conservation programme

1.2.1 Methods of removing the hazard.

Figure 1 shows a diagram of a hearing conservation programme. This commences with the assessment of hazard using the correct measurement equipment, and periodic rechecks. If the noise levels exceed the HSE safety criteria (Health and Safety Commission, 1981) action must be taken to reduce the exposure. The optimum solution is to procure new and quieter machines. This approach is subject to obvious financial constraints, and also engineering difficulties. It may not be possible to obtain quieter machinery; the modern trend is towards more powerful and faster machines or processes, which mitigates against the development of quieter machines in many cases, as the counterbalancing forces of legislation or customer pressure are not yet strong enough to make such development work cost effective for the manufacturer.

If procurement fails, the employer can turn to engineering noise control, whereby machinery or equipment can be altered to run more quietly or

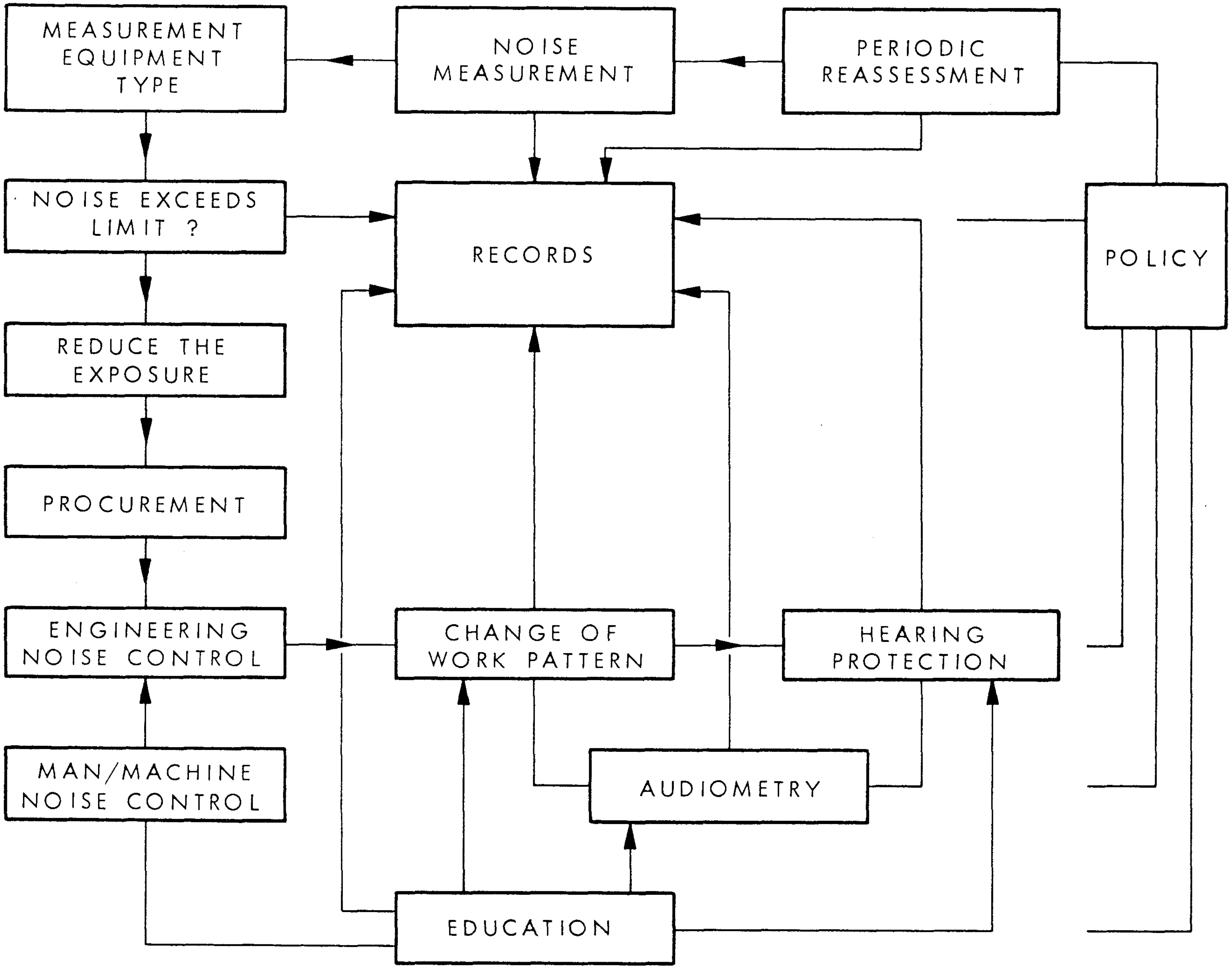


Figure 1.1 The components of a hearing conservation programme.

retrofitted with silencers. This approach can again be constrained by financial considerations, and engineering problems.

The cost of engineering noise control is discussed later in this section.

Figure 1 shows that if engineering noise control also proves not to be feasible, then the employer will consider secondary means of conserving the hearing. These include changing shift patterns so that a given employee remains in a hazardous noise level insufficiently long to accumulate a hazardous noise dose, or requiring the employee to take certain steps during the day to reduce the noise levels. These "man machine" noise control procedures could include such actions as ensuring that panels on a machine which can vibrate loose are tightened periodically, or ensuring that cutting edges are sharpened regularly, bearings are kept lubricated, or that doors on noise excluding enclosures around machines are kept closed. A further secondary noise control measure is the issue of hearing protection.

Whenever recourse is made to a secondary method of noise control, the co-operation and support of the employee must be obtained if success is to be achieved. Audiometry should be undertaken to check that this co-operation has ensured that noise induced hearing loss is no longer occuring in the workforce. Royster (1982) states "The fact that a hearing conservation programme is well thought out and well administered is no guarantee that the programme is in reality effective. As a result of the problems of utilisation of hearing protection devices and of limitations in the degree of protection afforded by hearing protection devices in real world environments, the only reliable estimate of the actual protection being provided comes from analysing the audiometric data base".

Changing the shift patterns is the least used secondary method of reducing noise dose, as it usually involves large administrative problems.

Although in theory the last method of conserving the hearing to be considered, the issue of hearing protection is the most widely adopted solution in practice, despite the future workload which it places upon management, which must ensure that the protection is worn, and the reluctance of employees who may feel that hearing protectors present a series of utilisation problems. Hearing protectors are usually adopted for use either if it is not reasonably practical to control the noise by engineering methods or if time must elapse before operational or financial constraints permit the completion of engineering noise control at source.

To validate this point it is of value to quote at length from work by Schmider (1975) who completed interviews with the management of 80 American companies which had run hearing conservation programmes for more than 5 years. Schmider stated "Engineering noise controls were reportedly tried out by almost every company before any other procedures were instituted. The engineering procedures ranged from replacing worn machinery parts to changing the process. The main complaints about the use of engineering procedures were difficulty in finding qualified consultants to solve difficult noise problems, the uncertainty of the availability of technology to solve certain problems, and the expense. Cost of successful noise engineering ranged from the minimal (replacement of worn parts) to $40,000 (£25,549 in 1986 pounds) for investment in accoustic screens and curtains. Of the companies which considered substitution of innovative new processes for the older noisier one, most found it to be too expensive. Companies mentioned that it was difficult to predict accurately the resulting attentuation from engineering noise controls. In one instance a $35,000 (£22,356, 1986) investment for quietening a noise source only reduced the overall noise level by 2-3 dB(A) .... the use of personal ear protectors was the most frequently encountered means of controlling the workers noise exposure. Most companies interviewed relied heavily on personal hearing protectors, realising that they are a temporary measure, and that engineering noise controls are required where feasible".

Custard (1984) supports this evidence stating that a 1980 survey performed by the Factory Inspectorate of 93 typical foundries showed that 93% of these firms provided ear protection to their employees. Approximately half the foundries were attempting to reduce noise in at least one area with varying degrees of success.

Pell (1982) argues that the issue of hearing protection can be a cost effective method of preventing noise hearing loss. This author describes the Du Pont Company hearing conservation programme as costing approximately $20 (£7.10p1986) per employee or $41 (£13.22p, 1986) per employee, exposed to noise levels in excess of 87 dB(A). The Du Pont programme embraced 2770 employees, 1329 of whom were exposed to levels of noise in excess of 87 dB(A) L_{Aeq}. The hearing conservation procedures included initial and follow-up audiometric testing, the fitting of hearing protection, education, training and the monitoring and supervision of personnel wearing ear defenders.

The evidence of Pell is corroborated by Willoughby (1981), who quotes from evidence given in the Occupational Noise Hearing Conservation Amendment, USA (US Department of Labour, 1981) where it is stated that the cost of a programme similar to that described by Pell would be $53 (£20, 1986) per worker exposed to noise levels above 85 dB(A) L_{Aeq}.

These costs can be compared with those of engineering noise control alone used as a method of protecting the hearing. Consideration of Bruce (1979), Bolt, Beranek and Newman Inc (1976) and the Health and Safety Commission (1981) yields the following financial estimates.

The cost of reducing workplace noise to 90 dB(A) in the UK manufacturing industry would be $4,610 (£2616, 1986) per employee exposed to levels above 90 dB(A) L_{Aeq}, or $2459 (£1396, 1986) per employee. Norman (1983) gives costs of the same order in describing large scale engineering noise control undertaken in a Pilkington Brothers glass manufacturing plant. Drinkwater (1983) states that for Du Pont to meet a 90 dB(A) L_{Aeq} criterion by engineering methods alone would cost £3000 (£3244, 1986) per employee. Additionally these costs do not contain any component related to the interest payable on any loans necessary to complete the work, or any factor related to the effect upon the cashflow or productivity of any company undertaking such work.

As a generalisation it could be concluded that these figures indicate that it would take a century before total reliance upon engineering noise control became a better financial option than the issue of hearing protection, and much longer if account is taken of the fact that expected plant life might only be in the order of 15 years. Publications which claim otherwise are usually vague and lacking in precise financial calculations (Cluff, 1980).

In practice total reliance would not be placed upon engineering noise control. A practical hearing conservation programme would consist of a mixture of engineering controls and the issue of hearing protection, and the cost ratios would change greatly. However, the foregoing arguments have served to illustrate the point that the issue of hearing protection is a widely adopted economic solution upon which industry must rely, in part at least, throughout the foreseeable future.

1.2.2 The effectiveness of programmes relying upon the issue of hearing protection.

The success of the Du Pont hearing conservation programme, in force since 1956 and described in the previous section, was analysed by Drinkwater (1983), who concludes his study by stating:

"We believe that hearing protectors - muffs or plugs - when properly fitted and conscientiously used - offer entirely adequate safeguards against injury to hearing by workplace noise. They also offer the optimum benefit to cost ratio for any control methods likely to be available".

That the issue of hearing protection can be a successful conservation measure when used correctly is also shown in studies by Gostonyi (1975), Pell (1973) and Sumar (1969). This latter author conducted an investigation using repeated audiograms measured on approximately 2000 employees. Regular monitoring audiograms were available over a ten year period from 1700 of these individuals, whilst the remainder had been periodically tested for 3 years or less. Noise exposures ranged from 85-105 dB SPL L_{eq}. Ear protection was worn by 70% of the tested group. After analysis of the audiograms Summar concluded that 98% of those wearing ear protection revealed no significant change in auditory threshold over the documented period, and that one third of the workers who did not wear ear protection showed significant threshold changes.

Pell (1973) performed a similar study, but one which was more closely controlled. The research was conducted using 1173 employees whose noise exposure did not change significantly over a five year period. Employees were divided into three groups by noise exposure. Group 1 included employees exposed to a noise level of 91 dB(A) or less, whilst the remaining two groups were defined in terms of SPL, but embraced employees whose noise exposure exceeded that of Group 1. Group 2 appears to have included employees with noise exposures between 91 dB(A) and approximately 100 dB(A), whilst group 3 exposure levels are likely to have exceeded 100 dB(A). Employees were distributed between groups 1 to 3 in the ratio of 3:1:1 respectively, and ear protection was utilised by groups 2 and 3. Pell compared the audiogram measured at the beginning of the study for each individual, with that obtained at the end of the research period, and showed that the audiometric thresholds within the three groups had behaved in an identical manner. He concluded that a hearing conservation programme utilising a hazard criterion of 90 dB(A) and the issue of hearing protection would successfully protect the hearing of employees.

Gosztonyi (1975) describes an investigation of the efficiency of the Ingersoll-Rand hearing conservation programme at the Phillipsburg plant, which housed approximately 4000 employees, 600 of whom were exposed to L_{Aeq} levels in excess of 90 dB(A). Heavy reliance was placed on the issue of hearing protection as engineering noise control was not feasible. 213 employees were included in the study, equally subdivided into three age matched classes. The first two classes were characterised by average L_{Aeq} levels of below 85 dB(A), whilst employees within the third class were exposed to average levels of approximately 93-96 dB(A). The noise immitted during various operations performed by employees within each of these classes exceeded the class L_{Aeq} bounds. As an example, work activities performed by individuals within class three could range from 95 dB(A) to 120 dB(A). Gosztonyi analysed audiometric records obtained over a five year period and showed that the hearing protection utilised was preventing noise induced hearing loss from occurring in those employees exposed to noise levels above the hazard criterion of 90 dB(A) L_{Aeq}.

Axelsson (1978) completed a less rigorous study in the Volvo plant, Sweden, in which he matched by age and noise exposure two groups of employees, the first containing 47 normally hearing individuals, whilst the second embraced 30 employees with noise induced hearing loss. By investigating the reported frequency of hearing protector usage in each of these groups over a period of 10-35 years, he was able to establish that normal hearing was far more prevalent in those individuals who claimed to have used hearing protection than in those individuals who had not used hearing protection. He concluded that hearing protectors, if used regularly, were efficient at preventing noise induced hearing loss.

Cohen (1976) also reports on a study of hearing acuity changes noted over a five year period in a group of 371 employees working in a noise environment of less than 80 dB(A), and in a group of 178 employees working in a noise environment of 95 dB(A) or greater. A hearing protection programme had been started at the beginning of the five year period and from the lack of significant change in the mean hearing levels of either group at the end of the five years, Cohen concluded that the use of hearing protection had been successful.

Glorig (1980) agreed with this finding during his presentation at the Carhart Memorial lecture which described progress in the field of hearing conservation, and also compared a secondary method of noise control described earlier, noise shielding, with the issue of hearing protection. He stated,

"just as much supervision is required to get the employee to use the (noise shielding) enclosures effectively as to see that he uses ear protection as he should, and my experience has shown that a well supervised ear protection programme can be just as effective as barriers and enclosures".

It is interesting that Glorig in his comment also highlights the problem of encouraging employees to utilise engineering noise control procedures correctly, a return to the motivational problem addressed by this thesis.

The foregoing discussion has served to demonstrate that hearing protection is capable of preventing noise induced hearing loss, if accepted by the workforce as was the case in the studies described above, which were not conducted in the United Kingdom.

However issue and acceptance are not synonymous terms, as observed by Champion (1982) who studied the UK steel casting industry. Champion showed that only 25% of fettling shop personnel were using the issued hearing protection in potentially hazardous noise environments during a survey of 20 foundries. As one example, only just over half of the 220 employees seen to be engaged in the fettling of large castings and exposed to approximately 106 dB(A) were observed to be using hearing protection. Although better than the estimate made by the Factory Inspectorate (Chief Factor Inspector, 1975) of only 12% of employees using the hearing protection with which they had been issued, when working in hazardous noise environments within the manufacturing industry, the usage estimate of 25% made by Champion is very much aligned with the experience of the author of this thesis when visiting noisy industries in the United Kingdom. The initial levels of protector usage in the 8 plants included in the study reported in the remainder of this thesis were also of the order described above.

Sugden (1967) describes a programme intended to increase the usage of earplugs in an iron foundry containing approximately 30 employees. Initial acceptance was high, but this dropped to 30% usage within six weeks. Custard (1984), describing the 1980 survey performed by United Kingdom factory inspectors in 93 foundaries states. "Furthermore, Inspectors found that where ear protection was provided (only 7% of the firms visited did not provide any protection) the majority of employees at risk were not using them; even 46% of those exposed to more than 100 dB(A) L_{Aeq} did not wear ear protection".

Axelsson (1978) noted that one third of workers exposed to hazardous noise levels within the Volvo plant did not make use of issued hearing protection, at the time that his study, described earlier, was completed. Oliver (1984) reports comment that only one in five workers in the UK who should be making use of hearing protection actually did so. Complete non-usage of an issued hearing protector is serious, but partial non-usage during a day can also be dangerous (Else (1973), Lundin (1980)), as discussed earlier.

The problem, therefore, is not only one of encouraging employees to use hearing protection, but also one of motivating them sufficiently to ensure continued usage throughout the entire working day.

Having shown the issue of hearing protection to be the most prevalent and most cost effective method in the majority of industries by which industrial noise exposure can be controlled, the following section will examine motivation techniques for increasing the usage of hearing protection in UK industry.

1.2.3 Motivating employees to use hearing protection.

It could be argued that industrial discipline can be used to ensure full usage of the hearing protection supplied. This would embrace verbal and written warnings to those individuals who did not comply, followed by dismissal for persistant refusal to co-operate. In practice, however, most firms are unwilling to enter into direct confrontation with a workforce over such safety matters as the use of hearing protection, preferring to take the more gentle approach of continued persuasion in recalcitrant cases. That this technique is almost universally used is confirmed by the fact that when a company does take a firm stand on this matter, it becomes newsworthy, as indicated by the article appearing in a Worcester newspaper (Evening News, 1984). In this article, Mr Dennis Symonds claimed that his employment was unfairly terminated after he told his employers that he could not wear ear protectors because they caused him pain. The Industrial Tribunal Chairman upheld the termination stating that the employee had taken an intransigent attitude to the hearing safety rules. It is also noteworthy that Mr Symonds claimed that just 8 months after the introduction of hearing protection, only one in eight employees on his shift used them.

Zohar (1980) reports on the attempts of the management of a large company to enforce hearing protector usage by declaring certain bands of time within the day "hearing protector periods" during which hearing protection was to be worn. Failure to do so would be penalised by the employee being sent off the job for a period of time with a corresponding loss of pay. The intention was to increase these "hearing protection periods" gradually but the attempt was a total failure due to the inability of management to carry out any of the proposed penal actions. Mandatory use of hearing protection is now a condition of employment in the GKN forge in Bromsgrove, but it is unusual for a firm to be able to negotiate such an agreement, and enforcement is still problematical.

Harvey (1981) increased the effectiveness of a hearing protection programme by taking employees from the factory floor, not permitting them to readjust their hearing protection, and measuring the effective acoustic attenuation attained by that employee at that time. Counselling of individuals found to be obtaining insufficient attenuation and subsequent rechecking was shown to produce a gradual improvement of the manner in which the hearing protection was fitted, and thus the attenuation attained. The additional equipment required for this test would cost approximately £100 providing that standard audiometric equipment was already available which could be adapted on an occasional basis to measure hearing protector attenuation. This technique does reveal an interesting additional use for audiometric equipment and expertise when not being utilised for audiometry. However, the measurements suggested by Harvey are perhaps not very cost effective when it is considered that only one, albeit important, benefit results from the technique; the increase usage and effectiveness of the hearing protection issued. By way of comparison, a listing of the multiple benefits accruing from the use of monitoring audiometry, a similar exercise, is given later in this chapter. However, the efficiency of industrial audiometry in increasing usage of hearing protection remains to be investigated, although Bearce (1975) suggest that audiometry can be used to increase the effectiveness of the protection worn, stating that the annual audiometric test presents a good opportunity for rechecking the fit and condition of any hearing protection issued.

Royster (1981) considers methods of undertaking the motivational training and describes conventional educational sessions utilising workshop seminars and educational films. Although the approach adopted by the majority of companies, it suffers from the problem that the sessions are indistinguishable from those run regularly on other safety procedures and they lose impact accordingly.

Most traditional hearing conservation programmes do, however, include a film or audio visual presentation. Gjermo (1976) evaluated the effect of a dental hygiene film shown in Norwegian cinemas using a sample of 200 viewers. Interestingly only 40% held the view that commercial films gave factually correct information, whilst 54% accepted these films as being only partly reliable. The remainder were divided between non respondents and those who felt commercial films to be totally unreliable. This would suggest that hearing conservationists should attempt to add a segment of their own to any commercial film used, in order to increase its validity in the mind of the viewer.

The Norwegian film advocated the use of inter-dental cleaning devices, and the author reported that 36% of individuals, started to use these after viewing the film. Questionnaires were dispatched to these viewers six months after the film was shown and the results obtained from a 75% return indicated that only 39% of these individuals still used inter dental devices fully, whereas 6% had returned to their old habits. The remaining 55% still practiced the advice from the film to some extent. It can be concluded that in this field educational films have only a limited effect for a limited time. Gjermo also states that "It seemed as if (already) well motivated subjects responded more readily to the information provided than those who exhibited a more reserved attitude". It would therefore appear that a hearing conservation film would achieve maximum effect if shown some time after the commencement of other hearing conservation activities, such as the display of warning posters.

Furthermore, Stapleton (1981) feels that the effectiveness of a film or slide/tape presentation may be increased if some element is included showing photographs of employees using hearing protection in the plant in which the education programme is being conducted. Foster (1983) describes a short study in which 143 employees were exposed to a lecture and audiovisual aids on the topic of noise induced hearing loss. Each employee was asked before the teaching session, and again six weeks after, whether they felt hearing protection to be unnecessary, necessary or important. Responses to a second question enquiring into the percentage of time that hearing protectors were used showed that employees claimed that the lecture had increased protector usage by approximately a third immediately after the session, although this statement was not checked objectively. However, up to 43% of the employees in the various age groups still did not use hearing protection, even though the lecture had caused them to increase their estimate of its importance. It is evident, therefore that although a lecture can increase hearing protector usage, at least temporarily, further elements in the education programme are needed if greater changes in usage are to be achieved.

Feeney (1976) considered the methods available to reduce noise levels at the ear of the employee, and concluded that the issue of personal protection was the most cost effective solution. The author then gave consideration to the use of industrial training films to motivate the employee to use the protection issued, viewing the problem as being analogous to those experienced during an advertising campaign. That the film used should be lively is an obvious recommendation, but Feeney also suggested the usage of button hole badges bearing a cryptic hearing conservation message during the week prior to showing the film, and a selection of five posters for display in the weeks after a film had been shown. Feeney did not evaluate the success of his technique, and again this forms a point of experimental interest investigated by this thesis.

Royster (1981) also suggests an interesting, but scientifically untested, idea for increasing the level of hearing protector usage in industry, when he discussed involving the family of an employee in some of the hearing conservation activities. Royster (1982) states that the attitude of employees towards management and hearing conservation programmes has been improved as a result of audiometric testing extended to members of the immediate family of the employee, the testing being directed at the identification of previously undetected hearing loss.

A similar approach is to be found in Spindler (1979) who recommends sending educational literature through the post to the home of the employee.

The majority of publications describing a good hearing conservation programme, especially those relying upon the usage of hearing protection, stress the need for employees to understand the reasons for running the programme. Stapleton (1981), Dear (1979) and Merriman (1977) are examples of authors who reached this conclusion. Royster (1982) also claims that it is important that the key individual responsible for the day to day running of the hearing conservation programme should also be well informed and enthusiastic in his approach to problem solving. Often the success of the programme can be related more to the ability of this key individual than to the financial resources of the company itself.

However it cannot always be assumed that such an individual will be available. Therefore a solution to the problem of motivating employees to use hearing protection must be found which is more amenable to standardisation, and one which is more successful than the traditional educational methods which have been used to date.

Mellard (1978) and Bearce (1975) discuss the components of a hearing programme. The latter author concludes that education should be "... immediate, continuous and varied". Meeting all of these criteria is difficult logistically if standard hearing conservation seminars are considered. If, however, industrial audiometry is added to the hearing conservation programme as an educational tool, it could be suggested that all three criteria are met. The audiometric results are of immediate interest to the employee, the testing can proceed continuously throughout the year, and the audiometric test provides a variation upon the standard programmes of industrial safety training.

However, the hypothesis that audiometry can increase hearing protector usage, implicitly stated above, is yet to be proven. Fritz (1980), however, does suggest that showing employees their audiograms might enhance their understanding of the reasons behind a hearing conservation programme, an understanding which Dear (1979) feels is vital for the success of this programme.

1.2.4 The value of audiometry in a hearing conservation programme.

It has been suggested in the previous section that industrial audiometry could provide a good method of motivating employees to use hearing protection.

However, the cost/benefit analysis relating to such an exercise also requires information on the value of audiometry in achieving other objectives. A discussion is given by Karmy (1982) and is summarised below.

The primary objective of industrial audiometry is to ensure that noise induced hearing loss is not still continuing to grow in a population, despite the elegance of any hearing conservation measures adopted once noise control at source had been found to be impracticable. Industrial audiometry provides a check on whether or not employees are making proper use of hearing protection. It measures whether or not noise induced hearing loss is occurring in the 16% of a population known to be receiving less attenuation from their hearing protection than shown by the assumed protection parameter upon which issue is based. The audiometric results also show whether or not employees are cooperating with any noise control procedures which may have been adopted.

Audiometry can be seen as one of the reasonable steps taken by a company in discharging its legal duty of care held towards an employee known to be working in a hazardous noise environment, or the discharge of the extra duty of care established as existing under civil law by the case of Parish versus Stephney Borough Council, when an employee with a pre-existing disability such as a hearing loss is known to be working in an environment which could worsen the disability.

Serial audiograms resulting from a programme of monitoring audiometry are valuable in establishing if a sudden acoustic accident has caused a loss of hearing. The existence of serial audiograms is also useful if the company decides to set up an out of court settlement scheme. Previous audiograms assist in evaluating the extent of the financial risk of such a scheme and the validity of any audiogram obtained after the scheme has been announced.

Audiometry conducted at the pre-employment stage is valuable in defining the future liability of the company, and in evaluating the hearing status of a prospective employee. This will assist in ensuring that the employee is not placed in a job in which he would be danger to himself, or his workmates, or one which he would find difficult to perform.

Pre-employment audiometry is also valuable in that it permits detection of a hearing loss unrelated to noise exposure at a stage early enough in the individual's working career for him to accept immediately the explanation that the factory generated noise was not responsible. Although eventual acceptance of such an explanation should be inevitable, swift acceptance saves time, money and frustration on the part of employee and employer alike.

It can be seen that if encouragement to use hearing protection could be added to the list of audiometric attributes, the case for performing industrial audiometry would be unassailable. However, debate has proceeded for two decades upon whether or not industrial audiometry is a sufficiently reliable test for detecting an increasing noise induced hearing loss at a stage early enough for remedial hearing conservation action to be successful. It would therefore be of value to establish the sensitivity of modern audiometry in this respect, as fulfillment of this primary objective must be possible before the secondary educational effect of audiometry can be seen to be economically viable.

1.2.4.1 <u>Audiometric sensitivity</u>.

Atherly (1981) presenting arguments also given in Phillips (1978) concludes after examining the available evidence "Occupational audiometry: the ultimate test of success (of a hearing conservation programme)? Since audiometry itself has never been conclusively and exhaustively tested for its overall validity, scientific or social, no answer can be given to that question when applied to the specific purposes claimed for audiometry". By inference, however, Atherly suggests that the reliability and repeatability of industrial audiometry is such as to make the required monitoring of hearing acuity difficult. This view is in accordance with those expressed by that author in earlier papers. (Atherly (1973), (1973(b)), (1964) and (1963)).

Estimates of the reliability and repeatability of audiometry have been made by other authors. As early as 1936, Steinberg (1936) found that relatively small changes in earphone placement could cause the standard deviation of the acquired data to alter by as much as 7 dB over the frequency range 100 Hz to 5000 Hz. Naturally, equipment types and audiometric techniques have improved since that time, but variability in audiometric measurement still persists.

Rodda (1965) highlighted apparent differences in audiometric threshold which arose when different audiometricians performed the measurements. Howell (1972) performed a similar study on 143 subjects and noted inter-audiometrician measurement differences in excess of 4-5 dB in 46% of the cases, and greater than 10 dB in 12.5% of the cases. Hartley (1973) confirmed this finding by showing that inter-audiometrician error exceeded intra-subject variability at 3 and 4 kHz.

It should be mentioned that criticism can be made of the methods chosen by Howell and Hartley to demonstrate their arguments but it is likely that inter-audiometrician error does contribute strongly to audiometric variability.

However, this source of variability should decrease as a greater number of industries undertake audiometry, and the sophistication of audiometrician training increases (British Society of Audiology, 1978).

A similar decrease in audiometric variability should be caused by the increasing prevalence of automated audiometers in industry, especially those machines which utilise methods of manual audiometry executed under microprocessor control (Robertson (1979), Klockhoff (1974), Sakabe (1978), Wood (1973)). Commercial pressure will ensure that this type of circuitry becomes progressively more available in increasingly less expensive audiometers.

However, evidence presented by Ivarsson (1980) would suggest that the major components of the observed variance in audiometric threshold are caused by factors other than inter-audiometrician differences .

One major source of audiometric error is the use of inadequate audiometric equipment and test conditions in industry. The situation is well defined in Schmideck (1976) who shows that 80% of the industries sampled made use of inadequate audiometric equipment. This situation could be rectified in the UK by a strong code of practice published by the Health and Safety Executive.

Hetu (1979) assumes that it would be possible to set up a good audiometric facility with well trained audiometricians, and then proceeds to measure experimentally the audiometric test/retest error still occurring in audiograms measured 1 hour apart using automated audiometers with a group of 30 subjects. The standard deviation of these errors is shown to be of the order of 2.5 dB up to 4 kHz but 3 dB greater at 6 kHz. The size of these errors is confirmed by other authors who noted similar trends under similar circumstances (Atherley (1963), Brown (1948), Burns (1957), Robinson (1960), High (1962), Cluff (1980), Robinson (1975), Delany (1970), Burns (1970), Fudmose (1963), Hickling (1966), Delany (1970), Robinson

(1970), Pelmear (1974)). Hetu then considers the rate of growth of noise induced hearing loss, and the size of the measured audiometric error, and shows elegantly that industrial audiometry is capable of the detection of a slowly growing noise induced hearing loss during at least the first five years of exposure, and probably throughout the first ten years.

Sutton (1983) completes an identical exercise to that of Hetu, and concludes that "Routine audiometry is likely to be useful in detecting noise induced hearing loss only if: (i) the actual exposure at the ear exceeds 90 dB(A) L_{Aeq}. (ii) Hearing protectors are used to control exposure to 90 dB(A) or below, but the unprotected exposure would exceed 95 dB(A)."

Furthermore both Hetu and Sutton performed their estimates of the sensitivity of industrial audiometry as a tool with which to detect increasing hearing loss using the 95% statistical confidence limit. However, in practice it should be possible to construct a stratagem for audiometric testing which does not rely upon the magnitude of the measured change exceeding this 95% confidence limit before being declared significant. The 95% confidence limit is not an immutable law of nature, but rather a method of regulating the frequency with which an experimenter falsely accepts a hypothesis of change. The acceptable level of the frequency of this occurrence should be set with regard to the seriousness of the consequence of a false acceptance. In the case of industrial audiometry the seriousness of false acceptance is not too great, as testing regimes can be devised whereby audiometric tests are repeated under certain circumstances. Hence industrial audiometry can be made a more sensitive test for detecting audiometric change than suggested by either Hetu or Sutton.

The concept can be extended to embrace other methods of reducing sources of audiometric variability. The literature does contain practical suggestions for strategies which would be of value, and if enacted in concert should be capable of reducing audiometric error substantially. One example would be the adoption of a parameter representing hearing loss which would have a smaller inherent variability than the individual hearing thresholds at each frequency. A parameter based on a mean hearing loss calculated over several frequencies should have advantages in this respect.

Additionally, Robinson (1975 and 1973) suggests forms of repeat frequency testing which could at least be used to obtain a reliable baseline audiogram and thus reduce the size of subsequent audiogram comparison error, even if such repeat testing was not possible for routine screening as a consequence of time constraints. Variation upon the repeat testing theme, perhaps extend only to one or two frequencies in the range, should be capable of providing one parameter with a reduced error suitable for use in developing a sensitive index of audiometric change. Even time constraints on repeat testing should not provide a strong argument for those who oppose the use of routine screening audiometry; for example, authors such as Harris (1974) put forward a reasonable case for testing every two years instead of annually. Drinkwater (1983) points out that industrial monitoring audiometry is a serial process: a good administrative or test strategy should ensure that an employee is not drastically misclassified as a consequence of a single poorly completed audiogram.

Somerville (1976) supports the view that industrial audiometry is of value in detecting a growing noise induced hearing loss, although that author does not quantify his arguments. Royster (1980), however, does provide data from a study involving 9,572 employees. Concentrating upon 5653 white males within this population, Royster tested several possible criteria which could be used to detect when a significant change in audiometric threshold had occurred, and indicated that a deterioration by 15 dB or more at any frequency provided the best such criterion. By inference Royster confirms that audiometry is of value in helping to prevent permanent threshold shift from occurring in noise exposed employees, by showing that audiometry can be used to detect a growing hearing loss caused by noise at a stage early enough for remedial action to be successful.

Bruton (1971) states that the hearing conservation programme run by the Air Corporations Joint Medical Services at Heathrow "... has been run on orthodox lines. This means that we: (i) conduct sound level measurements, (ii) provide hearing protection and (iii) perform pre-employment and periodic audiometric tests on noise exposed staff". Bruton found value in the audiometric tests, using a 25 dBHL criterion which if exceeded by an employee caused him to be examined further and his working environment to be checked for any failure of hearing conservation procedures. In this manner Bruton claims to have prevented any employee from sustaining a disabling hearing loss caused by industrial noise. Obviously Bruton must have felt that his practical experience of running this hearing conservation programme had been such as to show that audiometry was an effective exercise. Kihlman (1976) shares this view after completing a hearing conservation programme in the Gotaverken shipyards which employed approximately 7000 individuals.

Pelmear (1974) is more explicit in concluding that the results of his study of audiometric variability "support the view that the use of occupational health nurses with self recording audiometers is a satisfactory method of audiometric screening". That this author feels that audiometry has a firm place in a hearing conservation programme is indicated in an earlier paper (Pelmear (1973)) in which he makes the following claim of audiometry undertaken within his organisation, GKN Forgings Ltd. "Even so the variance of audiometric data is greater than one would wish, but losses in the order of 15-20 dB are unlikely to be artefacts, and it is this order of loss which we are seeking to detect and prevent in industry". Drinkwater (1983) echoes this sentiment almost exactly, but one decade later when examining the value of audiometry in the Du Pont hearing conservation programme, emphasising that the audiometric tests undertaken were "serial" and thus an adequate administrative strategy can be devised to minimise the effect of variability in audiometric measurement.

Dawson (1973) describes the programme of annual or six monthly audiometric tests performed at Rolls Royce Ltd, including the mechanism by which notice of significant audiometric change is fed back to the noise engineer to enable checks on the workstation of the employee to be made. Wright (1973) affirms the value of industrial audiometry in a hearing conservation programme in relationship to the programme run by the Royal Navy at Portsmouth Dockyard. Brown (1984) discusses the hearing conservation programme undertaken by the British Army in which "screening audiometry of all new entrants and regular screening of others at intervals depending on their risk category" is described as being essential. The inclusion of audiometry in the hearing conservation programme appears to have been a consequence of a 1979 survey showing that the issue of V5IR earplugs to soldiers did not appear to have been successful, as the hearing losses then measured appeared to be as poor as a similar set of results recorded prior to issue in 1965.

After conducting a study on behalf of the Medical Research Council, which linked measured hearing loss with the particular employee history of previous noise exposure, Burns (1973) and his co-author Robinson stated that routine monitoring audiometry was to be strongly advised above L_{Aeq} values of 90 dB(A) when hearing protection is used as a means of reducing the noise exposure at the ear. They suggested that a suitable regime of audiometry must be adopted to minimise audiometric measurement variability but do show a conviction that industrial audiometry is capable of detecting deterioration in hearing acuity between tests at an early enough stage for the information to have remedial value.

That audiometry is of value in a hearing conservation programme can be seen from consideration of the majority of relevant literature from the USA. Requirements for industrial audiometry in the Walsh Healey Act (section 50-204.10) and the Occupational Safety and Health Act 1970 (section 1910.95) and subsequent ammendments, has encouraged American industry to install audiometric facilities during the last decade. The subsequent experience appears to have been good for almost universally an American description of a good hearing conservation programme includes a reference to the need for industrial audiometry. If the experience gained from large scale audiometric surveys had been poor over the last decade, the literature from the USA would have borne appropriate comment (Miller (1977), Muraski (1981), Geier (1980), Dear (1979), Cluff (1980), Von Gierke (1982), Mellard (1978), Miller (1978), Bearce (1975), Zatek (1975), Lowe (1972), Wood (1976), Spindler (1979), Barr (1975), Royster (1980), Willoughby 1981)).

It is evident that the weight of published literature shows that modern audiometry can be of value to industry, providing that care is taken to adopt a good strategy of testing, to train adequately the audiometricians, and to select and maintain the correct equipment. Providing that these conditions are met, the detection of a growing hearing loss is possible at an early enough stage for the information to be of value in instigating remedial action.

1.2.4.2 Audiometry as a mechanism increasing hearing protector usage.

Atherly (1973) states "research has so far concentrated upon the technical aspects of audiometry. The wider aspects of audiometry have not been the subject of adequate research despite the many recommendations for its use".

Atherly (1981) explores the moral problems facing doctors employing industrial audiometry. The author also discusses most of the benefits to be obtained from such a programme, although curiously he does not mention the effect of audiometry upon the motivation of employees to use hearing protection, or comply with other hearing conservation measures.

The question is approached by Merriman (1977) who attempted to correlate hearing protector useage with the incidence of industrial audiometry on various industrial sites. Merriman states that this section of his study failed due to an inability to obtain the necessary co-operation from industry. Only 8 firms, half of which utilised audiometry, out of a total of 16 approached would cooperate even minimally, and only one visit to assess protector usage per firm was permitted, under the strict supervision of a manager or safety officer. Only three firms would allow even a proportion of their workforce to complete questionnaires dealing with hearing protection and audiometry and this resulted in a return of 52, 51 and 15 questionnaires respectively, insufficient for the purpose, and the statistical analysis techniques applied (Child (1970)). The questionnaires however, were used to obtain an estimate of the attitudes which employees held towards audiometry and then to hypothesise how the audiometry could be affecting the employees reaction towards the usage of hearing protection. Audiometry appeared to inculcate amongst employees a greater awareness of hearing problems and hearing protection but Merriman concluded that as a consequence of his inability to dictate and balance the experimental plan through the lack of cooperation from industry, too many confounding factors existed to provide any firm conclusions. Merriman, however, does provide the results of a good questionnaire survey of the attitudes held by Occupational Health Physicians towards industrial audiometry. A 50.4% questionnaire return rate was achieved yielding 268 questionnaires for analysis and although not of direct interest in this chapter, the data indicate that industrial audiometry is associated by industrial doctors with common law claims for noise induced deafness, and that medical officers performing audiometry do not have any appreciable preference for the issue of ear protection as opposed to engineering noise control.

Zohar (1980) was more successful than Merriman in correlating measures of hearing protector usage with certain non standard hearing conservation activities. These comprised of a lecture, and the measurement of Temporary Threshold Shift (TTS) occuring in employees not making full use of hearing protection during a working day.

Zohar utilised this interesting variant of industrial audiometry in the following manner. Two departments, each containing approximately 80 employees, within a large industrial complex in Israel were designated as experimental and control departments respectively. Zohar estimated the noise levels to be approximately 87-99 dB(A). The control department received a lecture on hearing conservation alone, whilst the experimental department received both the lecture and was also subjected to checks of TTS sustained by employees. The hearing acuity of a pseudo-random selection of six employees each day was measured at the beginning of the shift and then again at the end. Differences in hearing acuity measured during the pre and post shift tests were ascribed to TTS. Each employee received two such tests, and was actively encouraged to discard his hearing protection on one of the two test days. In this manner he was able to observe the difference in measured TTS between the day on which the earplugs were used, and the day on which they were not used. The "protected" and the "non-protected" audiograms were displayed on a notice board, and were interpreted each day by the audiologist. Measurements of hearing protector usage were performed regularly over a 7 month period, the first month being allocated to usage baseline measurements, the second to treatment, and the remaining five to "follow up". Zohar showed that the TTS technique caused hearing protector usage to rise from 30-40% during the baseline period to 80-90% at the end of the follow-up period. However, as discussed in an earlier section of this chapter, a 30-40% initial usage is high and the effect which the treatments would have had if the initial usage levels had been closer to the 10-20% norm, remains an unanswered question.

Problems were experienced by Zohar in assessing the reliability of the hearing protector usage data. The plant safety officer responsible for making these measurements was shown to be falsifying the records during a crucial period, and this prevents an assessment of the contribution of the lecture to this increase, but on the balance of probabilities it is likely that the TTS measurements and noticeboard display of results caused the major effect. The reported problem with the reliability of the data appeared to cause other anomalies, such as the finding that earplug usage was less in the control department after the end of the period in which the lecture was given, and indeed at the end of the follow-up period, than had been measured during the baseline evaluation month. However, one interesting finding was that protector usage continued to increase smoothly after the end of the treatment period, until the end of the five month follow-up period in the section receiving both the TTS measurement and the lecture as a treatment.

It is unlikely that the TTS technique would receive wide acceptance in the United Kingdom as a consequence of ethical considerations, and the fact that medical records are considered to be confidential in the UK (Drew (1973)). Proposals to display audiograms on a noticeboard would meet with resistance from medical officers and trade unions alike.

A modified, but weaker, technique could be used involving individual counselling, but a more serious drawback of the method is that it could prove counterproductive. If an employee already exhibits a sizeable permanent threshold shift and would therefore sustain a reduced TTS, or the time allowed to elapse between leaving the noisy area and undergoing a hearing test is too great, or the noise environment is not sufficiently intense, the measured TTS may be too small to make the point intended. Thus the employee could become convinced that this hearing protection was not necessary.

Other authors have written qualitatively of the value of industrial audiometry in increasing hearing protector usage. Pelmear (1973) states "In one large GKN plant audiometry has been a primary influence in helping to persuade the majority of employees of the necessity to wear ear defenders". In a later communication, Pelmear (1975) confirms that this comment was in the nature of a personal judgement and not made on the basis of any properly controlled evaluative procedure.

Arlinger (1974) makes a similar comment when describing hearing conservation programmes conducted over a two year period in Sweden.

Fritz (1980) suggests that showing employees their audiograms might enhance their understanding of the reasons behind a hearing conservation programme, a recommendation endorsed by Royster (1982) who states that "Immediate feedback when the employee emerges from the test booth offers the greatest potential for influencing his or her attitudes towards the HCP (Hearing Conservation Programme) and HPD (Hearing Protection Device) use". Somerville (1976), expounds further describing one of the uses of monitoring audiometry as "Propaganda. Keeping the need for protection fresh in peoples' minds".

However, although indications exist in the literature that routine screening audiometry might increase hearing protector usage, the link is still to be proven. It can be stated that audiometric results provide a powerful discussion point when confronting an employee in an attempt to make him understand clearly that the risk of permanent hearing loss applies to him, and not just to his fellow workers. It can also be argued that properly used these results must change an employee's attitude, but what cannot be argued is that this change will be sufficient, or sufficiently long lasting to cause a change in behaviour in terms of hearing protector usage. Experimental proof of this mechanism is required.

1.3 Conclusions

In 1972 a voluntary code of practice was published by the HSE detailing the action required of industry to reduce auditory hazard within a workplace. In 1984 the Member of Parliament for Newham North East, Mr Ron Leighton, stated in the House of Commons that "My conclusion is that the voluntary approach has failed. The Health and Safety Commission recognised that last year when it issued the first comprehensive (draft) set of regulations for the reduction of noise in Britain" (Hansard 1984).

It was stated within this chapter that up to 1.75 million employees are today exposed to noise levels in excess of the HSE limits, and that up to 80% of these individuals are insufficiently protected from these damaging noise levels. It was further shown that engineering control at source was the most complete, but not the most economic solution, providing that some mechanism could be found to ensure that employees made proper use of the hearing protection otherwise issued. Evidence was discussed showing that the issue and full use of hearing protection could adequately safeguard the hearing of employees.

Three forces were examined which could cause the required full usage of hearing protection. These were; moral forces, legislative forces, and forces generated either directly or indirectly by the workforce and focussed on the employer. All three were shown to be lacking in effectiveness to varying degrees.

As stated by Mellard (1978) "... the only incentive which works in the final analysis is the employee's attitude towards the need to protect his hearing. The educational effort is critical in the achievement and maintenance of this attitude. To get the employee sufficiently concerned about his hearing, to use effective personal hearing protection consistently without causing undue alarm or anxiety is a major objective of the educational effort".

From the review of the literature described in this chapter it would appear that the educational effort made by employers is lacking, either as a result of constraints in resources or inclination, or because standard educational programmes involving films, posters and seminars, are not particularly effective.

Suggestions were noted in the literature that serial industrial audiometry could provide the necessary impetus to the employee to make use of his hearing protection. Although a concept proposed by a few authors as evidence of a further benefit to be obtained from industrial audiometry, no properly controlled large scale study had been performed to investigate the link between the performance of normal industrial audiometry and any observed change in hearing protector usage.

Furthermore, no indication was given in the literature as to whether routine industrial audiometry was more or less effective in persuading a workforce to use hearing protection than was a standard educational package.

In view of the lack of any potent force working on employees to increase their hearing protector usage, and the apparent failure of standard educational packages to persuade them to take this course, it was decided to conduct a study to investigate the potency of industrial monitoring audiometry to increase hearing protector usage in the industrial environment.

1.3.1 The study hypotheses

Eight main hypotheses will be considered in the study. These are shown below

(1) Industrial audiometry can produce significant long term changes in attitudes held by employees.

(2) Education alone can produce a significant long term change in the attitudes held by employees.

(3) Industrial audiometry is more effective than education in causing long term changes in the attitudes held by employees.

(4) Industrial audiometry plus education is more effective than either of the two components used singly to change the attitude of employees.

(5) Industrial audiometry can produce long term changes in the behaviour of employees.

(6) Education alone can produce significant changes in the behaviour of employees.

(7) Industrial audiometry is more successful than a programme of education in changing the behaviour of employees.

(8) Hearing protector usage can be increased more effectively by a programme of industrial audiometry with education than it can by a programme of audiometry alone or education alone.

It is also proposed that during the course of the research programme those problems should be addressed which, if left unresolved, could prevent either the audiometry or programmes of education from increasing hearing protector usage.

The research work proposed in this section is described in the thesis in the following manner.

Chapter 2 describes the experimental plan and treatments, the site on which the research was conducted, and the measurements made of the noise levels in which the employees worked. Chapter 3 details the results of a pilot, or preliminary, Hearing Conservation Study exploring initial ideas on hearing conservation matters. A problem identified during this study was that of discomfort experienced by users of earmuffs, and resulted in an investigation of the comfort of these protectors and the specification of a comfortable device. This work is described in chapter 4.

Chapters 5 and 6 detail the considerations given to the choice of the type of questionnaire to be used in the study to measure attitudes, and the analysis methods available. Chapter 7 shows how these techniques were used to develop the pilot attitude questionnaire, and the analysis of the subsequent response. Chapter 8 discusses the refinement of the attitude questionnaire and the results of using this questionnaire on the pre-treatment test population. Chapter 9 shows how hearing protector usage changed in the experimental plants as a consequence of the treatments, whilst chapter 10 describes the attitude changes caused by these same treatments. The attitude changes were measured by use of a post-treatment despatch of attitude questionnaires.

Chapter 11 describes the analysis of the audiometric data obtained during the research programme. Chapter 12 draws the results of the research work together and presents the overall conclusions.

CHAPTER 2

THE EXPERIMENTAL PLAN

2.0 Introduction

To achieve the objectives described in sections 1.3 and 1.3.1 of Chapter 1 it was decided to design a large scale experiment to be completed in industry. This experiment would test the relative efficiencies of industrial audiometry and programmes of education in increasing hearing protector usage, and changing employee attitudes towards hearing conservation in industry.

The field work was undertaken at the Imperial Chemical Industries Wilton Site near Middlesborough, England. The generous cooperation of ICI thus permitted access to a large industrial site containing various plants with noise problems, physically separated from each other, but controlled by a managerial structure which responded ultimately to a single Board at the ICI headquarters in London.

It was therefore possible to devise an experimental plan in which the treatments of interest, these being audiometry, education, and audiometry with education, could be applied to experimental plots, or groups of plants, chosen so that a high degree of homogeneity existed over a variety of factors. Thus a classical scientific experiment was constructed using a large number of employees in a noisy manufacturing industry. The work described in this thesis is directed towards investigating the efficiency of industrial audiometry and programmes of education in causing attitudinal and behavioural change measured in terms of increased usage of hearing protectors. It was realised, however, that attitudinal changes may be of little value if powerful physical counterforces exist which mitigate against an increased usage of hearing protection, thus reducing behavioural change. Acccordingly a preliminary Hearing Conservation study was completed in addition to the main study described above, to assess any physical problems associated with hearing protector usage.

This chapter describes the structure of the Wilton site on which both the main experiment and the Hearing Conservation study were completed. The chapter details those physical and organisational factors relevant to the success of the research programme, and the preliminary groundwork necessary.

Details are given of the plants participating in the Main Experiment and Hearing Conservation study in addition to a description of the site Medical Centre, and the audiometric facilities used.

The treatments utilised in the Main Experiment are described in this chapter in outline, but a full description is reserved until chapter 9. The methods used to measure the success of the treatments are also described in outline in the present chapter but are given in greater detail in chapters 5 and 9.

2.1 A description of the Wilton Site, and its organisation

Purchased in 1945, the Wilton site was one of the 39 main ICI production centres in the United Kingdom (Reader, 1975), and embraced 3500 acres of land, 1500 acres of which were developed. Approximately 40 miles of roads serving a large number of closely grouped plants were contained within the industrialised section.

At the time the field work was performed, 14000 people were employed on the site, 10350 of whom were weekly paid. Participants in the research programme were drawn from this weekly paid population. These individuals were employed in the plants listed in column (c) of table 2.1 . Figure 2.1 shows a photograph of a model of the Wilton Site, and indicates the location of these plants.

Weekly paid employees belonged either to one of four shifts, or to a group known as "day workers". The Wilton Site utilised a continental four shift system, three shifts working consecutively for eight hour periods during any 24 hour day, with the fourth shift resting.

Table 2.1 Showing the organisation and responsibilities of the various divisions present on the site at Wilton. Only those works and plants which were included in the research programme are shown in this table.

(a) Division	(b) Works	(c) Plant or section
Petrochemicals	Nylon Chemical	Nylon Chemical
	Olefines	Olefines V
		Para-Xylene
	Services	Power Station
	Engineering Services Ltd. *	Central Workshops
Mond	Bain	Titanium
Organics	Organics	Aniline
		Lissapol
Fibres	Fibres	Terylene Polymer
		Nylon Polymer
		Terylene Drawtwist
		Terylene Spinning
		Terylene Drawbulk
Plastics	Teeside	Polythene II
		Polythene IV
		Polythene V
		Polythene VI
		Polythene Finishing
		P.F. Plant
		Propathene Finishing
1	2	3

* This is not a true 'works', but a wholly owned subsidiary

Five divisions were represented on the site at Wilton, these being Fibres Division, Mond Division, Organics Division, Petrochemicals Division and Plastics Division.

The host division on the Wilton Site was Petrochemicals; and was responsible for the supply of essential services to the plants owned by other divisions situated at Wilton. These services included the supply of water and power, engineering services, site safety, water treatment, site security and more importantly, with respect to the research programme, the medical service.

Each division retained a high degree of autonomy of action, and was responsible in theory only to divisional headquarters, which in all cases except that of Petrochemicals Division was situated in another part of the country. In practice a high degree of cooperation existed between the divisions on the Wilton Site, which were also unified in their acceptance of a common medical policy.

The divisions were further sub-divided into "Works" each Works being responsible for the activities of one or more plants. Table 2.1 shows this sub-division of responsibility at Wilton, but only those divisions, works and plants which were included in the research programme are listed.

Passage of the research programme through the field work phase was facilitated by cooperation received from Management and Trade Union groups as a result of a policy of repeated discussions as the project proceeded. The structure of these groups is discussed briefly below to indicate the work necessary both before and during the study to progress the project through the required administrative channels, and to show the problems in communication encountered when setting up a Hearing Conservation programme.

Each division of ICI was controlled by a Board of Directors located in the headquarters of that division. These Boards reported to the Company Board at Imperial Chemical House, Millbank, London. The Petrochemical Division maintained its headquarters, and hence Board, on the Wilton site.

It was necessary to gain the cooperation of this Board at the inception of the programme in order to obtain permission for the research work to be undertaken at Wilton. This exercise set the pattern for many meetings with the various managers below board level.

A Works Manager was responsible for each of the works shown in column two of table 2.1 , except for the Organics Division in which the position was known simply as "Manager", and Services, Works and Engineering Services Ltd, which both possessed a general manager above the works manager level. The majority of the plants or areas listed in column 3 of table 2.1 were controlled by a single manager, known as a plant manager, plant group manager, or section manager. However, in the case of the Titanium plant, the Central Workshops, the PF Plant, and the Propathene Finishing Plant, the management structure was more complex, dictated by the organisational requirements of the process. Three strata of management could be involved at this level.

The last links in the management chain were provided by the Shift Managers and Shift or Day Supervisors, and finally, the Shift and Day Foremen.

Each level of management described above required a full verbal description of the project so that permission to work in the relevant area could be obtained. This policy was also necessary to ensure full cooperation with the activities of the research study, down to the shop floor level.

In addition, a site meeting of the Works Managers was addressed at intervals throughout the research programme to inform them of the progress of the study.

Two other management groups, Personnel Officers and Safety Officers were also kept fully informed of the progress of the research programme.

The Safety Officer of Services Works supervised overall site safety. The research programme was discussed with this officer on several occasions, whilst the other safety officers employed by individual Works were approached as the work progressed. These individuals were enthusiastic about the proposed hearing conservation programmes in the various plants, as they regarded such excercises as being ancillary to their own efforts. Care was taken to stress that for the duration of the study the hearing conservation programmes undertaken in the selected plants were to follow strictly the lines dictated by the research plan.

Contact was made with the the plant Personnel Officers whenever the plants for which they were responsible were used in the study. They were especially valuable when listings of employees in a particular area were required, either to facilitate the computer storage of research data, or to organise hearing conservation activities on the plants.

A site meeting of Personnel Officers was addressed at the beginning of the research programme to discuss the objectives of this work, and request their assistance.

It was also vital to the success of the research that the cooperation of the Unions on the site should be enlisted . Seven of the eight ICI signatory unions were present on the Wilton site.

As suggested by its name, the Senior Shop Stewards Committee represented the most senior Trade Union forum on the Wilton Site. This committee met weekly, and was comprised of 15 members.

Trade Union opinion and reaction were extremely important in achieving the success of the programme, and conscious effort was made throughout the research period to keep the Senior Shop Stewards Committee informed of the research and of its progress. The Senior Shop Stewards were well disposed towards the study. Their main concern centred around the confidentiality of the data collected on individual members. As a basis for trust was progressively established, work which required the agreement of the Trade Unions to facilitate employee participation, proceeded smoothly.

Indication that the initial reaction of the Trade Unions to the research programme was wary is shown by the letter reproduced in Appendix A2.0, sent by a Senior Shop Steward to the Legal Department of his Trade Union. Nevertheless towards the end of the research programme, cooperation from the Trade Unions was so high that two Senior Shop Stewards appeared, with the Divsional Medical Officer, in a publicity photograph designed to improve the employee response to the final exercise undertaken on the site.

The ICI organisation of the Wilton Site into divisions and plants was not paralleled by the structure of the Senior Shop Stewards Committee. Furthermore, as a Shop Floor Steward was present in a plant to represent the interests of any members of that particular union working in that plant, there could be several Shop Floor Stewards in a plant, but not necessarily one on every shift. If a Shop Floor Steward was present on a shift, he did not necessarily represent all the employees in that shift. All these factors meant that the flow of information through union channels to the employees was sometimes difficult. It should be stressed, however, that the majority of Senior Shop Stewards made an appreciable effort to ensure that principles agreed at the Senior Shop Stewards Committee, and information relating to the research programme, were known to all plant employees.

In view of these difficulties however, it was decided that each time a research excercise commenced using a particular shift, the research programme would be explained to the local Shop Floor Steward in a form which was accurate, but which would not bias the outcome of the experiment.

A meeting of the Senior Shop Stewards was addressed during every major visit to ICI Wilton. Topics for discussion, in addition to the progress of the research programme, ranged from concern that noisy machinery was still being installed on plants, to disquiet at the lax wording, apparently in favour of the employers, to be found in the "Code of Practice for Reducing the Exposure of Employed Persons to Noise" (Department of Employment, 1972).

2.2 The Medical Department

2.2.1 The facilities

The Medical Department at Wilton is located centrally on the site. Facilities include a small ward, physiotherapy department, Analytical Laboratory and a Radiology Section. A Dispensary and two Dental surgeries are housed within the Medical Block.

An audiometric facility also forms part of the Medical Centre, and was utilised during the research programme. The audiometer and test environment is described fully in chapter 11.

The Medical Department was completed by a large Records Office, with secretarial staff and an ambulance section. The secretarial staff employed in the Records Office also assisted the research programme by administering the flow of employees to the audiometric facility.

2.2.2 The project group

The activities of the medical centre were directed by the Petrochemicals Division Medical Officer. At the time the research programme was undertaken the remainder of the medical complement comprised two Works Doctors, a nursing staff of 9, a radiographer, three laboratory technicians, two physiotherapists and two ambulance drivers.

The research plan discussed later in this chapter included a large component of audiometric testing, which although organised by the author, was conducted on a daily basis by Wilton site medical staff.

In order to facilitate the administrative task, and to give a feeling of unity of purpose to those ICI medical personnel involved in the daily audiometric testing, a Project group was formed.

The overall responsibility for the research programme on the Wilton site was held by the Petrochemicals Division Medical Officer. The remainder of the Project Group consisted of a Works Doctor, one Nursing Sister, a member of the secretarial staff, the Radiographer and a Laboratory Technician.

The last three named members of the group were trained at the beginning of the programme in the audiometric technique to be used in the study. The laboratory technician was primarily responsible for effecting the flow of employees from the relevant plants in accordance with lists sent weekly from the University. The nursing sister dealt with any medical problems which arose during the course of audiometric testing, such as examination of the ear canal, and ear syringing to remove wax. The radiographer was charged with maintenance of the audiometer, and the despatch of audiometric data to Southampton University.

A secondary team was also trained in audiometric techniques, and acquainted with the objectives of the research programme so as to be available for duty if a member of the primary group was not available on a particular day. This secondary team consisted of three occupational nurses.

2.3 The Experimental Design

2.3.1 The prelimary hearing conservation study

Eighty employees particpated, drawn from the Lissapol plant, Nylon Chemical Outside Services and the Titanium plant in Bain Works. The location of these plants is shown on figure 2.1 . The three groups were selected as they were not to be included in the Main Study, and yet their working environments were representative of those to be found within plants which were to particpate in the main experiment. Furthermore, as described within Chapter 3, hearing protector usage was high if intermittent, within the selected groups, thus giving validity to comments upon hearing protectors.

The three plants or workplaces are described in section 2.4, and their associated noise levels are given in section 2.5.

Chapter 3 describes the manner in which the study was conducted, involving the use of a questionnaire enquiring into certain aspects of hearing protector usage. This questionnaire was completed by an industrial nurse on behalf of each employee when he attended the Medical Centre for an audiometric test.

2.3.2 The design of the main experiment

The experimental plan was based upon four treatment plots each comprised of two industrial plants. One plot was used as a control, whilst each of the remaining three received either audiometry, education, or both as a treatment. The success of the treatments was evaluated by monitoring the change in hearing protector usage, and through questionnaries used before the treatments commenced, and again when they had terminated.

The experimental plan allowed clear conclusions to be drawn at the end of the study but did require that four groups of plants be found which exhibited a high degree of homogeneity across a variety of factors. Furthermore the eight plants needed to be sufficiently physically separated to preserve the purity of the treatments.

The use of two plants in each treatment group allowed a comparison to be made between results obtained on each of the plants within a group. Just as importantly, however, the use of a pair of plants within each group protected the study to an extent, from failure caused by an event such as the closure or withdrawal of cooperation of a single plant at a critical stage. The necessity of designing the experimental plan in this way was underlined early in the research work when two plants which had been included in the experimental plan closed and thus required replacement soon after the initial noise surveys had been completed. The closure was caused by the prevailing economic conditions.

Two plants within each experimental group also increased the amount of information obtained from the study but, naturally doubled the work necessary.

The selection and allocation of plants to each of the treatment groups was made after consideration of six factors. These were: the measured noise levels, the distribution of noise sources and employees within the plant, the types of industrial process undertaken in the plants, the level of ear protector usage pre-dating the beginning of the study and the designation of hearing protection areas, the criterion that no plant participating in the research programme should have been exposed to education material describing industrial noise as a hazard to the hearing later than 18 months prior to the commencement of the study and, finally, the size of the workforce within each plant.

Because it was required that the statistical comparisons performed at the termination of the study should be of equal precision, the workforce size in each of the plants needed to be comparable, and high enough so that despite the natural process of resignation from ICI occurring during the 2-year field study stage, sufficient numbers of the original employees would remain at the end of the study to complete usefully the post-treatment questionnaires.

The experimental plan devised, and shown in table 2.2 , represented the optimum arrangement in respect of the criteria discussed above, and encompassed 1,716 employees.

However, the study described in this thesis differs from the more standard laboratory experiments in that every variable cannot be controlled exactly when operating using factories as plots in an experimental design. Comparison can be made between the present study and those performed in the field of education for which the term "Action Research" has been coined. Morris (1967) defines Action Research thus: "Action attempts to comprehend all the factors relevant to an immediate problem whose nature can continually change as events proceed where (classical) research abstracts one or two factors for attention, and holds to constant definition of the problem until the experiment has been concluded". Smith (1970) argues strongly for the use of Action Research in studies conducted outside the laboratory environment stating that whilst absolute control of every variable is often seen as of paramount importance by the scientific community, "whether such control would produce the type of information about expected outcomes that would satisfy the planning element in the project is a separate question". The point made about planning is of particular importance to the present study for the results of the study will be used for planning hearing conservation programmes in the future. Smith concludes this point "What it (Action Research) offers is an aid to intelligent decision making, and not a substitute for it". The essence of the argument leading to this conclusion is that rigorous control of each variable in a study such as the one described in this thesis would constrain the plot (the plant) in such a way as to make it an unnatural testbed for the treatment, and thus invalidate the results.

The experimental plan of this study follows the "Classical Research" ideology more closely than that of "Action Research", but throughout the study ideas have been taken from the concept of "Action Research".

2.4 The Plants

The plants participating in the main experimental plan are shown on the map

Key

A	Medical Centre	11	Terylene Drawtwist
1	Nylon Chemical	12	Terylene Spinning
2	Olefines V	13	Terylene Drawbulk
3	Para-Xylene	14	Polythene II
4	Power Station	15	Polythene IV
5	Central Workshops	16	Polythene V
6	Titanium	17	Polythene VI
7	Aniline	18	Polythene Finishing
8	Lissapol	19	P.F. Plant
9	Terylene Polymer	20	Propathene Finishing
10	Nylon Polymer		

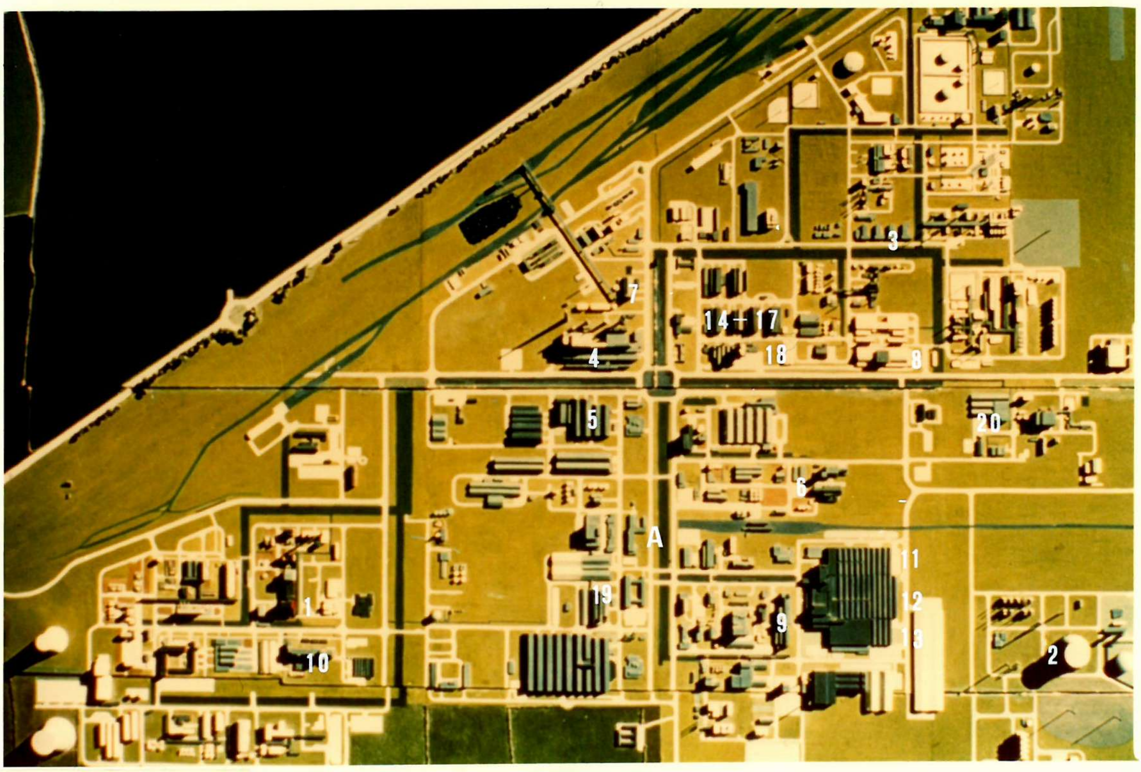
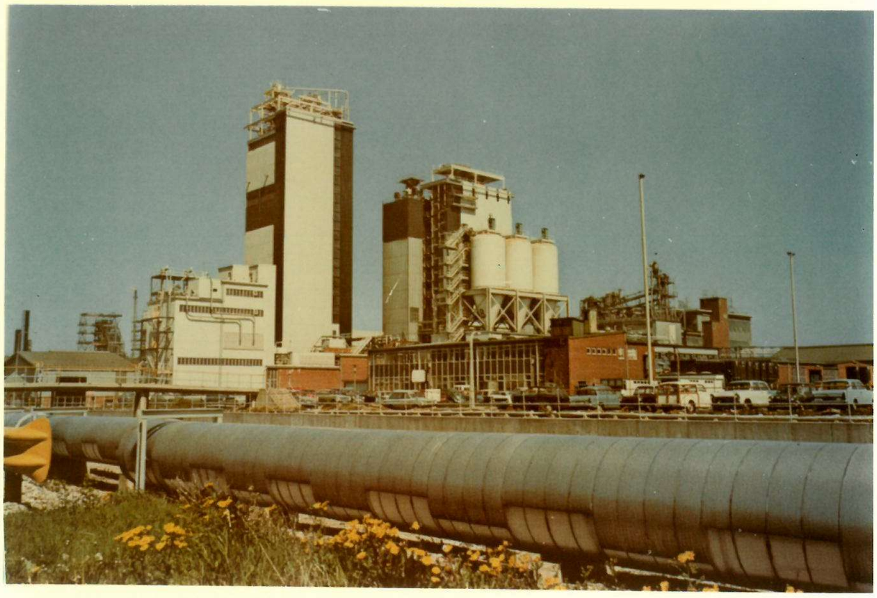


Figure 2.1

A model of the Wilton site, showing participating plants and areas.

Nylon Polymer

Propathene
Finishing



Olefines V

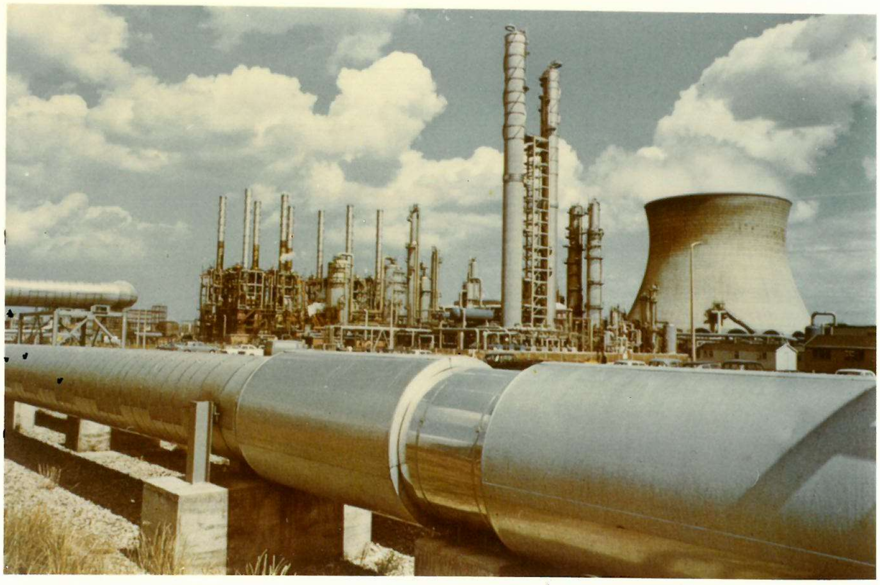


Figure 2.2 Plants on the ICI Site

Table 2.2 The Experimental plan showing "n", the number of employees in each plant, and the treatments.

Audiometry	Education	Audiometry and Education	Control
Terylene Polymer Plant 1 n = 198	P.F. Plant Plant 3 n = 311	Propathene Finishing Plant 5 n = 224	Polythene Finishing Plant 7 n = 143
Olefines V Plant 2 n = 175	Central Workshops Plant 4 n = 180	Nylon Polymer Plant 6 n = 247	Power Station Plant 8 n = 238

in figure 2.1 . Each plant worked a shift system, three working in any 24 hour period, with a fourth resting, except for the Central workshops, which contained only day workers.

2.4.1 Plant 1. Main experiment, Terylene Polymer

This four storied plant is subdivided internally into North and South plants, and was part of Fibres Division. The product is an ivory coloured plastic produced from terephthatic acid and ethylene glycol, which is cut into chips prior to conversion to a fibre. The plant is capable of producing 90,000 tonnes each year, and the main noise sources are the Bandcasters, guillotines, autoclaves, Tornado air blowers, Nash Hytors, these being items of plant, the Bag Filling station, and the Carbon Annexe.

2.4.2 Plant 2. Main experiment, Olefines V

A plant built around product separation columns, cracking furnaces and compressor units, parts of Olefines V are on the ground level, whilst others are on as many as five main levels, those above ground level being in the nature of catwalks. Smaller catwalks exist above level five. The plant produced 450,000 tonnes of ethylene each year, in addition to Propylene and Butenes starting from Naptha feedstock. The main noise sources were the cracking furnaces, compressors, superheaters and steam raising boilers. The Olefines V plant is shown in figure 2.2 .

2.4.3 Plant 3. Main experiment, PF plant

The PF plant is constructed on two main levels and is further divided into two sections; Propathene and Alkathene. The plant was used for reworking unsatisfactory plastics manufactured elsewhere on the site. The main noise sources were the extruders, Eagan cutters, Banbury mixers, cyclones, these being items of plant and the "packing off" stations.

2.4.4 Plant 4. Main experiment, Central workshops

The Fabricating shop of the Central Workshops is on the ground level and produces small scale and large scale finished pieces for use on Wilton plants. Noisy activities include, welding, grinding, chipping, plasma cutting, hammering and swaging. The shop is divided internally by barriers designed to facilitate the flow of work rather than to offer noise protection.

2.4.5 Plant 5. Main experiment, Propathene Finishing

The Wilton site produced 190,000 tonnes of Propathene each year at the time the study was conducted. The main production areas were housed in three buildings, the first encompassing the packing area, and Extruders 9 and 10, the second being the main Extruder building and the third, No 11 Granulation Tower. Activity in the first of these buildings was confined mainly to a single ground floor, although additional, much smaller, floor levels did exist in other sections of this building, which also included the refeed tower. The Granulation tower had several stories, whilst work in the main extruder building was confined mainly to one level, with several subsidiary, smaller levels existing. The main noise sources were the extruders, packing stations, Spin Dryers, and polymer transfer lines. The Propathene Finishing Plant is shown in figure 2.2 .

2.4.6 Plant 6. Main experiment, Nylon Polymer

Constructed with as many as seven levels in some areas, this plant produced Nylon 6:6 polymer used for spinning into yarn and staple fibres at sites other than Wilton. The product output was approximately 110,000 tonnes per year, produced from 6:6 Nylon salt. The main noise sources were the Casting troughs, and cutters, autoclaves and Thermex heaters. The Nylon Polymer plant is shown in figure 2.2 .

2.4.7 Plant 7. Main experiment, Polythene Finishing

This plant re-works ICI produced plastics into desired blends or qualities, and was built mainly on ground level with one ten-story feed tower. Towards the end of the study period certain new machinery was added in a section of the plant which had previously been one of the quieter areas. However, the noise emission from this addition did not alter the type of noise within the plant, nor the overall noise level. The main noise sources were the Banbury units, the packing stations and P3 and Bemis packlines, and the blowers and driers.

2.4.8 Plant 8. Main experiment, Power station

The power station can produce 280 MW of electricity for Wilton site plants, and 4.25 lb per hour of steam for process use and feedwater heating. Two main levels existed within the power plant: the operating floor, and the basement. However, there were additional annexes and smaller operating levels. The main noise sources were steam leaks, the turbines, and the boilers.

2.4.9 Preliminary Hearing Conservation Study, Nylon Chemical

This plant manufactured 6:6 Nylon salt from cyclohexane produced at Wilton, and ammonia and hydrogen sent from ICI Billingham. The salt was used by the Wilton Nylon Polymer plant to produce a polymer suitable for spinning. Nylon Chemical was a plant subdivided internally into small plants each completing part of the process. The plant was built on several main levels, and the typical noise sources were vibrators, hoppers, air and hydrogen compressors, pumps and ovens.

2.4.10 Preliminary Hearing Conservation Study, Titanium Plant

Titanium was produced on the Wilton site by the reaction of sodium and titanium tetrachloride. The plant was on four levels, and the main noise sources were slurry pumps, air fans, crushers, and vibrators.

In addition the process involved controlled detonations inside "Pots" the contents of which were then chipped free. Thus, hand held tools such as chippers and metal grinders represent the main noise sources, together with the detonations.

2.4.11 Preliminary Hearing Conservation Study, Lissapol plant.

This plant uses ethylene glycol to produce Lissapol, a form of detergent.

The Lissapol plant is constructed on three main levels, and the main noise sources are the polyether reactors, the Lissapol pump, resin reactor and Lissapol ejectors.

2.5 Noise Measurement

One of the major constraints within the main experiment was that exposure of the workforce to noise within each plant was to be similar. Accordingly noise surveys were undertaken prior to allocation of the plants to the experimental plan. These surveys were undertaken using both noise dose meters and sound level meters. Employees were told that each type of survey acted as a check upon the other, and that the results of the noise measurements would be used for research purposes only, and would not be shown to management or trade unions.

The surveys were not intended to measure the noise immission of every item of noisy plant, but rather to measure the noise levels in the sections of the plant in which employees worked.

Sound level meter surveys were also performed in the three plants participating in the Hearing Conservation Study.

2.5.1 Instrumentation and methodology

The sound level meter surveys were performed using a Bruel and Kjaer precision grade sound level meter type 2203, fitted with an octave filter set, type 1613. A free field one inch condenser microphone was used, type 4145 and the system was calibrated before and after each survey using a pistonphone, type 4220.

A technique was adopted for the sound level meter survey, which involved noting the approximate movements of employees within a plant, and then following a similar track with the sound level meter, stopping every 8-12 metres to make a noise measurement. If the employees were stationary for relatively long periods of time, measurements were completed at the workstation. A similar technique of spatial sampling has been described by Miller (1978).

The strength of this technique is that the noise survey results provide a description of the plant biased towards the noise levels which an employee is likely to encounter during a working day, and away from the less valuable type of survey showing the level of noise emitted by each item of plant. In this manner the frequency with which the employee is likely to encounter a particular noise level can be assessed, in addition to its magnitude, as both factors are likely to affect hearing protector usage.

Additionally this technique permitted easier comparisons to be made between the noise environments within plants, a prerequisite of the study, than would be possible if traditional noise maps were drawn.

Accordingly the results of the sound level meter survey are shown in figures 2.04-2.11 plotted as histograms of the frequency of occurrence of given noise immission levels for each of the plants participating in the preliminary Hearing Conservation Study, and the Main Experiment.

Main Experiment plants were also surveyed by measurement of employee noise dose, permitting comparisons to be made between plants using this extra parameter.

Computer Engineering Ltd (CEL) type 122 dose meters, certified for use in a Class 1 atmosphere (British Standards Institution (1958)) and Du Pont dose meters, type E-100, also certified for use in a class 1 atmosphere were used. Both dose meters met the specifications of BS 3489 and IEC 123 (British Standards Institution 1962 and International Electrotechnical Committee 1961).

Research work completed by Martin (1974), Roberts (1973), Toremalm (1974), Stearman (1974, 1975), Wilson (1973), Norgan (1977) and Nelson (1980) indicated that both types of dose meter would provide excellent tools for assessing employee noise dose to the accuracy required in this study, even in environments in which impact noise was prevalent, although in this latter case an underestimate of 1-2 dB could result.

The meters utilised were of an industrial grade, as at that time no precision grade personal dose meter was available. However, it was felt that the direct measurement of L_{Aeq} using a dose meter would provide a

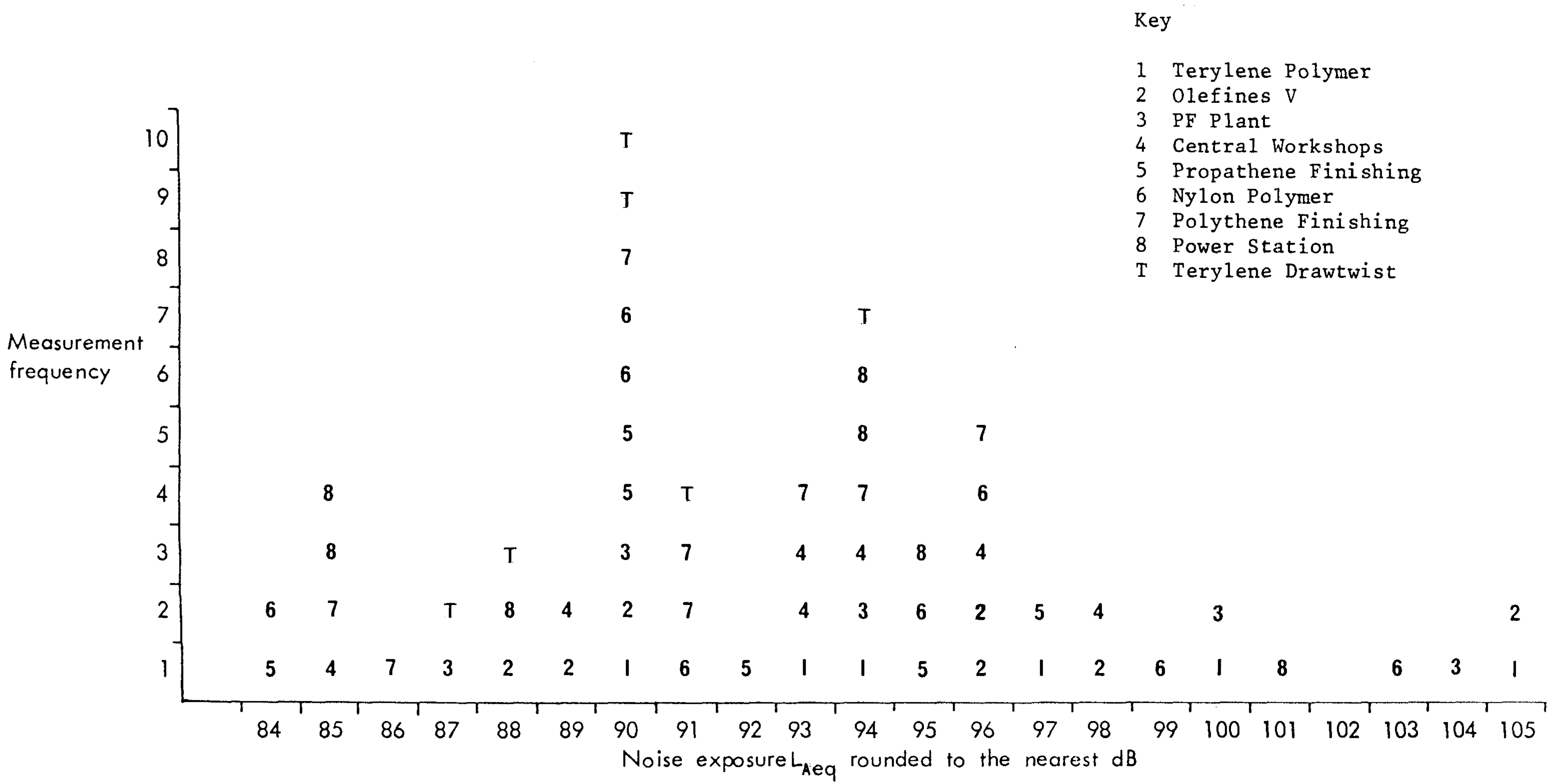


Figure 2.3 The L_{Aeq} ratings measured on employees from the eight plants in the main study. The symbol "T" represents Terylene Drawtwist which contributed audiometric records, although it closed early in the study.

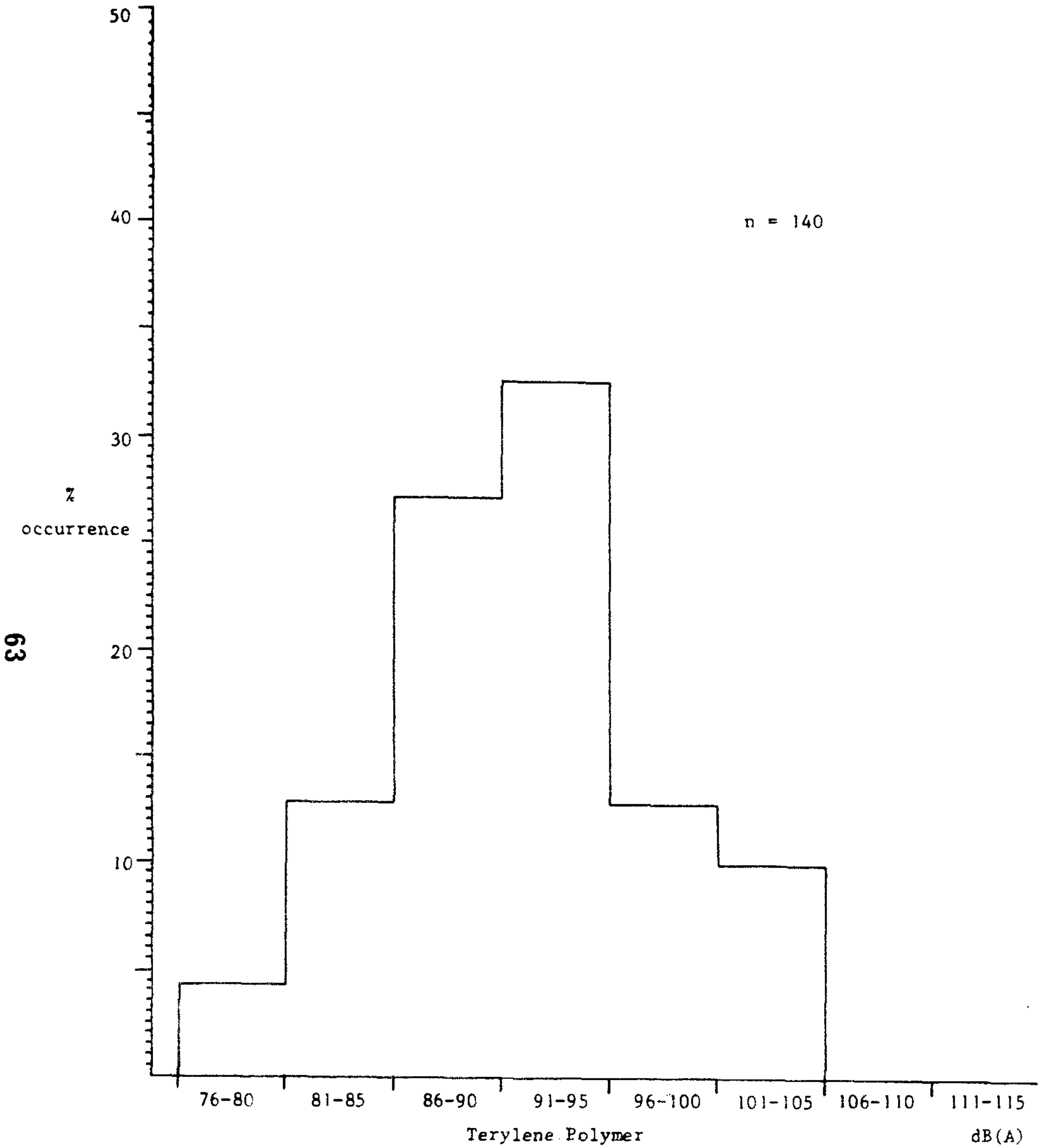


Figure 2.4

Noise Levels

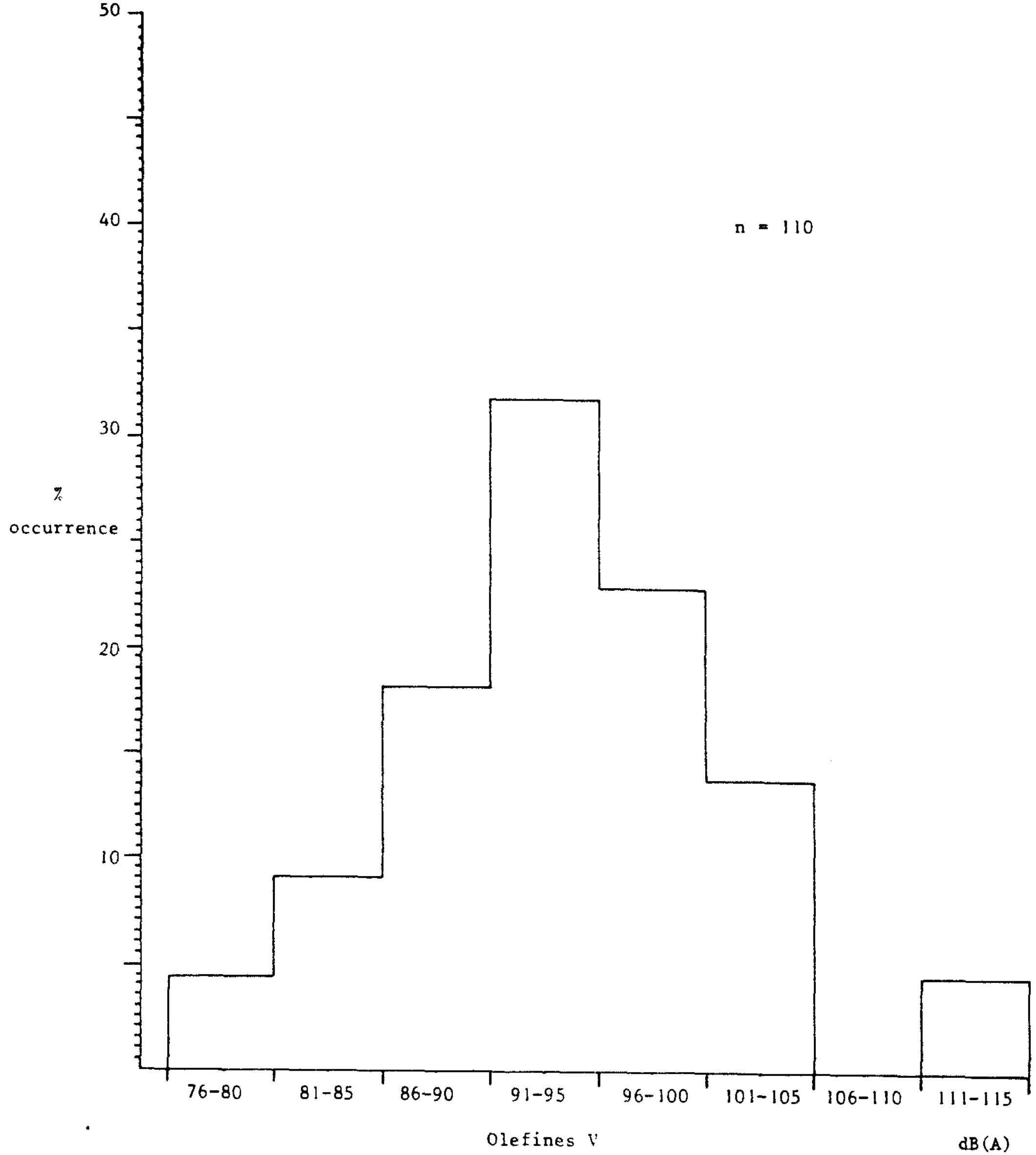


Figure 2.5

Noise Levels

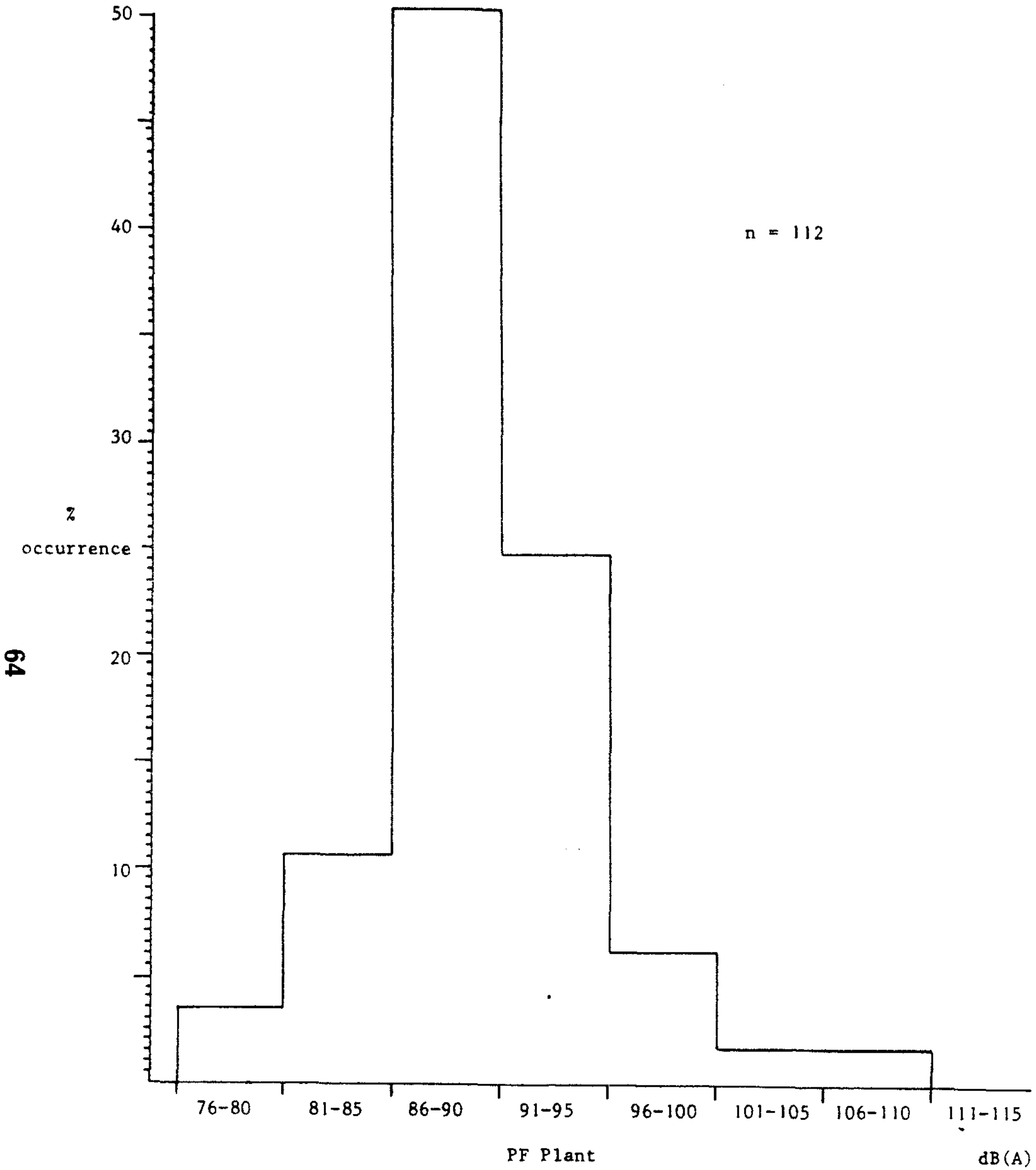


Figure 2.6

Noise Levels

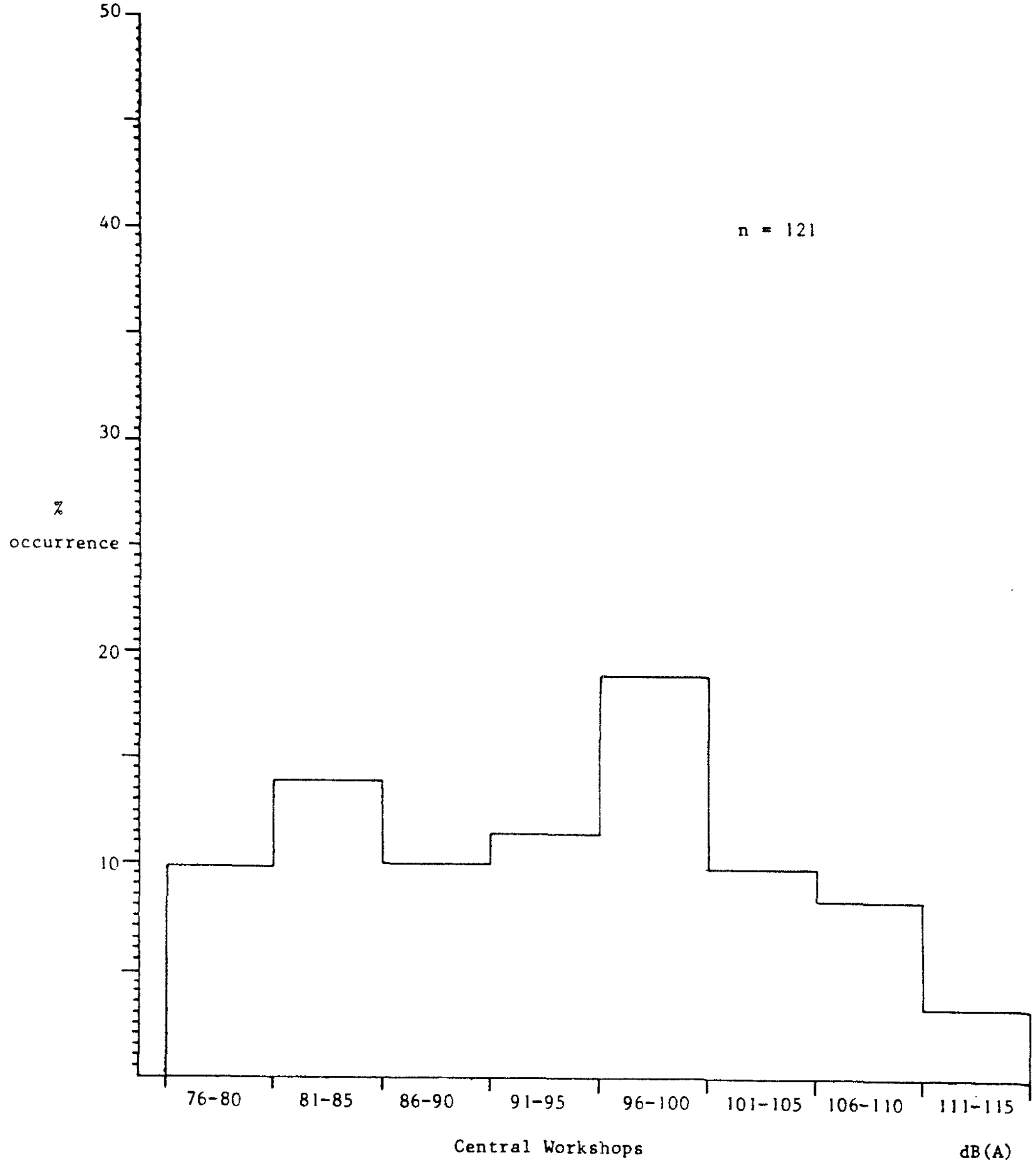


Figure 2.7

Noise Levels

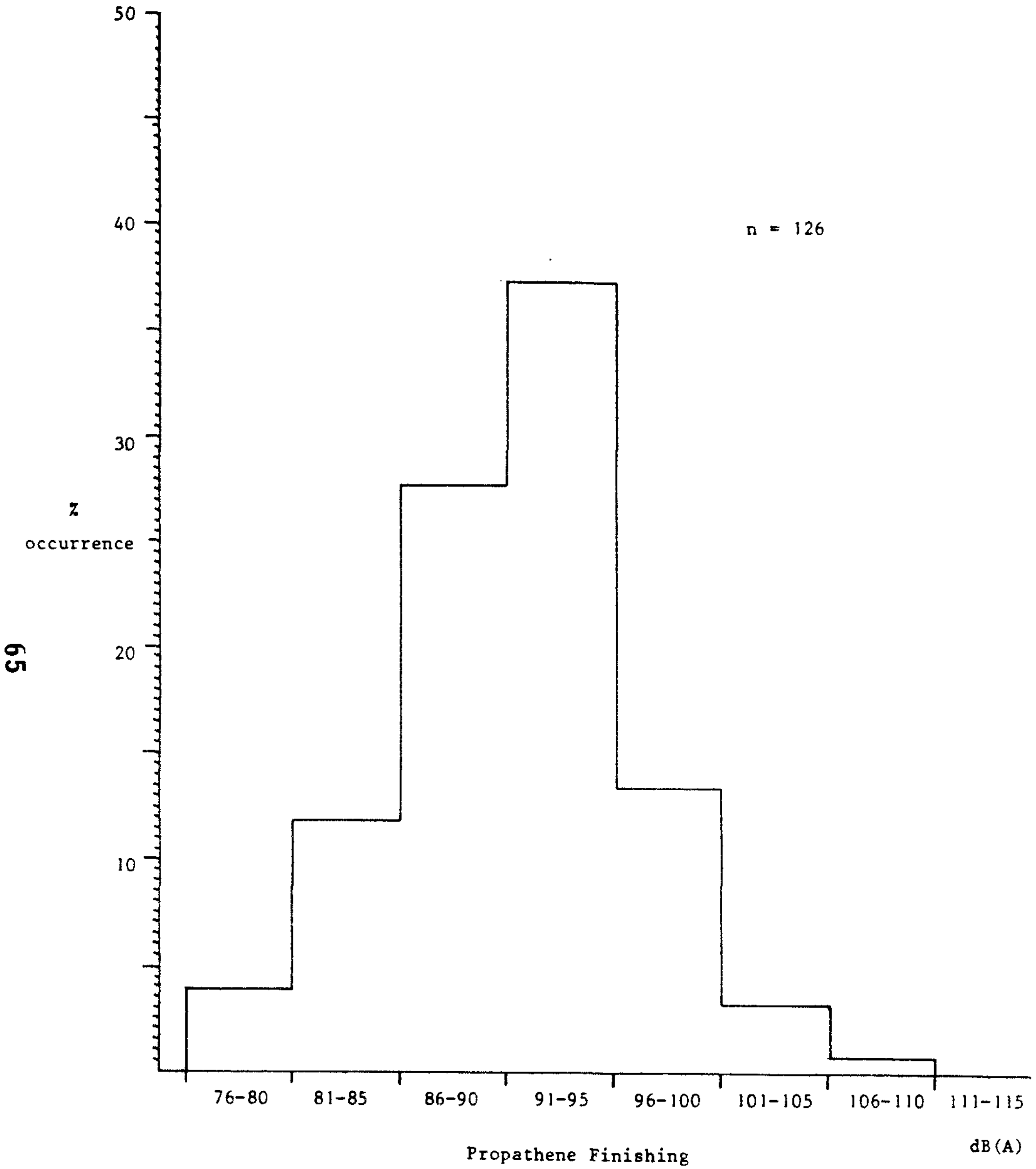


Figure 2.8

Noise Levels

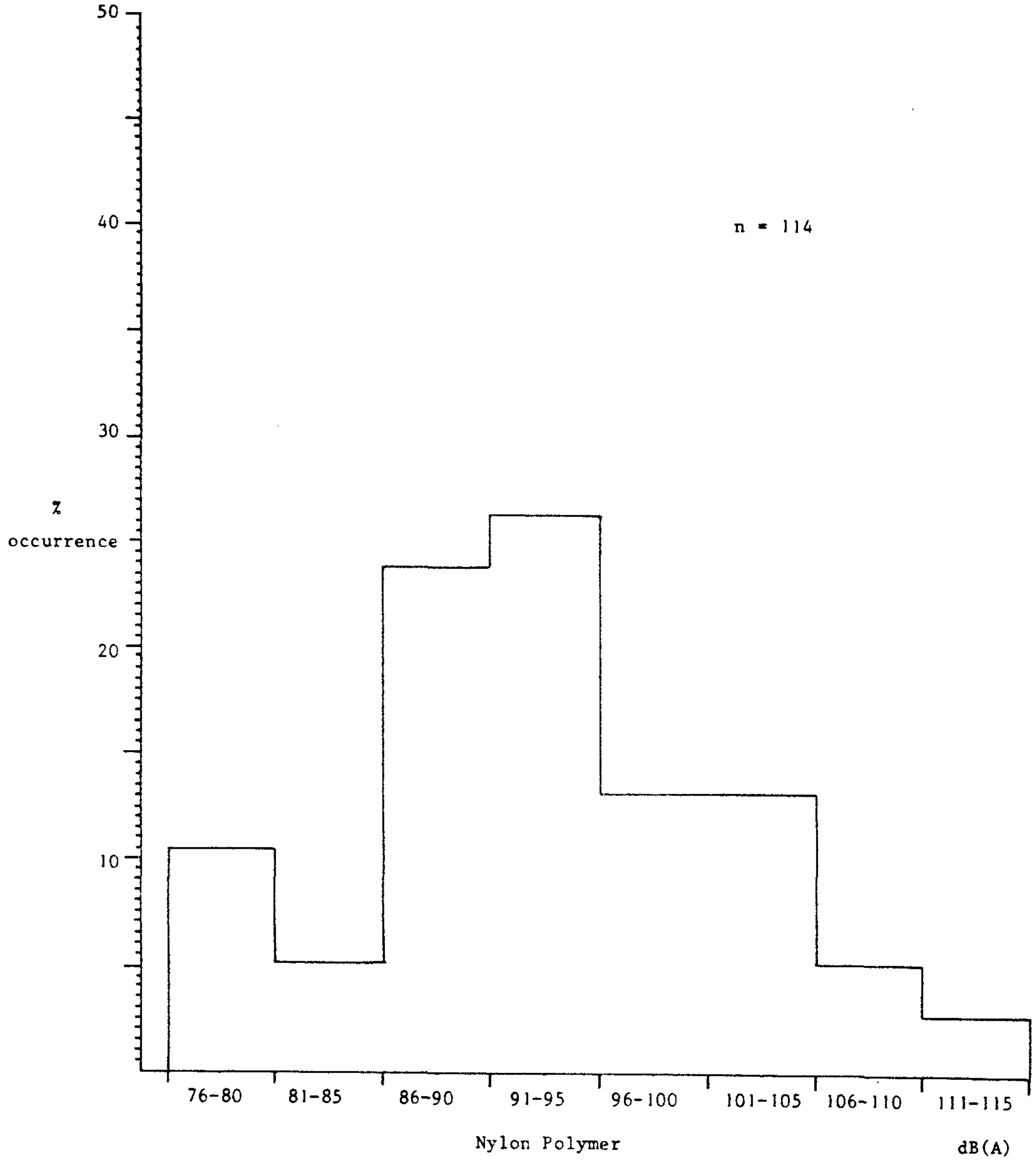


Figure 2.9

Noise Levels

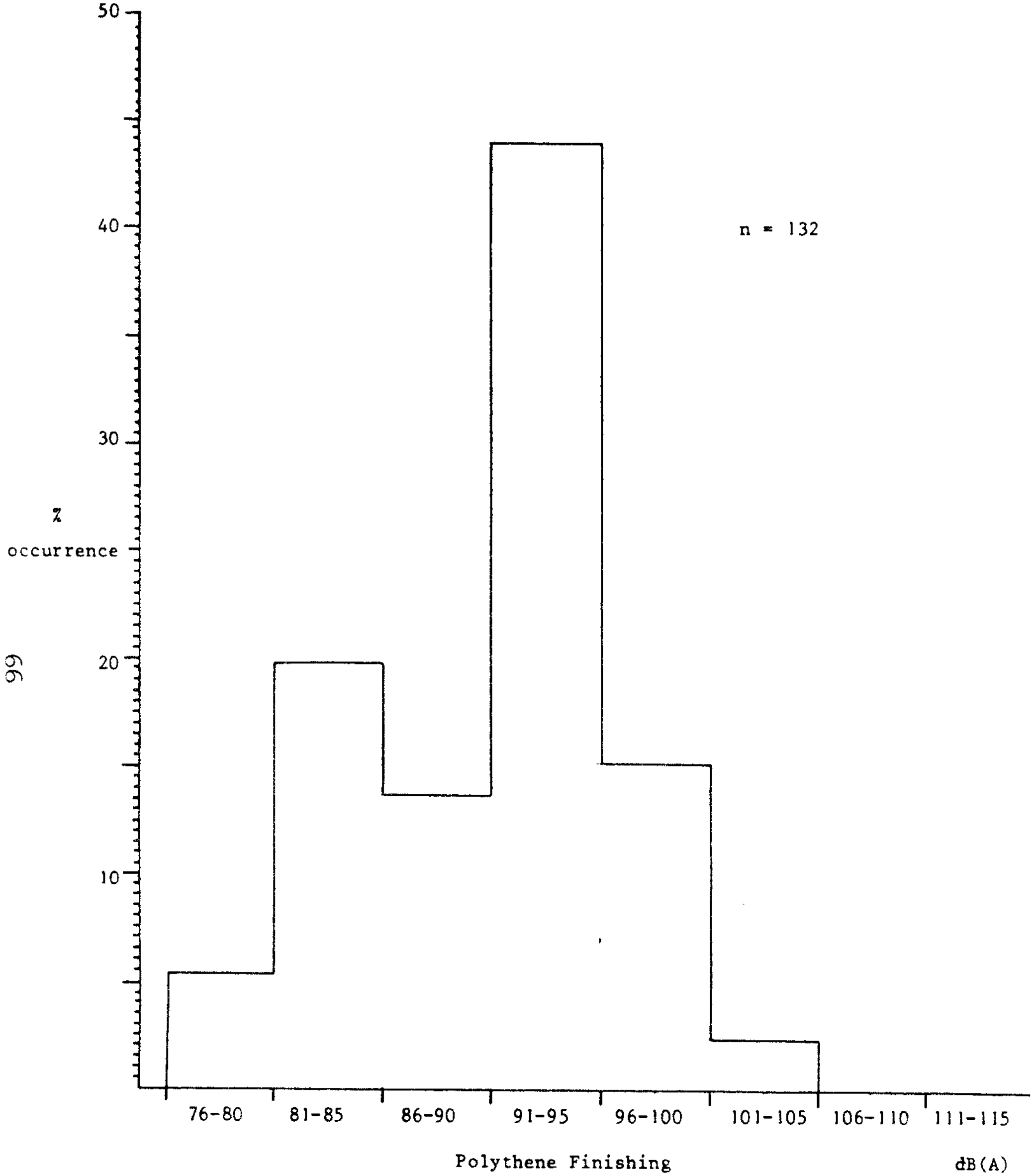


Figure 2.10

Noise Levels

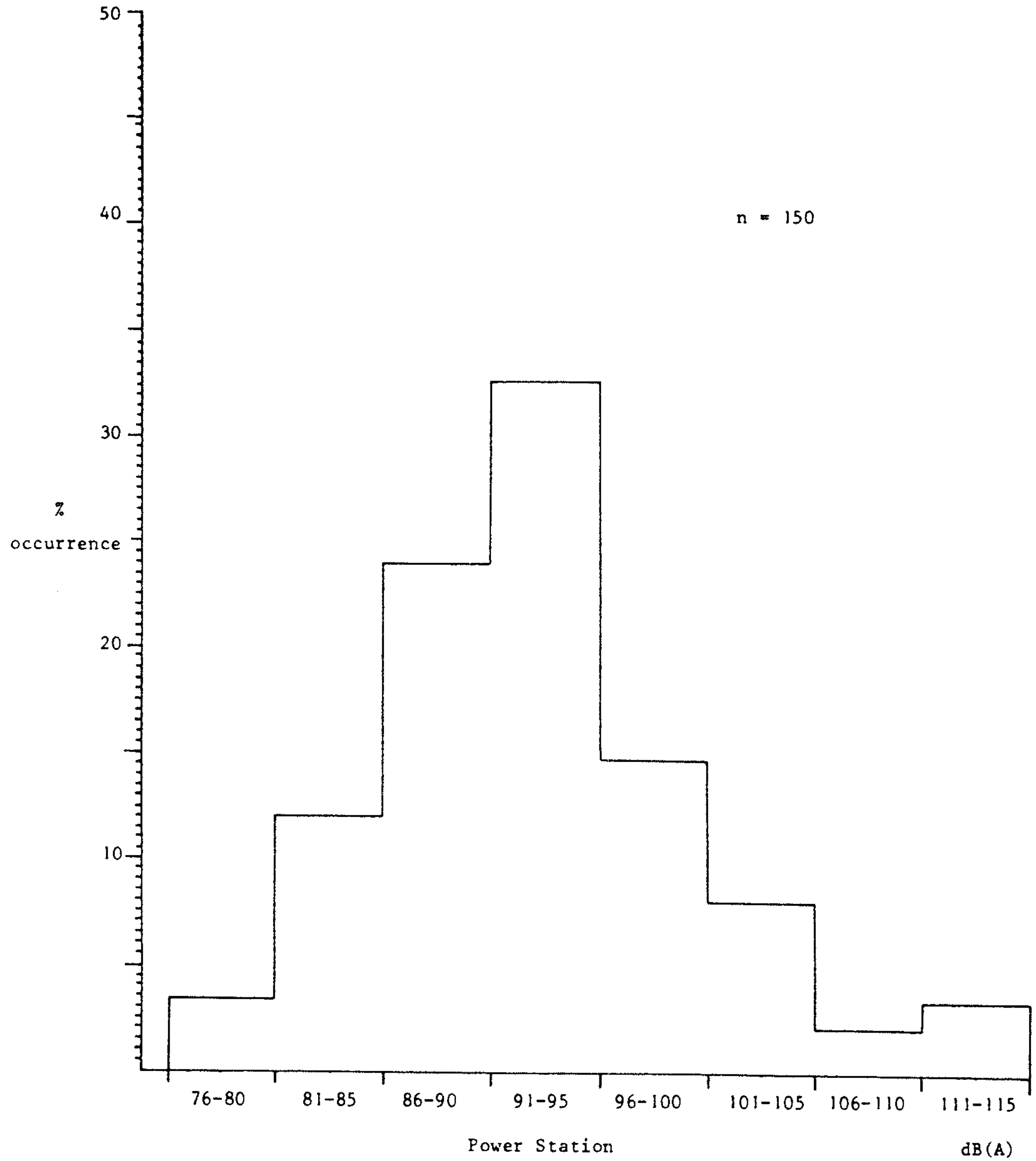


Figure 2.11

Noise Levels

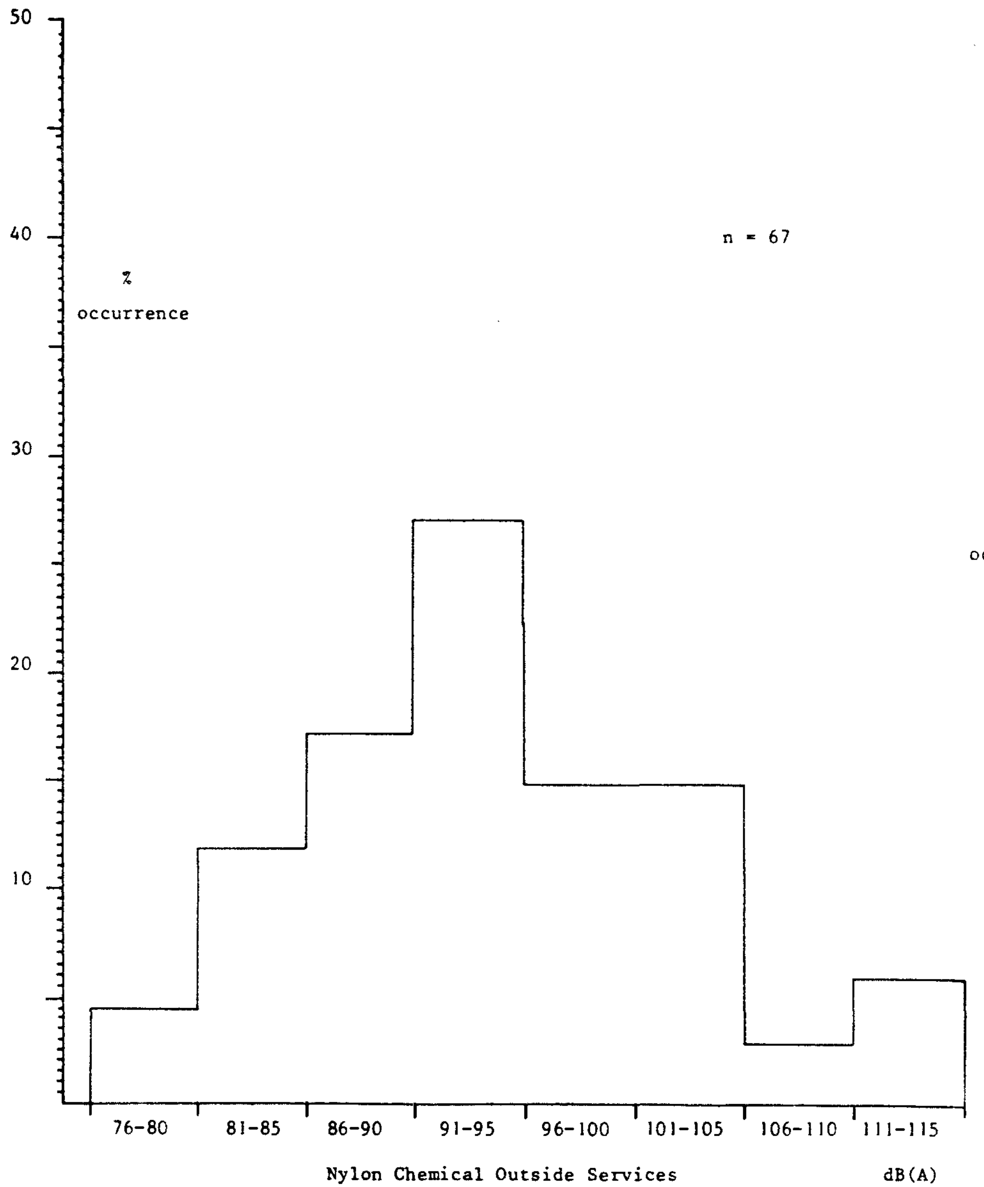


Figure 2.12

Noise Levels

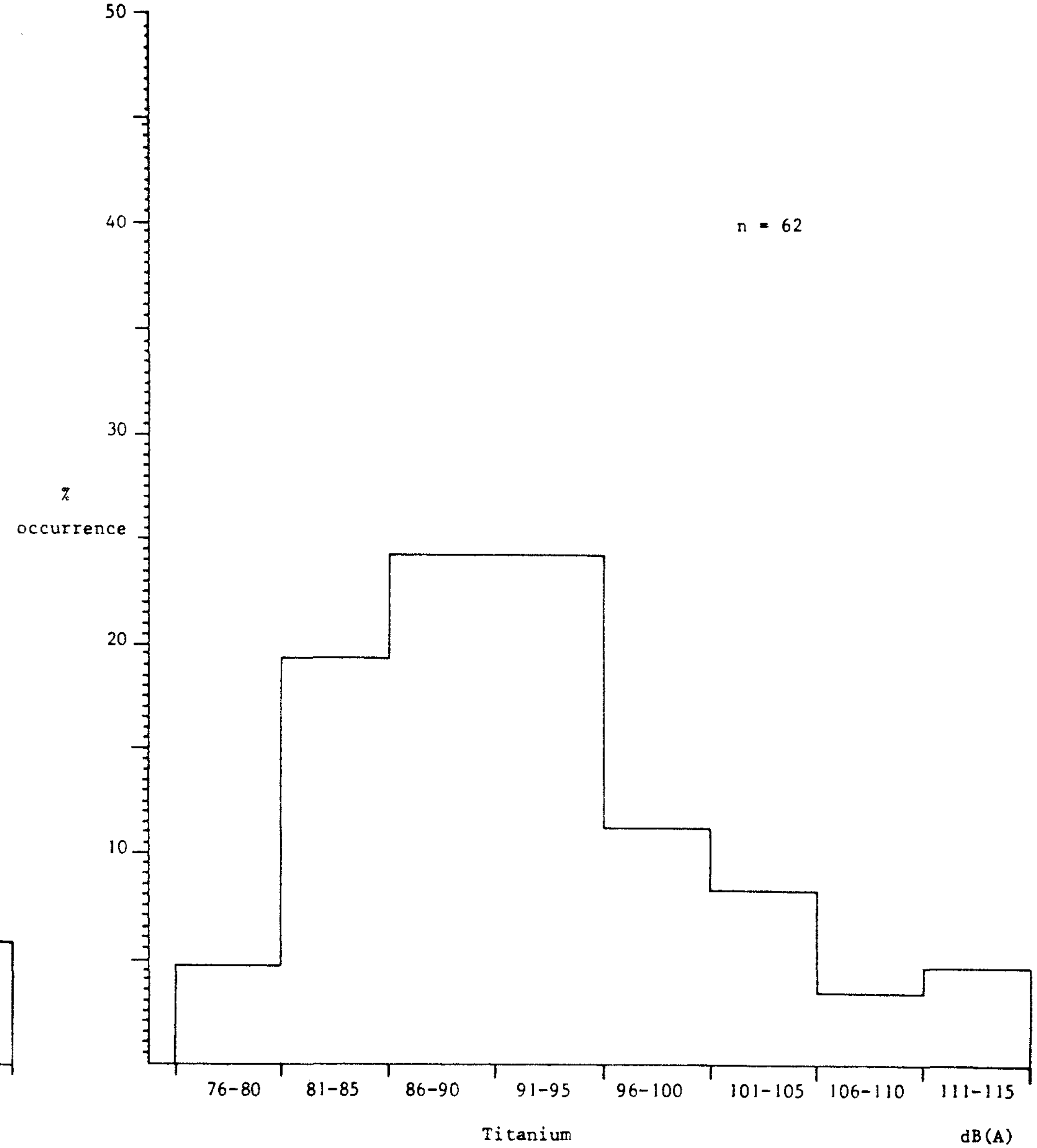


Figure 2.13

Noise Levels

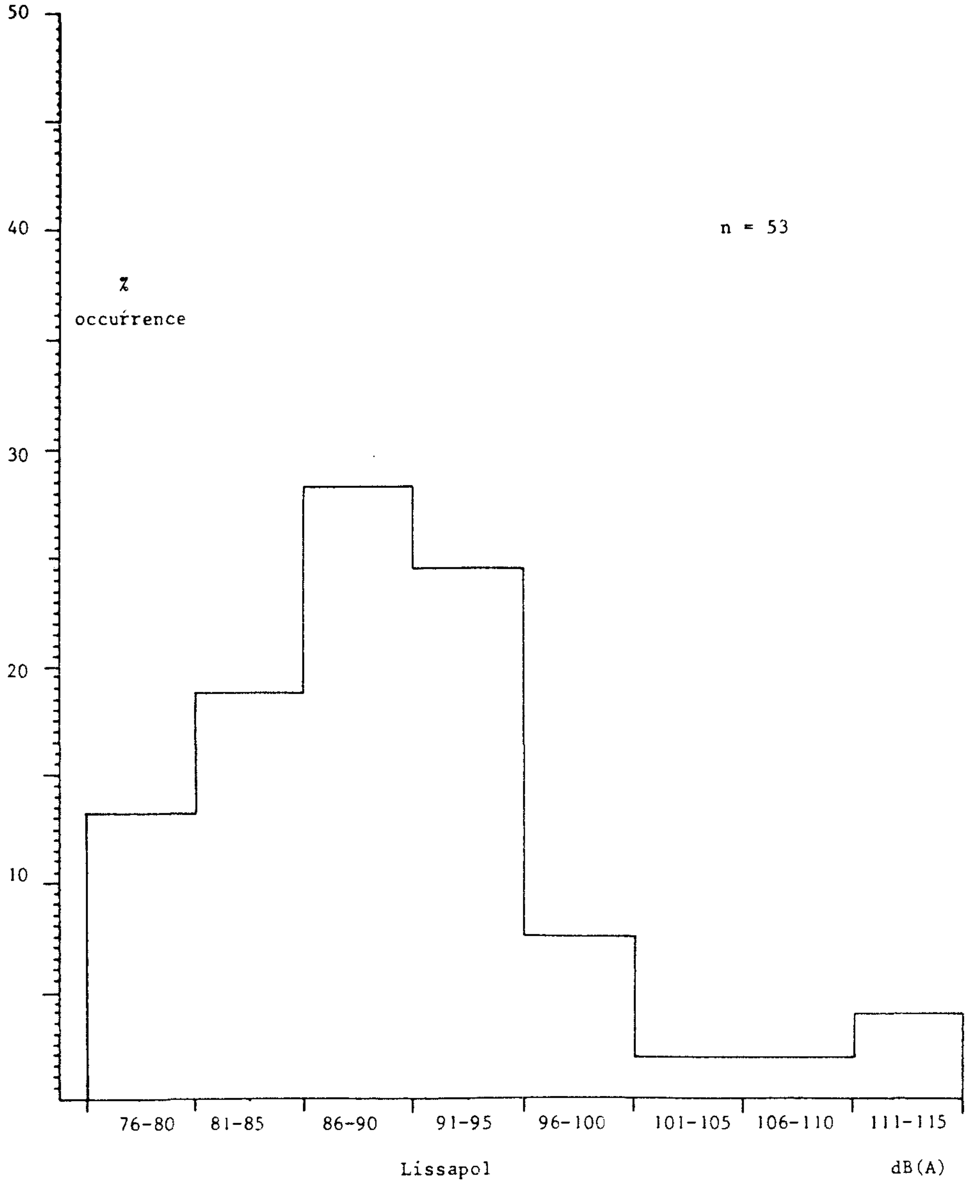


Figure 2.14

Noise levels

better estimate of employee noise exposure than measurements made using a precision grade sound level meter and stopwatch to permit the calculation of L_{Aeq}. The sources of error in the latter were thought to be smaller than in the former.

Erlandsson (1978, 1976), Hakanson (1980) and Shackleton (1984) produced results substantiating this assessment, and showing in particular that sound level meter measured L_{Aeq} can substantially underestimate noise dose in such job categories as steel moulding or fettling, where errors of 2.4 dB and 7.2 dB respectively were reported. Karmy (1982) produced a similar conclusion after a study in a manufacturing workshop in which calculated L_{Aeq} values were shown to underestimate dose meter measured L_{Aeq} values by between 1.75 dB(A) and 2.75 dB(A).

The dose meters were issued for a full shift to a representative sample of employees. Employees were divided into groups with similar work patterns, and one individual from each group wore a dose meter. These instruments were calibrated before and after issue. The microphones were clipped to the lapel as this appeared to be the most reasonable position, given that the majority of employees participating in the study did not wear safety helmets. This decision was justified by the work of Redwood (1977) who showed that overestimates caused by this placement would only be approximately 0.75 dB.

2.5.2 Results of the noise surveys

The results of dose meter surveys in the eight plants participating in the Main Experiment are shown in figure 2.3 . It is apparent that 78% of the measurements equal or exceed the 90 dB(A) criterion level at which a hazard to the hearing is deemed to exist (Health and Safety Executive, 1972). Only 9.25% of the L_{Aeq} values measured exceed the 100 dB(A) level, whilst all plants employ some individuals whose noise exposure lies between 96 dB(A) and 101 dB(A). Similarly all the plants are represented in the L_{Aeq} range 88 dB(A)-90 dB(A). Given the nature of the process and operations on the plants, it is unlikely that the L_{Aeq} values measured resulted from short duration exposure to extremely high levels of noise. The narrowness of the L_{Aeq} bands which encompass all the plants at the top and the bottom ends of the measured range, and the fact that the sensation of loudness only doubles for each 10 dB increase in sound pressure level (Burns 1973) argues that the subjectively perceived noise environments were essentially similar within the 8 main experiment plants.

This conclusion is further strengthened by figures 2.4 -2.11 showing the results of the sound level meter surveys. These indicate that the noise environments within the eight plants are similar, in all cases but that of the Central Workshops.

The histograms have an approximately "normal" shape, peaking in the 85-95 dB(A) range with tails which decrease sharply from the central value. It is certainly interesting to note that the histogram shown in figure 2.3 representing the distribution of employee L_{Aeq} values within the eight plants, also peaks in the 86-95 dB(A) region. This observation supports the choice of sound level meter noise sampling technique used to obtain the noise "signatures" of each of the plants and displayed in figures 2.4 -2.11.

The histogram relating to the Central Workshops and shown in figure 2.7 has a more pronounced low frequency tail than exhibited by the other 7 plants. This was caused by the presence of areas of relative quiet which were used for the storage of materials, or work planning. Although relatively few individuals worked in the latter areas, those that did had the incentive to wear hearing protectors in that they reduced the level of distracting noise. The noise within the workshops was emitted by hand held tools, which explains the slightly higher peak value in the histogram relating to the Central Workshop than is to be found in those of the remaining seven Main Experiment plants; the noise sampling technique described earlier required a measurement to be taken either every 8-12 metres, or at an employee's work station, and the use of hand held tools ensured that for short periods of time the work station of an employee would be the origin of the highest level of noise in the immediate area. However, the intermittent nature of this noise ensured that the employee L_{Aeq} measurements were similar to those obtained on other plants participating in the Main Experiment.

Figures 2.12, 2.13 and 2.14 show the noise level histograms obtained from the three plants or employee groups participating in the preliminary

Hearing Conservation Study, these being Nylon Chemical Outside Services, the Titanium plant and the Lissapol plant respectively.

The results indicate that the noise environment in which the three employee groups work are similar, and similar to that of the eight plants participating in the Main Experiment, in that the maximum frequency of noise levels measured occurred in the 86-95 dB(A) range. The Nylon Chemical Outside Services employees were exposed to slightly higher noise levels more often than their colleagues in the two other plants, due in part to their work including the repair of high pressure steam leaks in pipework. Of the noise measurements relating to Nylon Chemical Outside Services, 38% exceeded the 86-95 dB(A) range discussed above, with the corresponding figures for the Lissapol and Titanium plants being 16% and 27% respectively.

2.6 Conclusions

The ICI Wilton complex offered an excellent site on which to conduct a scientifically controlled study on the relative power of industrial audiometry and programmes of education to change employee attitudes towards the conservation of the hearing, and increase hearing protector usage.

It was decided to complete a single long term experiment involving 1716 employees located in eight plants, balanced for size and noise environment. This work would be preceded by a preliminary Hearing Conservation Study on three plants to ascertain the strength of any physical factors mitigating against an increase in hearing protector usage.

Discussions throughout the Wilton site with managerial and trade union bodies were successfully concluded and a project group formed in the Medical Centre to conduct the audiometric testing required.

Finally a sound level meter survey was conducted on the plants participating in the Hearing Conservation Study, and this was repeated for the eight plants selected for use in the Main Experiment, supplemented by a second survey using noise dose meters. The results of the measurements showed the plants to be essentially similar in noise environment although certain small differences were noted in the case of the Central Workshops resulting from the greater use of hand held tools.

CHAPTER 3

HEARING CONSERVATION STUDY

3.0 Introduction

This thesis is directed towards evaluating the capacity of routine monitoring audiometry or simple education techniques to alter certain attitudes of employees working in noise and increase their usage of hearing protection.

However, even if attitude changes can be induced in this way, they may be of little benefit if substantial physical counterforces exist which might mitigate against an increased usage of hearing protection. Accordingly a study was undertaken early in the research programme to assess any potential physical problems associated with hearing protector usage, either in terms of design or difficulties caused by their use in the work environment.

The preliminary Hearing Conservation Study also permitted initial ideas on Hearing Conservation matters, derived from a study of the literature, to be explored and validated. In turn, this process made easier the design of the more sophisticated attitude questionnaires described later in this thesis.

3.1 Method

Eighty employees participated in the exercise, drawn from Nylon Chemical Outside Services, (18 employees), the Lissapol plant (23 employees), and the Titanium plant (39 employees). These three plants were chosen as they were not to be included in the main research design, but their working environments were representative of those plants which were to be used in the Main Experiment.

Participation in the study was voluntary, although foremen were requested to ask only those employees to participate who worked in areas or jobs in which a noise hazard had been designated to exist, and who used hearing protection regularly. Figure 3.1 indicates that hearing protector usage amongst participants was high, a point further discussed in section 3.2.2.

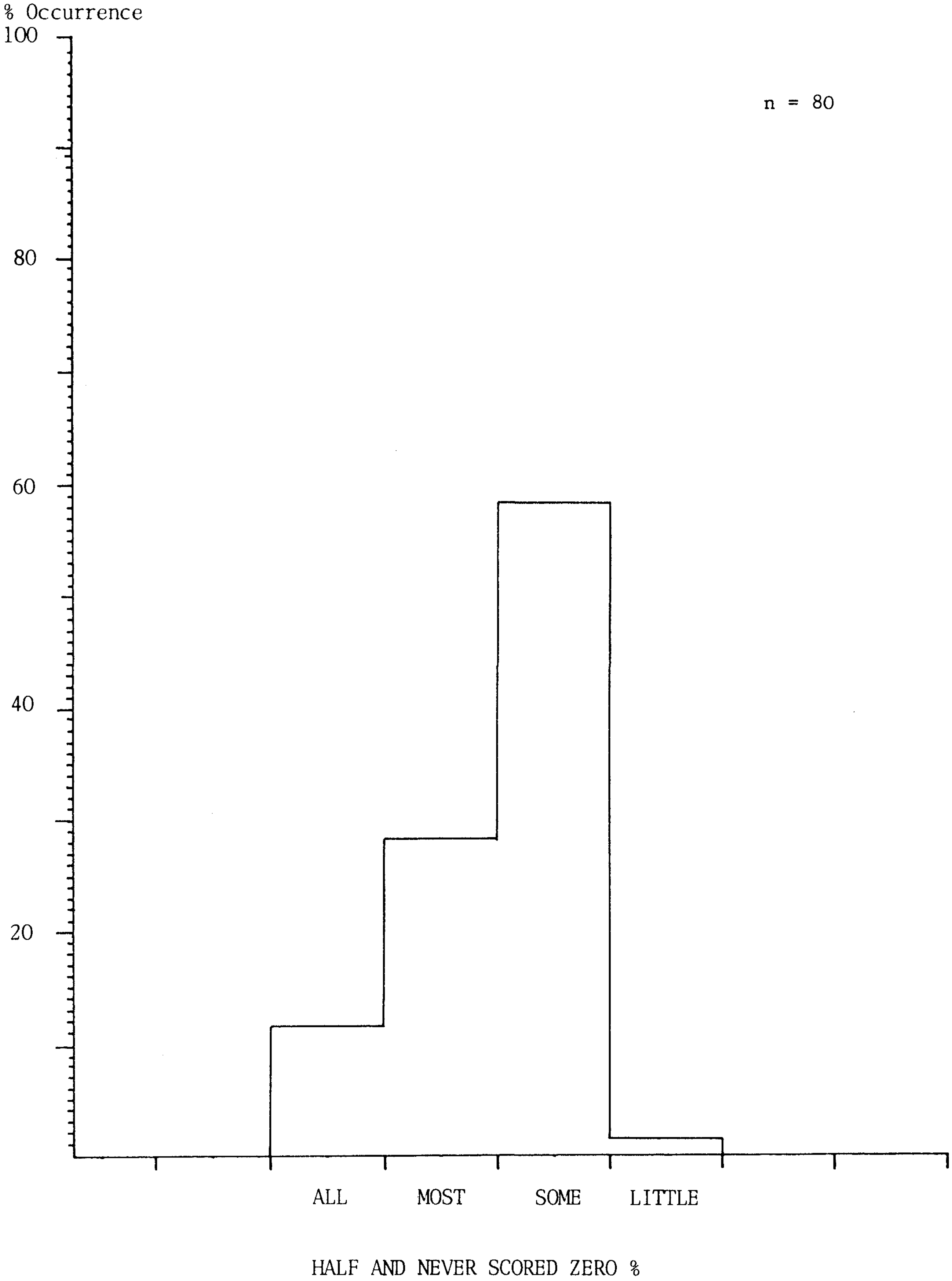


Figure 3.1 Hearing protector usage.

Employees attended the Medical Centre for a hearing test, and were interviewed by a specially instructed nurse who completed a questionnaire on their behalf.

The decision to use interviewer completed questionnaires was made to maintain the original intention that this preliminary study should provide a wide ranging exploratory investigation of Hearing Conservation matters. The interviewers were instructed to ask further questions in response to particular answers given to the printed questions. If interviewers had not been used, the number of questions required to prevent ambiguity in a self-completed questionnaire would have been impossibly large.

The questionnaire was designed by the author after careful consideration of the literature, and enquired into difficulties which might be experienced whilst using hearing protection, opinions as to the suitability of the design of ear protectors, the frequency of use of hearing protection, and the working environment in which the protectors were used. This latter information allowed results of the survey to be considered together with environmental factors influencing the employee.

The preliminary Hearing Conservation Study also allowed audiometric procedures to be tested prior to use in the larger scale Main Study, together with the coding for computer analysis used on the questionnaires, audiograms and audiometric history data.

The final form of the questionnaire is shown in Appendix A3.0.

3.2 Results

3.2.1 Working Environment

A description of the plants on which the 80 employees worked, or the activities in which they engaged has been given in chapter 2, sections 2.4 and 2.5 together with the results of measurements of their noise levels

The physical working environment of the test group is described further in figure 3.2. Over 90% of employees worked both inside and outside their plants, although often the physical construction of petrochemical plants is such that is is difficult to differentiate "inside" from "outside". Data shown on figure 3.2a indicates that employees split their time between the inside and outside of the plants in an approximate ratio of 2:3. Temperature outside the plants was, not unnaturally, judged to be "seasonal" (figure 3.2b), whilst that inside was never cold but was at the warmer end of the range, as shown on figure 3.2c. Figure 3.2d indicates that almost 70% of employees were exposed to radiant heat, either routinely, or sometimes, whilst figure 3.2e shows that approximately 40% of the sample worked in a humid atmosphere, the remaining 60% working either in a "dry" or "normal" environment.

The shapes of the "Humidity" and "Dust" histograms as shown in diagrams 3.2e and 3.2f respectively are not completely complementary; but inspection of the questionnaires showed that in general the "dry" atmospheres were "very dusty" but some environments existed which were both humid and dusty, thus explaining the two histogram shapes.

The histogram describing the cleanliness of the workplace was bimodal with response peaks at "mildly dirty" and "very dirty", with under 10% of the jobs being rated as "clean", as shown in figure 3.2g.

Almost all of the employees worked as part of a team, as shown in figure 3.2h suggesting strongly that a need for adequate communication would exist within the group.

3.2.2 Problems associated with the usage of hearing protection

Figure 3.1 indicates the success of the strategy of requesting only individuals to participate in the study who had been observed to be making use of hearing protectors. The frequency of hearing protector usage is shown as an aggregate of the results from the three groups, as the distribution in each group was similar, and indicates that only approximately 2% of the employees admit that they made little use of hearing protection. The remainder used hearing protection with a frequency ranging from "most of the time" to "all of the time".

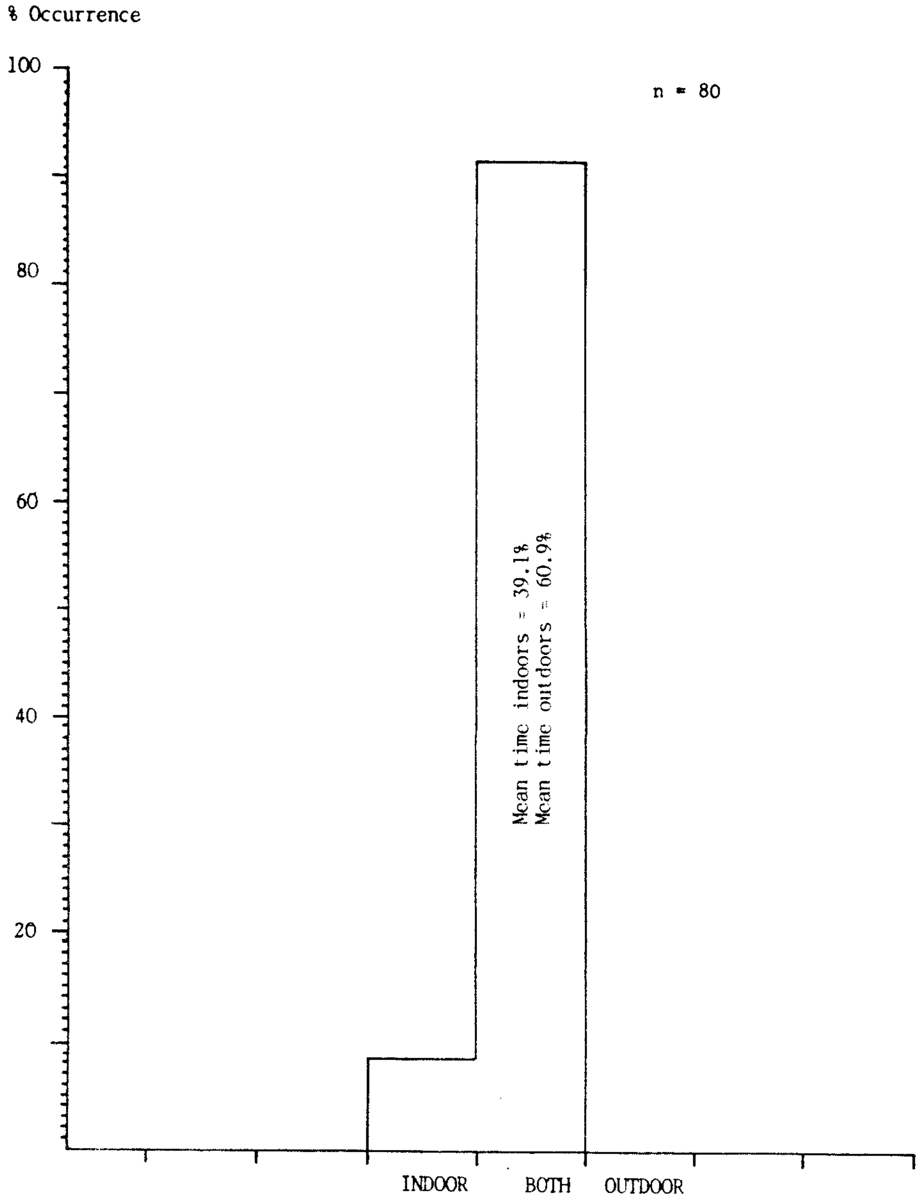


Figure 3.2 (a)

The location of employee workstations.

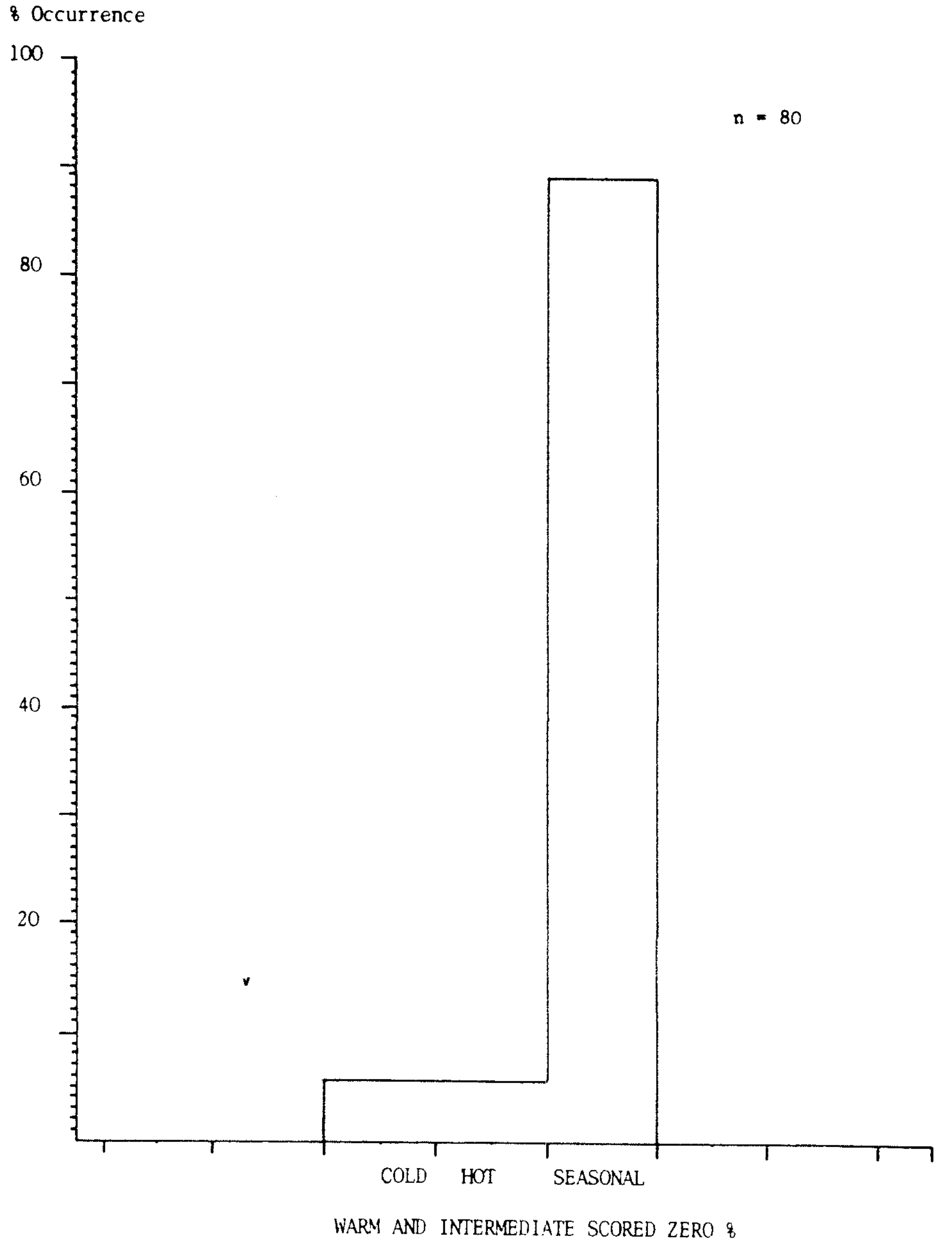


Figure 3.2 (b)

The outside working temperature experienced by the three employee groups.

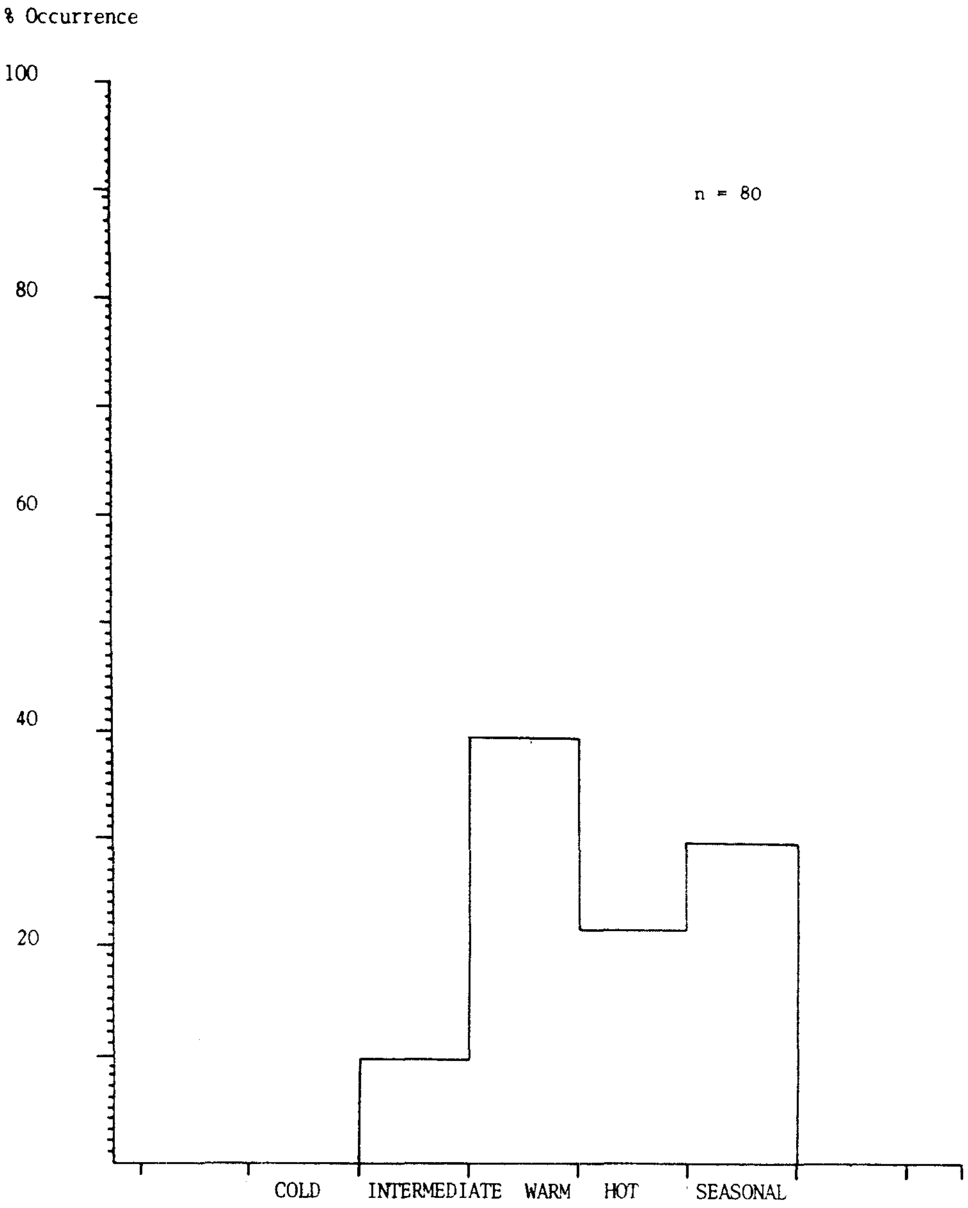


Figure 3.2 (c)

The inside working temperature.

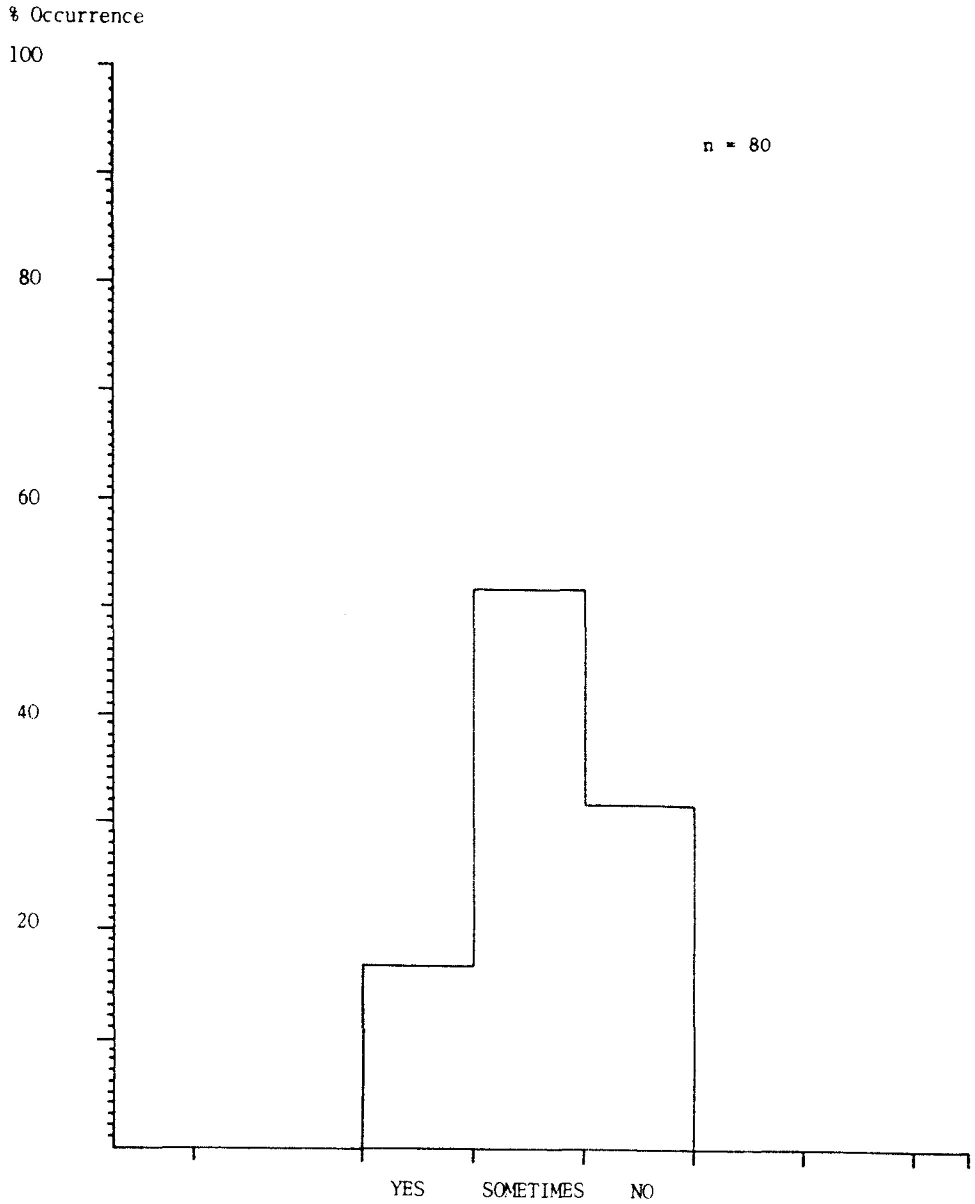


Figure 3.2 (d)

The presence of radiant heat.

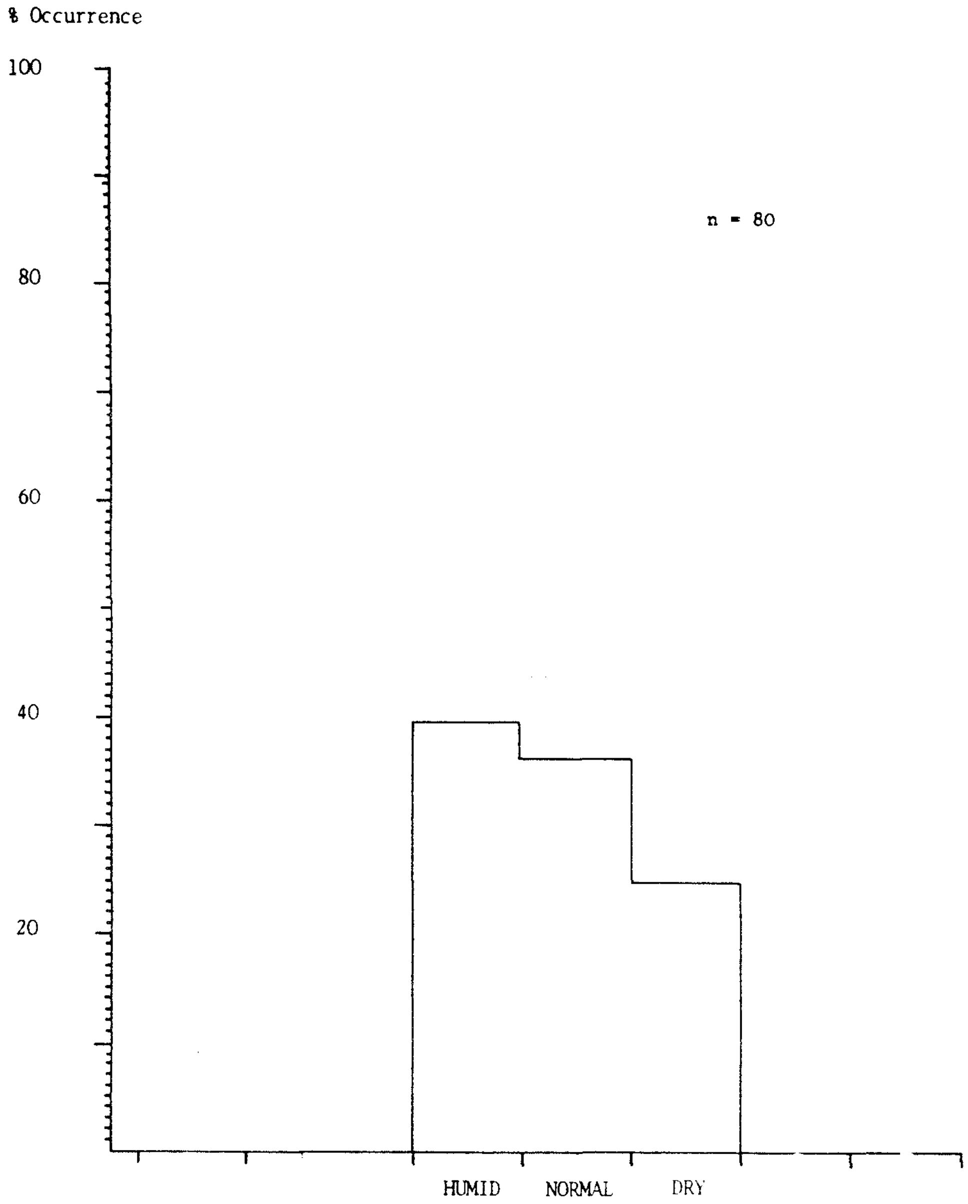


Figure 3.2 (e)
The humidity of the working environment.

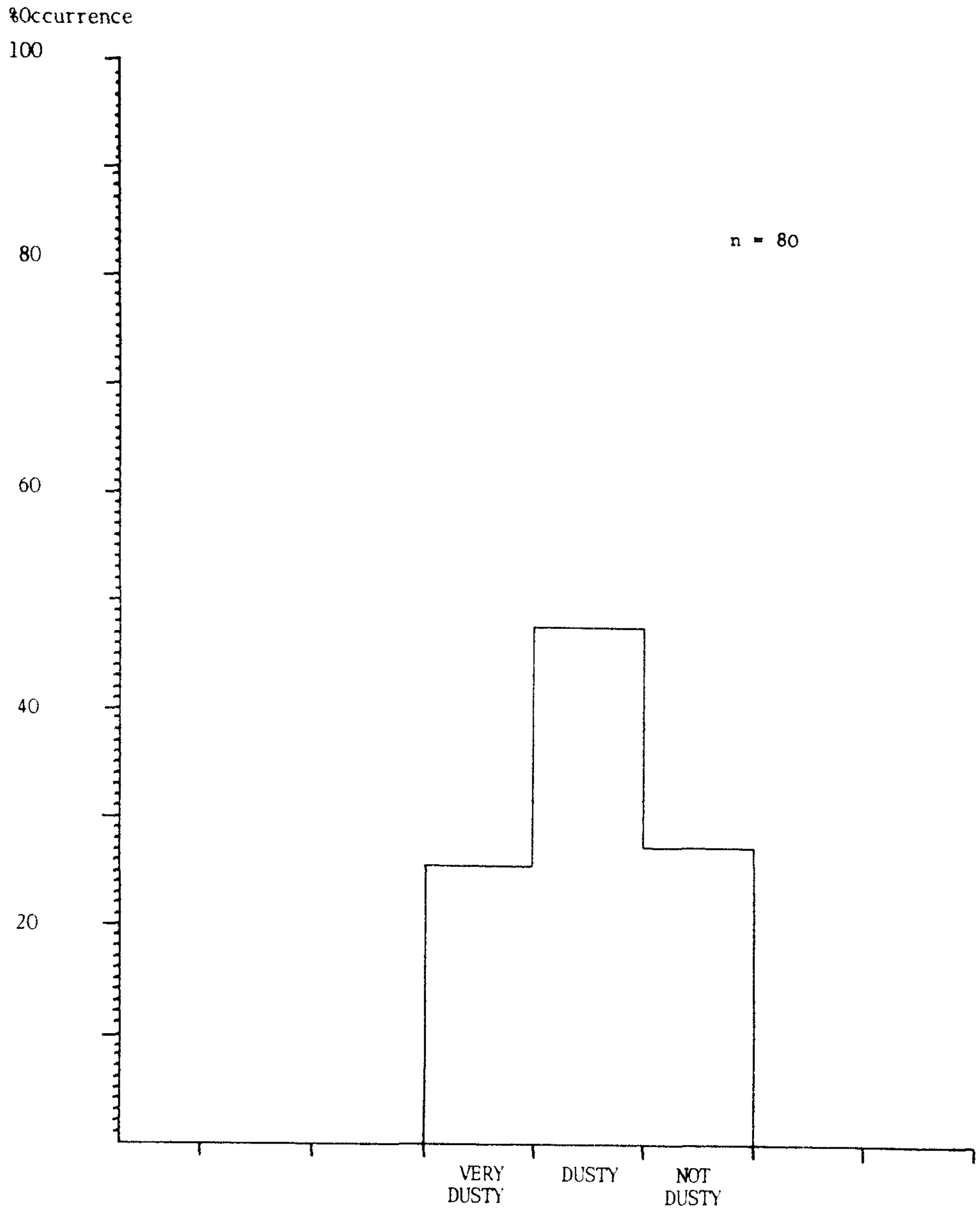


Figure 3.2 (f)
The dust content of the working environment.

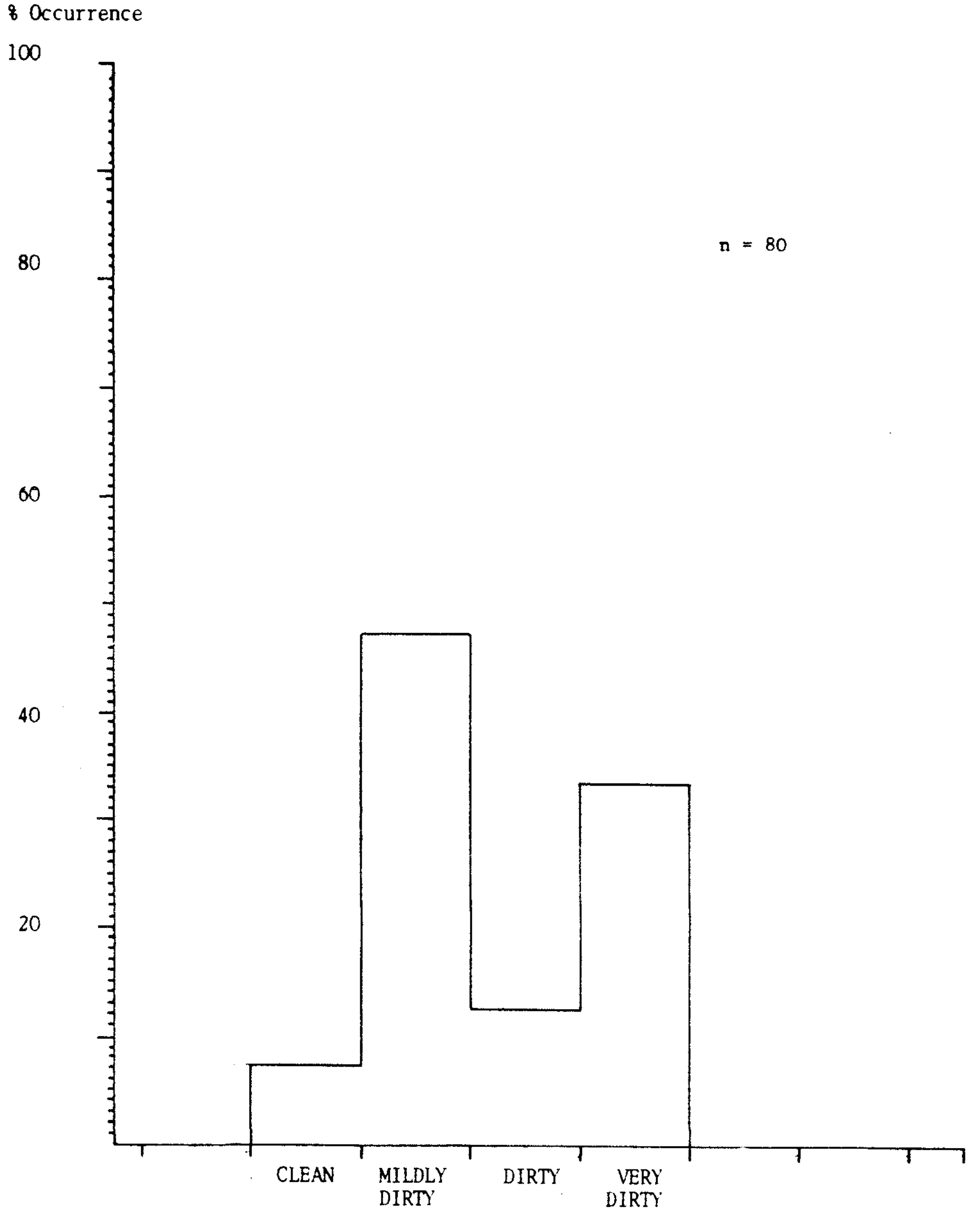


Figure 3.2 (g)

The cleanliness of the working environment.

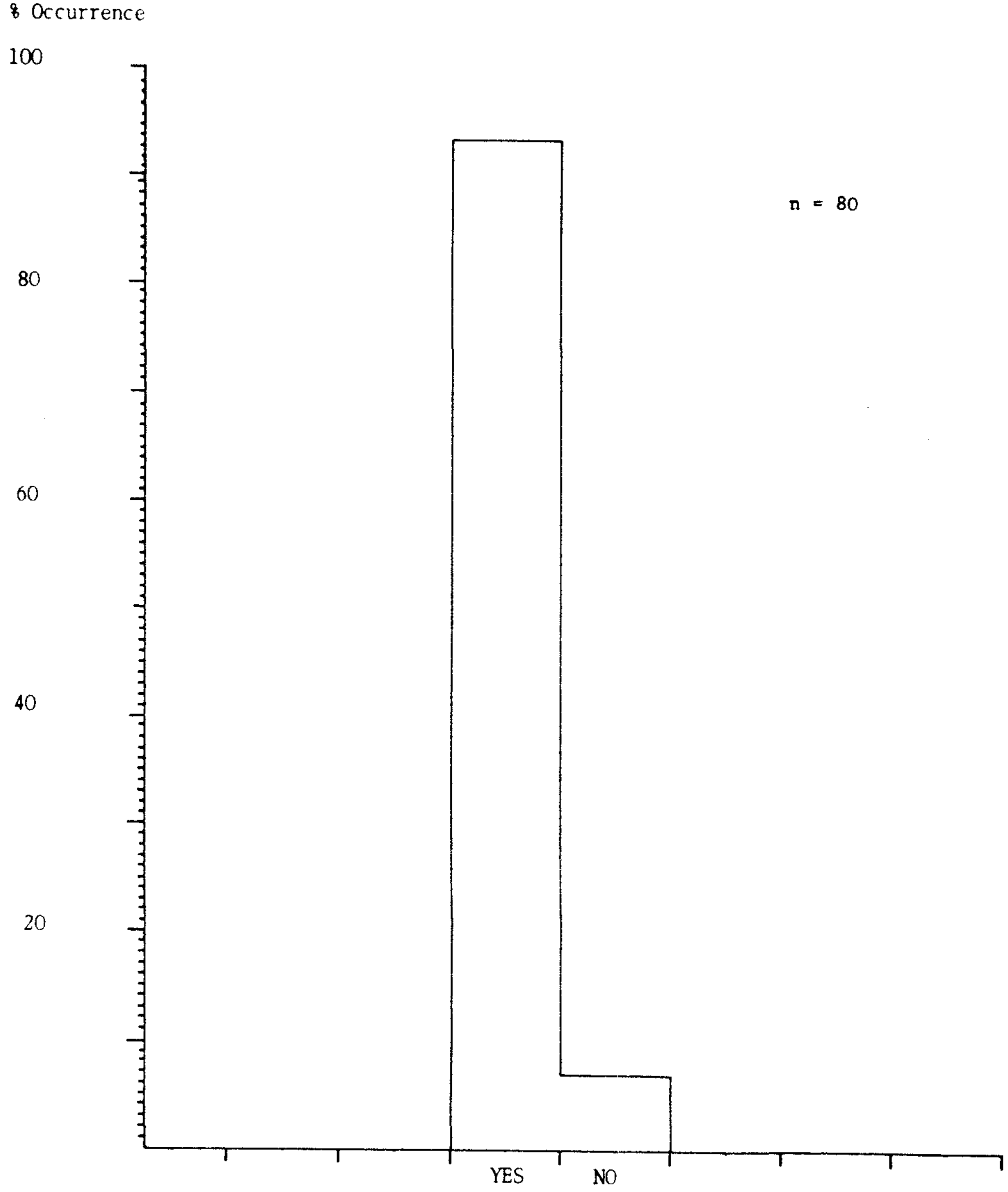


Figure3.2 (h)

The percentage of employees working as part of a team.

Earmuffs were used by 71 of the 80 employees, whilst the remainder made use of a mineral fibre earplug.

Figure 3.3 shows the response obtained to the question "what factors do you think deter people from wearing hearing protectors?" The question was phrased in this manner, as informal discussions with hearing protector users prior to compilation of the questionnaire had suggested that the more direct question "What factors do you think would deter you from wearing hearing protectors?" would probably produce defensive and inhibited answers.

Precedents exist in the literature for the use of such a technique. Davis (The Economic and Social Research Institute, 1980) commenting upon the design of questions used in his study of attitudes of the people of Northern Ireland towards the Irish Republican Army (IRA) stated "We believe that attitudes towards the IRA in particular is a very sensitive issue, and that individuals may not be entirely frank in response to direct and explicit questions. Accordingly an indirect approach to the issue is required". Similarly, Adorno (1950) "One might enquire why, if we wish to know the intensity of some ideological pattern, such as anti-Semitism, within the individual, we do not ask him directly after defining what we mean. The answer is ... anti-Semitism, ethnocentrism and politico-economic reactionism or radicalism are topics about which many people are not prepared to speak with complete frankness. Thus even at this surface ideological level, it was necessary to employ a certain amount of indirectness".

Earmuff users were asked to confine their answers to earmuffs. Similarly the nine mineral down earplug users were asked to comment only upon earplugs. Their responses are similarly separated. Figure 3.3a shows a histogram detailing the main problems experienced whilst wearing earmuffs. The major difficulty experienced by users is one of discomfort, closely followed by the bulk of the earmuffs.

This latter problem could also be considered to be comfort related, but with an emphasis laid on usability. This theme is amplified in the third most common problem encountered by the employees, that of difficulty in using earmuffs with other safety equipment.

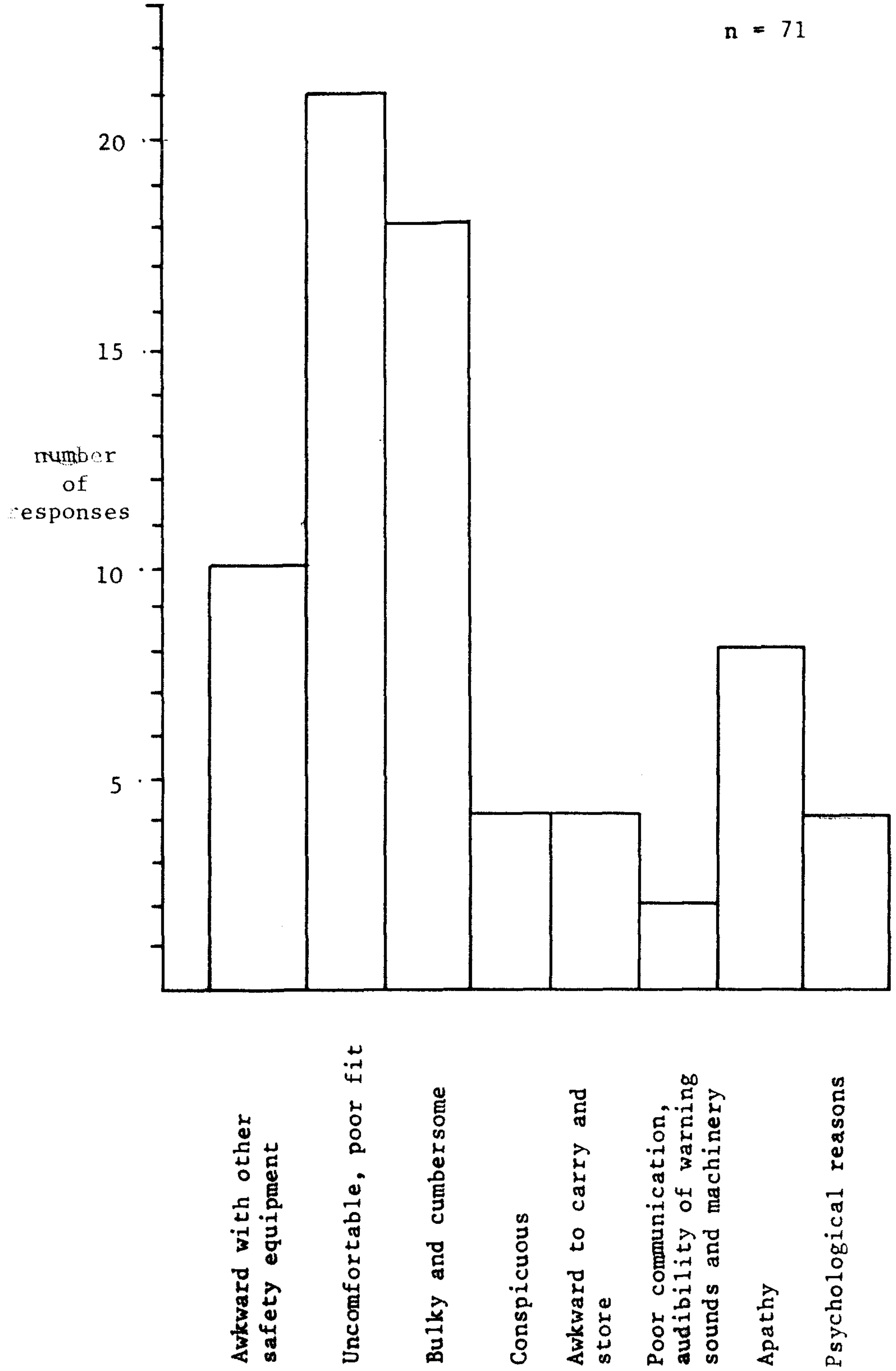


Figure 3.3 (a) Problems mitigating against the full usage of earmuffs.

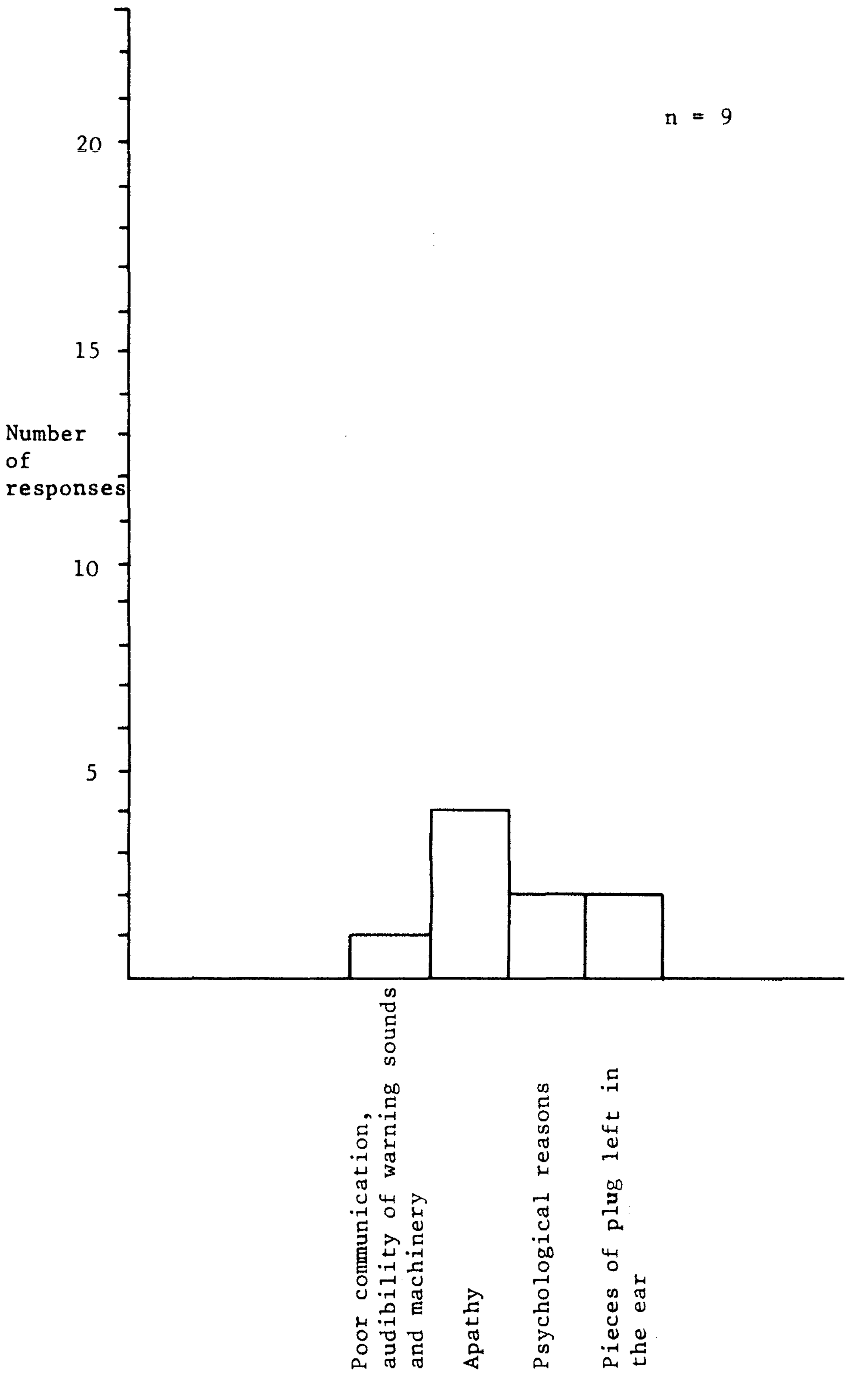
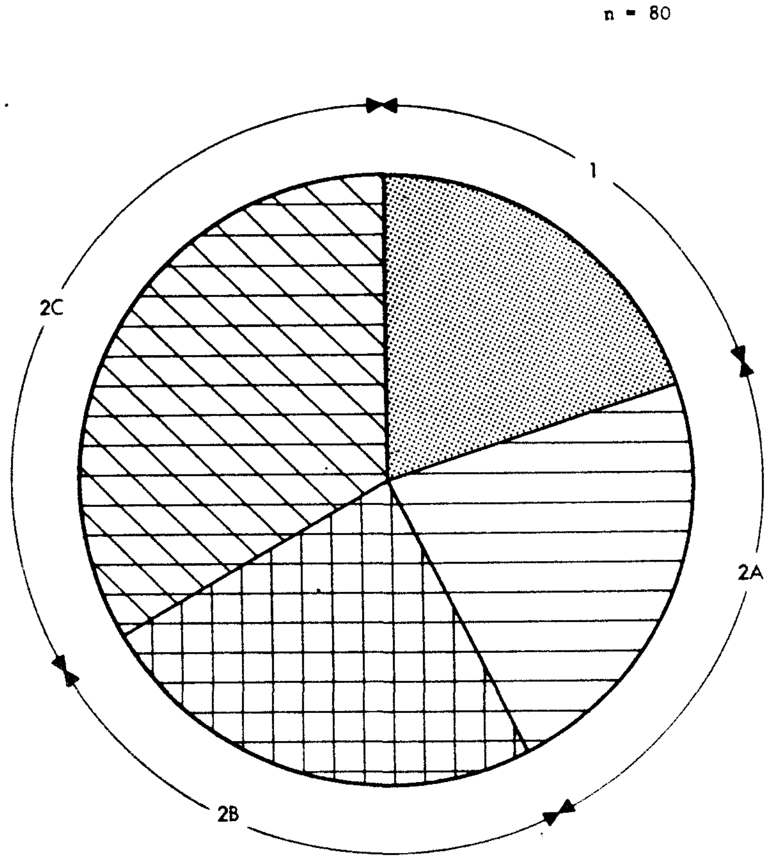


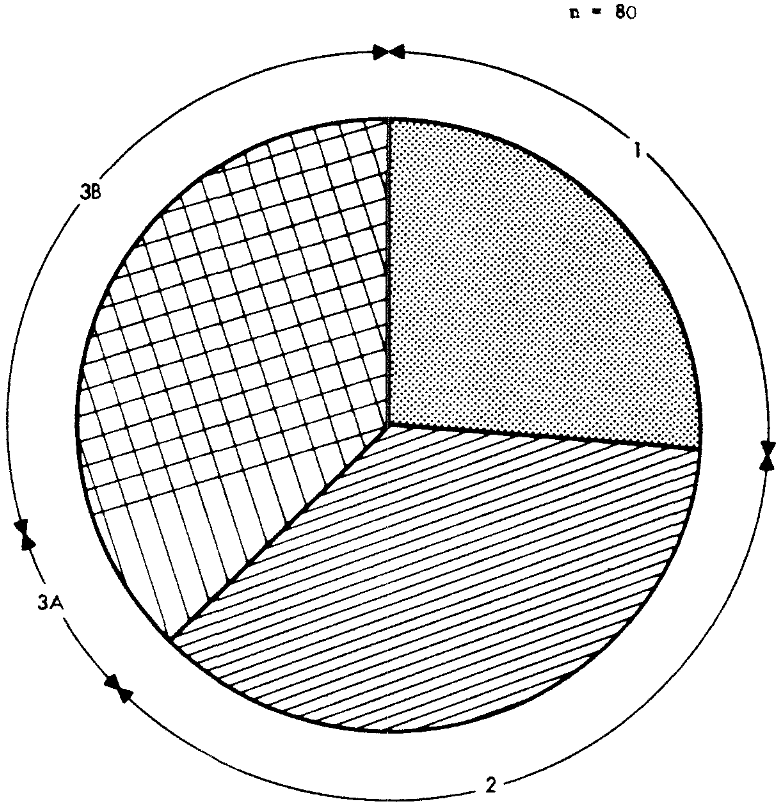
Figure 3.3 (b) Problems mitigating against the full use of earplugs.



1. No necessity to be able to localise sound during working hours.
2. Need to be able to localise sound during working hours
   (a) Wearing hearing protection does not make this difficult
   (b) Wearing hearing protection makes this difficult, but h.p. is not removed
   (c) Wearing hearing protection makes this difficult and so is removed.

Figure 3.4

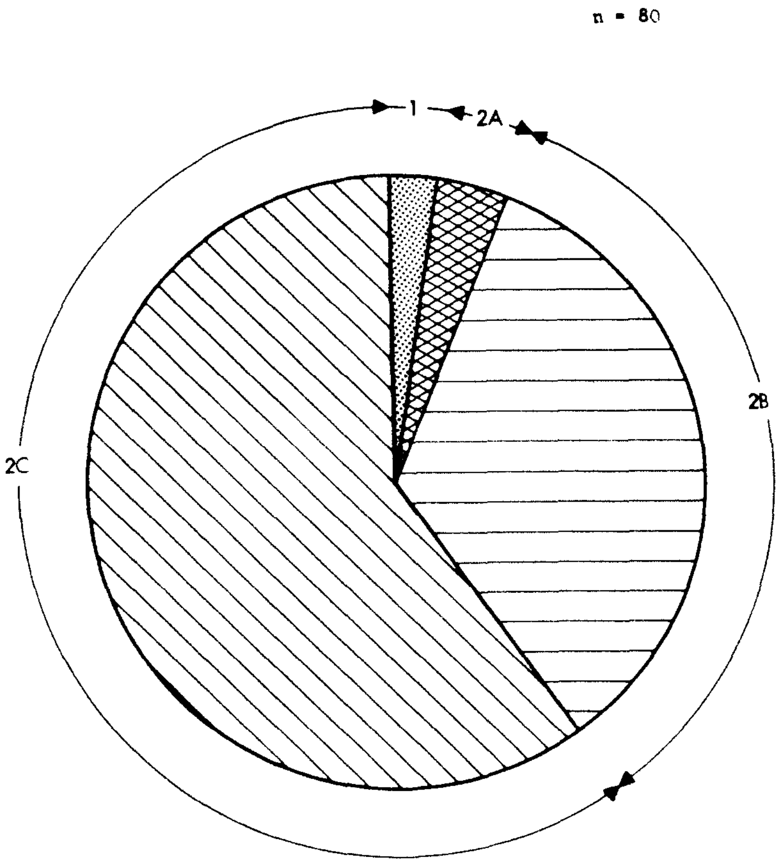
Difficulty in localising sound caused by wearing hearing protection in a noisy environment.



1. Hearing the noise made by the machine is unimportant in carrying out the work.
2. Hearing the noise made by the machine is important, but is unaffected by wearing hearing protection.
3. Hearing the noise made by the machine is important, but is affected by wearing hearing protection
   (a) Hearing protection is not removed
   (b) Hearing protection is removed

Figure 3.5

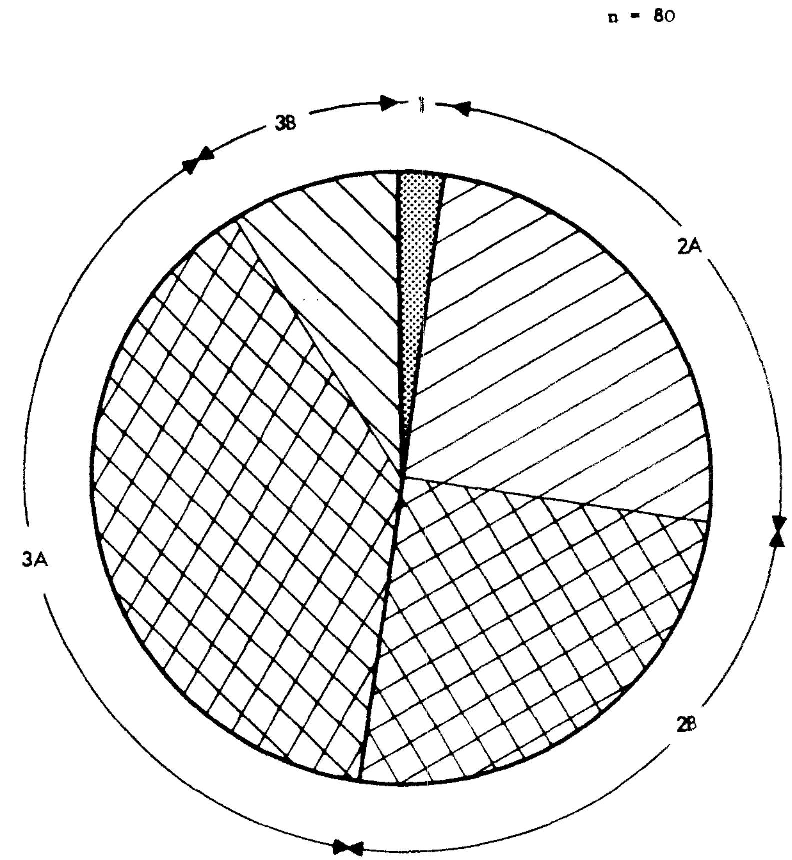
Difficulty in hearing machinery indicator sounds caused by wearing hearing protection in a noisy environment.



1. No warning sounds present at the place of work.
2. Warning sounds present at the place of work
   (a) Easier to hear warning sounds when wearing hearing protection
   (b) Ability to hear warning sounds unchanged when wearing hearing protection
   (c) More difficult to hear warning sounds when wearing hearing protection

Figure 3.6

The detection of warning sounds when wearing hearing protection in a noisy environment.



1. Wearing hearing protection improves the ability to communicate.
2. The ability to communicate is unchanged when hearing protection is worn
   (a) Therefore hearing protection is not removed
   (b) However, hearing protection is still removed for psychological reasons whilst communicating.
3. The ability to communicate deteriorates when wearing hearing protection
   (a) Therefore the hearing protection is removed
   (b) However, the hearing protection is not removed.

Figure 3.7

Communication whilst wearing hearing protection in a noisy environment.

"Apathy" is revealed in figure 3.3a to be a significant factor in the non-usage of earmuffs, followed by the sentiment that earmuff users felt "conspicuous". Several other points were raised against the usage of earmuffs which were classified as "psychological reasons". These included such comments as a sensation of being "cut off" from the external world, instability felt whilst climbing ladders, and a type of claustrophobia. The feeling of being "conspicuous" could also be designated as a "psychological" problem but is not included in figure 3.3a as being such.

Figure 3.3b is a histogram showing the main problems encountered by users of the mineral down earplugs. This group is numerically small (9) and the results should be considered with commensurate caution. However, the main point which can be stated with some confidence is that comfort does not present the same problem as noted by the users of earmuffs. "Apathy" is still a significant reason for non-use, and "psychological reasons" and "poor communication and audibility of warning sounds and machinery" are still mentioned.

Figures 3.4 to 3.7 show an analysis of the responses to the questions designed to evaluate the effect of wearing hearing protectors upon the perception of speech, and the ability to localise a sound source, or perceive an indicator sound important for assessing the condition of noisy machinery or processes.

Figure 3.4 shows the effect of the usage of hearing protection upon the ability to localise sound in a noisy environment. Eighty percent of the population stated that they needed to be able to localise sound whilst working, and of these individuals, approximately 72% found that wearing hearing protectors made this task difficult, with 42% representing approximately 34% of the entire test population, claiming that they removed their hearing protection to alleviate this problem.

A similar trend is observed in Figure 3.5, which shows that approximately 74% of the population state that the successful monitoring of the noise emitted by their machine was important. Of these, 51% claimed that usage of hearing protection prevented them from doing this successfully, with 41% representing approximately 30% of the entire test population, removing their ear protection at some time in order to listen to indicator sounds from their machine or process.

The perception of warning sounds is shown in figure 3.6 to be important for 97.5% of the population studied. Almost 4% would suggest that the hearing of warning sounds is made easier when ear protection is worn, but 60% feel that the use of ear protection degrades the ability to hear warning sounds.

Figure 3.7 quantifies difficulties experienced in communicating in noisy environments when wearing hearing protectors. The number of individuals believing that using hearing protection enhances the ability to communicate is very small, at 2.5%. The total population is reasonably evenly divided into two sub populations; those employees who stated that wearing ear defenders degrades communcation in noise, and those individuals who felt that this ability was unchanged with the use of ear protectors. Approximately 65% of these two sub populations would remove their hearing protectors to facilitate communication in noise, either to improve the perception of the speech, or because listening to speech with the ears occluded is considered unnatural, and hence psychologically disturbing.

Indications, discussed in section 3.4, exist in the literature that persons with a hearing loss may experience more difficulty than the normally hearing individual when attempting to communicate, or detect warning or other indicator sounds whilst wearing hearing protection in noise. Accordingly the audiometric records obtained during this study were divided into two populations; that which reported difficulties in communicating verbally, or in detecting warning sounds or other indicator sounds when wearing hearing protection and that which did not. The two populations appear as "sections" in table 3.1, which also indicates the hearing acuity of the test population by frequency.

A two way analysis of variance was performed on this data using a nested fixed effects model. The right and left ears were treated as replicate measures as the evidence discussed in chapter 11 concerning right/left ear differences would suggest that no significant error would be introduced using this strategy, the result being simply to slightly obscure the difference between populations, rather than enhance it.

Table 3.1 Analysis of variance of the audiometric data drawn from those employees experiencing auditory problems whilst wearing hearing protection against audiometric data drawn from employees not experiencing such problems.

Source of variation	df	ss	ss%	ms	vr	significance level
Section	1	3002.95	0.92	3002.95	35.156	*
Freq	7	33557.43	10.23	4793.92	56.123	*
Section.subject	77	154885.94	47.22	2011.51	23.549	*
Section.freq	7	836.92	0.26	119.56	1.400	nonsig
Section.subject.freq	539	81770.81	24.93	151.71	1.776	*
Residual	632	53983.90	16.46	85.42		
Total	1263	328037.88	100.00	259.73		
Grand Total	1263	328037.88	100.00			
Grand Mean	15.16					
Total number of observations	1264					

Mean loss		250Hz	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz	Age yrs $\bar{x}$	Age yrs σ
Problems	n=59	13.38	11.54	9.43	10.19	16.34	20.24	22.63	24.74	34.9	10.9
No Problems	n=20	10.68	7.63	6.88	9.00	14.13	16.25	18.75	16.87	31.9	8.1
significance level		*	*	*	nonsig	****	*	*	*		

t tests performed using the M.S. of the residual. Significance at: 0.1% = *, 0.5% = **, 5% = ****

Hearing loss given in dB HL re BS 2497

The results of this analysis of variance are shown in table 3.1, indicating that the main effects, "section", and "frequency" are significant at the 0.1% level, as are the two and three way interactions involving subjects. The statistical significance of these interactions is to be expected, as the experimental design is such that any one subject appears only in one section and as the audiograms were not age corrected, then hearing loss within any one section is dependent on the age of the subjects as well as the "treatment". Age is an indicator of the possible effects of presbyacusis and the possible length of time for which each subject could have been exposed to industrial noise. The mean age within each section is also given in table 3.1. With this understanding of the model, it is possible to conclude from the table that hearing loss within the two populations differs. Additionally hearing loss alters with frequency, an effect which reflects the effect of presbyacusis and other causative factors such as noise exposure.

3.3 Discussion

The results reported indicated that the lack of comfort of earmuffs was a prime reason for non usage.It was therefore decided to study the comfort of earmuffs as these represented 89% of the protectors used on the site, and the lack of comfort was likely to be a major factor mitigating against any increase in usage which would otherwise be caused by programmes of audiometry or education.

Factors to be investigated included earmuff weight, headband tension, seal filling material and width, and earshell size. The results of this study are reported in chapter 4.

The problem of earmuff bulk and compatibility with other items of safety equipment is linked to that of comfort, but is a design problem which is being tackled progressively and efficiently by commercial companies in response to market forces. Accordingly the problem will not be discussed in detail in this publication. However, work has been performed by the author of this thesis on the loss of earmuff attenuation occasioned by the simultaneous use of safety spectacles (Karmy, 1980), the difficulty of using earmuffs with seal perspiration covers (Grose, 1981(a)) and the attenuation losses caused by the use of standard earmuffs with safety helmets. (Grose 1981(b). In general wearing earmuffs with these other items of safety equipment caused a loss of acoustic attenuation, except in the case of a safety helmet used with an earmuff worn with the tensioning headband behind the neck, and the flexible supporting band across the top of the skull. In this configuration the attenuation was shown to have improved when compared to that of the earmuff worn in this manner, but without the helmet in place.

"Apathy" appears in figure 3.3 as a significant reason for the non usage of hearing protection, but it is felt that a well designed programme of education and audiometry could be produced to reduce this problem. Such a programme could also emphasise the serious implications of a noise induced hearing loss, with a rigour sufficient to encourage the employee to make a positive attempt to overcome the "psychological" problems occasioned by hearing protector usage, and noted in figure 3.3.

The problem of earmuffs being "awkward to carry and store" suggests the need for personal earmuff lockers close to the work areas in which the protectors are to be used. Alternatively an earmuff could be designed which would fold, and thus could be carried in the large pocket of an overall.

The relatively low ranking of the comment that the wearing of earmuffs caused "poor communication and audibility of warning sounds and machinery", is of interest. Prior to the inception of the study, informal discussion with ICI management and the response at seminars on the topic of hearing protector usage held for lower management had suggested that difficulties experienced in communciation and the effect upon the audibility of other necessary sounds formed the major reason for earmuff non-usage. However it is apparent that the workforce did not share this view. It is felt that the explanation for this apparent discrepancy is that when eardefender usage is discussed in a formal negotiating forum attended by management and employee representatives it is easier for the employees to defend non usage on the grounds of difficulties experienced in speech communication and the audibility of necessary sounds, than those of comfort. It should not be thought, however, that these problems are unimportant, but rather that they are secondary in importance to that of comfort; and they are discussed again later in this section in relation to data presented in figures 3.4 to 3.7.

Figure 3.3(b) displays the reasons given by the users of earplugs for the nonusage of these protectors. It should be remembered, however, that only 9 employees wore earplugs, and that these were of the disposable mineral fibre type. The most obvious finding is that discomfort does not occur as a reason for non usage, although it may have done had other forms of earplug been in use. The major reason for non use was "apathy", followed by the "psychological problems" already discussed, and the comments that the plugs tended to leave small pieces behind on withdrawal. This problem has now been rectified by the manufacturers who have totally enclosed the plug in a plastic film. "Poor communication and audibility of indicator sounds" is again the least significant of all the reasons given for non usage.

Figures 3.4 to 3.7 indicate that whilst the degradation in the ability to communicate, detect warning or indicator sounds, or localise the direction of a sound whilst wearing hearing protection are secondary problems, this degradation does cause difficulties for employees. Figure 3.4 for example, showed that over 57% of individuals felt that using hearing protectors interfered with the ability to localise sound. This data was supported by a laboratory study by Kerivan (1981) which indicated that the localisation of speech shaped noise was made more difficult when wearing ear protectors, the mechanism being one of alteration of binuaral temporal cues rather than spectral changes. Interestingly, Russell (1977) commenting upon the results of a laboratory study of the ability of subjects wearing earmuffs to localise sound, concluded that the degradation in ability was permanent; that subjects cannot be retrained such that they can localise sound whilst wearing earmuffs. Furthermore, Hirsh (1950) published the results of a laboratory experiment which suggested that the interference with the normal localising mechanisms caused by ear protector usage, prevents the user from separating speech from a background of masking noise, thus degrading the ability to communication in such conditions.

Experimental evidence presented by Else (1981) supports the results of the field study reported in this chapter. This author reports that the ability to localise warning shouts is degraded when earmuffs are worn. Else also states that this degradation is not dependant upon any hearing loss which may be present, although he does show that subjects with a noise induced hearing loss missed completely the warning shouts more frequently than those with normal hearing.

The interaction of hearing loss with the auditory problems experienced whilst using hearing protectors was investigated in the present study, using the audiometric data obtained at the time that the questionnaire was completed, and the results are discussed later in this section.

Figure 3.7 shows that an approximately equal division exists between the numbers of employees reporting difficulties in communication whilst wearing hearing protection, and those who did not. This finding requires explanation, as figure 3.2(b) showed that at least 94%, and probably closer to 100% of the population would need to communicate whilst wearing hearing protection.

Two possible explanations exist: firstly that the two sub populations worked in environments in which the speech to noise ratio was different, or secondly that the hearing acuity of the two subpopulations was different. Some insight can be gained by considering the results of several laboratory experiments published in the literature.

Coles (1965) undertook speech intelligibility studies in the laboratory using normal and hearing impaired subjects wearing earprotection, with and without a background of noise. Although the earprotection used was an earplug with a relatively unusual attentuation characteristic, the results of the study indicated that employees with a high frequency hearing loss would be disadvantaged acoustically in the quiet, if compared to their colleagues with normal hearing acuity, for whom no change in speech discrimination could be shown to exist between the occluded and nonoccluded conditions. However, in a background of noise, the use of the earplugs did not cause a loss of speech discrimination in either of the two hearing acuity groups.

Lindeman (1976) performed work using subjects with a high tone hearing loss and showed that speech intelligibility was improved if the hearing protectors were worn in high ambient noise levels, providing that the hearing loss was mild. If the loss was severe, the use of eardefenders caused a deterioration in speech intelligibility. The results of this work were confirmed in similar studies undertaken by Chung (1979) and Frolich (1970).

Rink (1979), however, published laboratory derived data indicating that the user of hearing protection who has a noise induced hearing loss will not suffer a deterioration in the ability to discriminate speech in noise, whilst the speech discrimination of subjects with normal hearing will be improved by the use of earprotection.

Kryter (1946), using subjects with normal hearing acuity, demonstrated that wearing earplugs in ambient noise levels of 80 dBSPL or above increased the intelligibility of speech, a result which was later confirmed in other laboratory studies by Pollack (1957), Micheal (1965) and Williams (1971). Martin (1976), again using subjects with normal hearing, produced similar results in that the use of hearing protectors in a noise environment of 85 dB(A) or above did not degrade the listener's discrimination of speech. However, it was found that part of the problem encountered by employees communicating in noise whilst wearing ear protection resulted from a tendency by the speaker to reduce the sound pressure level of his speech by approximately 3dB. This occurred as a result of interference by the hearing protection with the Lombard reflex (Lombard 1911).

Drawing together the results of the laboratory experiments described above, it would appear that above ambient noise levels of 80-85 dB(A) the user of hearing protection with normal hearing acuity will not suffer a deterioration of the ability to discriminate speech. The ability may even be improved, providing that the speaker does not lower his voice as a consequence of his own usage of hearing protection. The user with a noise induced hearing loss, however, could suffer deterioration in his ability to understand speech when wearing hearing protection in a noisy environment.

Section 3.2.2 reports the results of a study undertaken as part of the present research programme, designed to evaluate the validity of the conclusions given above, using an industrial population working in their normal environment. However, discussion of these results is reserved until after the comments on the detectability of warning sounds, given below, and which share common arguments.

Coles (1965) argues that as warning or indicator sounds carry less redundant information than speech, perception of these signals would be more severely affected by the attenuation supplied by an earmuff than is the case for speech. Wilkins (1980) performed experimentation in which normal subjects were required to detect the sound of a siren, drill, lathe, or engine in a background of industrial noise. It was concluded that there was little appreciable effect of wearing hearing protection on the detection of warning or indicator sounds, providing that these sounds were above that level at which they would become masked by the ambient noise. Wilkins suggests a minimum signal to noise ratio of 10 dB if warning or indicator sounds are to be effective. If the warning or indicator sounds were near their masked thresholds, it was concluded that a user of ear protection might be slightly disadvantaged. However, in a noise level of approximately 90 dB(A) the user of ear protectors could expect to benefit from an improvement of 3 dB in the masked threshold of the warning or indicator sounds which Wilkins ascribes to the improved frequency discrimination ability of the ear at lower sound pressure levels.

These conclusions are supported by other research workers. Houston (1949), Ceypek (1974), Talamo (1979), Levin (1978) and Casey (1975). It should be noted that these papers, including that of Wilkins, describe research work undertaken using either individuals with normal or undisclosed hearing acuity.

The results of the present study do not appear to support those of the research workers described above. Figures 3.5 and 3.6 show that 61.5% of those employees who were required to listen for warning sounds during the working day felt that the use of hearing protection increased the difficulty of this task, whilst approximately 51% of the individuals wishing to detect indicator sounds from machinery or processes under their control felt that wearing hearing protectors made this task more difficult. These data are comparable with information published by the National Coal Board (1975) which found in a study of 65 colliery workers that 48% felt that wearing hearing protectors blocked the perception of necessary sounds.

Naturally the present study and those in the literature described differ in points of detail and the test populations used. However, the findings of the present study can be reconciled with those of the literature if it can be shown that the hearing protector user with a hearing loss is more disadvantaged in auditory detection tasks than his normally hearing colleague.

Accordingly the broad based study described in section 3.2.2 was devised, cutting across points of detail and simply looking for a statistically significant difference of measured hearing loss between a group of hearing protector users reporting difficulty in any of a variety of auditory tasks, and a group of protector users not reporting such difficulties.

The analysis of variance presented in section 3.2.2 shows clearly that the hearing acuity of those employees reporting problems when wearing hearing protectors whilst localising sound, detecting warning sounds, communicating verbally or receiving indicator sounds was worse than that of the remainder of the total population in the study, who did not report such difficulties.

Table 3.1 shows a comparison of the mean ages of the two subpopulations with the associated standard deviations. An 'F' test indicates that the variance of employee age within the two populations is not significantly different at the 5% level, and a 't' test produced a statistic value of 1.33 showing that the mean age within the two subpopulations was not significantly different at the 5% level. This finding permitted rejection of the hypothesis that the difference in incidence of reported auditory problems when wearing hearing protection was a direct function of age alone. For example, it could have been suggested that an older population might have been less tolerant of auditory problems than a population of younger colleagues.

Table 3.1 shows the mean hearing loss tabulated by frequency for each of the two subpopulations and the results of eight 't' tests performed using the Mean Square of the Residual as the error estimate, and obtained from the preceding analysis of variance. The validity of multiple 't' tests of this nature is discussed fully in chapter 7, section 7.2.2 where the approach adopted is to desensitise the test by multiplying the significance level of the difference measured by the number of comparisons made. Thus the 0.1% level of statistical significance shown in table 3.1 would become an 0.8% level, as 8 tests are performed.

Even using these desensitised criteria, it is apparent that the auditory differences between the two groups are pronounced in two frequency ranges, 250 kHz to 1 kHz, and 4 kHz to 8 kHz with that group reporting auditory problems whilst wearing hearing protection exhibiting the worse acuity. The former frequency range is important for the good discrimination of speech, whilst it might by hypothesised that the latter is important if indicator sounds are to be detected.

It would, therefore, appear that the results of the analysis of hearing acuity are consistent with the auditory problems reported by employees, and establish that persons with an existing hearing loss and using hearing protection will experience additional auditory problems when working in a noisy environment compared to those experienced by hearing protector users with normal hearing acuity.

Inspection of figures 3.4, 3.5 and 3.7 indicates a further important point. It was stated by 30% of the total population that they would remove their hearing protection in order to improve their ability to detect indicator sounds emanating from machinery. Approximately 64% felt that they had to remove their hearing protection in order to communicate successfully, whilst almost 34% would remove their hearing protection in order to localise sounds from the machinery or process in their charge. This behaviour could have serious implications for the success of a hearing conservation programme. Else (1973), restating the relationship between noise level and the permitted time of exposure, showed clearly that apparently insignificant periods of non usage of hearing protection during a working day would result in a risk of hearing damage even in a moderate noise environment. As one example non usage of slightly longer than 15 minutes in a noise environment of 105 dB(A) during a working day would cause the employee to be exposed to a noise dose above the UK safety limit.

The level of non usage of hearing protection by employees reported above, is therefore of concern. The solution to the problem probably lies in a combination of two approaches. Firstly both hearing protection and process equipment can be selected or modifed to minimise the problems tempting employees to remove their ear protectors. The audibility of warning sounds can be increased, and transducers of various types can be fitted to machinery to reduce the dependency of an employee upon his auditory senses to ensure the correct functioning of the machine. Problems of communication in a population with a high incidence of hearing loss can probably be reduced by the selection of ear protectors offering the minimimum attenuation consistent with auditory safety or the installation of communication earmuffs, if the financial resources are available. The second approach to resolving the problem of partial usage of hearing protection caused by the auditory detection difficulties uncovered in the present study, is to increase the resolve of employees to overcome these problems without removing their hearing protection.

It is therefore the intention to investigate in the Main Experiment the relative powers of traditional programmes of education and industrial audiometry to strengthen this resolve and bring about the necessary attitude changes.

3.4 Conclusions

The preliminary Hearing Conservation Study described in this chapter was brought to a successful conclusion, serving the dual purpose of testing the administrative and audiometric procedures necessary for the smooth running of the large scale Main Experiment, and obtaining basic hearing conservation data from 80 noise exposed employees on three plants.

Analysis of this data showed that at least one major factor was acting against any future increase in hearing protector usage, and that was the discomfort of earmuffs, which were at that time used on the Wilton site by the majority of employees.

Accordingly it was resolved to undertake a theoretical study of those parameters affecting the comfort of an earmuff with the objective of specifying a design which could be both comfortable and acoustically adequate. The results of this study are reported in chapter 4.

The preliminary Hearing Conservation Study was successful in obtaining a description of the working environment of the employee. This could be used both as a perspective in which to view the findings of the study, and an indicator of the conditions likely to be experienced by employees participating in the Main Experiment.

Data obtained during the study indicated that up to 75% of the employees were tempted to remove their hearing protectors for at least a portion of the working day to alleviate auditory problems cuased by usage. This finding stressed the importance of good plant design work to reduce auditory problems, and of finding methods to increase the motivation of employees to resist the temptation to remove their hearing protection. This thesis is directed towards evaluating the potential of industrial audiometry in this role.

Finally the test population was divided into two subgroups; consisting of those who reported auditory problems of any kind whilst wearing hearing protectors, and those who did not. A statistical analysis of the audiometric data obtained during the study was completed, and showed that the latter group exhibited significantly better thresholds of hearing than the former. By adopting this broad based approach to a problem hitherto only discussed in a fragmented fashion in the literature, it proved possible to demonstrate that individuals with a hearing loss would experience a greater number of auditory problems when using hearing protection in noise than would colleagues with normal hearing acuity.

CHAPTER 4

EARMUFF COMFORT

4.0 Introduction

The results of the preliminary Hearing Conservation Study described in Chapter 3 indicated that the discomfort experienced by users of existing earmuffs was a strong demotivating force acting against any improvement in attitude or behaviour relating to the full use of personal protection which might otherwise be engendered by programmes of education or industrial audiometry.

Accordingly it was decided to investigate the literature describing those physical characteristics of an earmuff which affect comfort, with the objective of producing a specification for an earmuff which offered good attenuation, and yet was comfortable to wear.

Comfort is most easily defined in terms of the impact the environment has upon the individual, modified by the individuals own view of the environment. If the total impact is judged to be unpleasant then the individual is uncomfortable. Comfort would appear to be a negative concept, typified by descriptive phrases which commence with the words "freedom from ...". Attempts to achieve comfort are usually resolved by ensuring that the body is in a neutral state, free from intrusive stimuli.

This definition of comfort indicates that an individuals' assessment of the comfort of a protector will depend not only upon the physical parameters of the device but also upon the environment in which it is used. It is more likely that an employee will suffer the discomfort of an earprotector when he is working in an environment of 115 dB(A) than he will when working in a level of 93 dB(A), because the immediate subjective benefit obtained overwhelmingly outweighs any discomfort experienced, (Nixon (1959)).

Discussion of hearing protector comfort in the literature is surprisingly sparse, being confined, with the exception of one or two papers, to brief annotations in reports directed primarily towards the attenuation performance, or to comments of a general nature intended as guidelines for purchasers. Various national standards have been produced which make some mention of hearing protector comfort. Those which are felt to make a positive contribution towards the body of information are discussed even though it is probable that the suggested limits for the various earmuff parameters were derived following a survey of protectors currently thought to be acceptable.

As a summary of the findings of this chapter were submitted to the committee preparing British Standard 6344 dealing with the durability and comfort of ear protection (Karmy (1979)), reference to this standard is delayed until section 4.3, the discussion terminating chapter 4.

4.1 The comfort of earmuffs

Chapter 3 described the results of the preliminary Hearing Conservation Study, and indicated that whilst comfort was an important reason for the non usage of earmuffs it was not raised at all as a reason for the non usage of earplugs, at least of the disposable mineral fibre type used on the Wilton site. The results of a survey undertaken by the National Coal Board (1975) are not incompatible with this finding, and also serve to show that good design can improve the comfort of earmuffs.

The National Coal Board study investigated the comfort of three types of earmuff, a non-disposal earplug, and the disposable mineral fibre earplug. Six surface workers and six underground employees from each of 7 collieries tested each device for a period of one week, and then completed a questionnaire which included a nine points scale to assess the comfort of the protector. The authors stated that the experiment did not proceed as smoothly as might have been hoped, and that they were unable to perform any statistical analysis of the results. Moreover it was not possible to control the survey for the effect of differing noise exposure in each of the groups, and thus it was possible to draw only broad conclusions from the research.

Table 4.1 shows a summary of the scores achieved on the nine point questionnaire scale described earlier. Although no data was available from above ground workers using earmuff C, or below ground employees using earmuff A, the apparent trends would make it not unreasonable to conclude

Table 4.1 The mean comfort scores for three types of hearing protector. Scores are based on a nine point scale: 1 = very uncomfortable 9 = very comfortable Therefore those protectors with the highest mean scores are those rated as the most comfortable.
Data drawn from National Coal Board (1975).

	Earmuff A	Earmuff B	Earmuff C	Permament Earplugs	Disposable Mineral Down Earplugs	
Workers above ground	4.64	4.36	no data	4.16	6.36	Figures based on a nominal 25 observations
Workers below ground	no data	5.22	6.62	4.65	6.72	Figures based on a nominal 40 observations
Mean	4.64	4.79	6.62	4.40	6.54	

that the disposable mineral fibre earplugs were the most comfortable with a rating appreciably above the neutral "neither comfortable nor uncomfortable" point on the scale. Earmuffs A and B were rated below or on the "uncomfortable" side, of this neutral point. However, had a full set of data been available it is likely that earmuff C would have achieved a comfort rating close to, but below, that achieved by the mineral down earplug.

Unfortunately it was not possible to obtain a description of earmuff C, or details of its attenuation efficiency, but the results from the study served to indicate that it is possible to design a comfortable earmuff.

4.1.1 Earmuff weight

The British Occupational Health Society recommended a maximum weight of 500 grams for an earmuff after a survey of "acceptable" hearing protectors currently in use. (British Occupational Health Society, 1975). This figure is repeated in the Russian Standard GOST 15762-70 (Russian Standards Organisaton, 1971) and endorsed by Zwislocki (1955(a)). This latter author sets the weight limit for earmuff comfort at 200 grams per earshell, bringing the total earmuff mass close to 500 grams, on the basis of his general experience. Von Lupke (1964), however, completed a wearability test embracing 17 types of earprotector used by 120 industrial employees, and set the weight limit for comfort at 350 grams, reporting later that on this basis one third of the available earmuffs were too heavy (Lupke, 1971).

Scholer (1975) refers to Osterreichischen Arbeitssing fur Larmbekamfung guideline No 13 (OAL 1962) and sets the upper weight limit to 300 grams. Data published by Piesse (1962) and Dickson (1954), displayed in tables 4.2 and 4.3 respectively, suggest that this maximimum limit is slightly low. Both authors measured the physical characteristics of a sample of currently used earmuffs and made a simple assessment of wearer acceptability. Table 4.3 shows that critical comment upon the weight of a protector only occurred above 500 grams. Consideration of table 4.2 further strengthens this latter comment. Piesse (1962) concluded that "With the exception of the CAL Earmuff Heavy and the Nosonic MkVI, all devices were considered suitable for continuous wear..." The remaining earmuffs all weighed less

Table 4.2 Earmuff weight and clamping force on median head, the data drawn from Piesse (1964). Seperation of the earcups being 14.5 cm.

Earmuff	Weight in grams	Clamping force in grams
C.A.L Earmuff Heavy	561	2086
R.A.F Mk III Ferranti	343	952
Wilson	383	862
C.A.L Earmuff Medium	439	907
Nosonic Mk VI	218	1860
Amplivox	312	544
Noisefoe Mk II	346	1089
Nuplac	312	318
Pamir	156	907
C.A.L Earmuff Light	250	635

Table 4.3 Relating earmuff weight to wearer acceptability. Data drawn from Dickson (1954)

Earmuff type	Weight	Main wearer complaint
Nosonic Mk II	241 g	The headband spring is so tight one's head feels as if gripped in a vice. Fits well
Nosonic Mk I	312 g	Relatively comfortable but does not fit behind the ears satisfactorily.
Royal Airforce Acoustics Lab Mark VI	482 g	Very comfortable. A few subjects thought it had a tendency to be too loose.
Royal Airforce Acoustics Lab Mark I - V	453 g to 595 g	Generally comfortable with a good fit, but a few subjects considered them to be somewhat heavy.

Table 4.4 The comfort of various earmuff types. Weight is given for one earshell alone. OH- overhead headband. BH- behind the head headband. Force exerted measured at a 152.4 mm earshell seperation. Data drawn from Flugrath (1971)

Earmuff	Seal	Weight	Force exerted	Volume	Headband	Comments
A	Cotton	-	-	-	helmet	Very comfortable but impractical
C	Thin plastic	67.5g	907g	80cc	OH	Because these earmuffs were light, the subjects related that they were comfortable, and would be easy to wear for extended periods of time.
D	Thin plastic	66.4g	907g	81cc	BH	As for C.
B	Double plastic	87.6g	1361g	88cc	OH	The subjects reported that this set was comfortable.
E	Foam rubber	84.7g	1134g	119cc	OH	The subjects reported that this set was comfortable, but for unstated reasons was not prefered.
F	Foam rubber	89.3g	1814g	126cc	BH	Because the headband applied considerable pressure on the side of the head, the set was judged most uncomfortable by the subjects. It could not be worn for long periods of time.

than 440 grams. However it should be noted that the CAL Earmuff Heavy and the Nosonic MkVI also exhibited a high headband tension, which was probably the prime reason for rejection.

Table 4.4 shows data drawn from Flugrath (1971), who attempted to measure the correlation between the attenuation of an earmuff and several of its physical parameters, such as weight, headband tension, shell volume etc. The experimental subjects made informal judgements on the comfort of the protectors worn as shown in the table. None of the subjects reported that any of the earmuffs were too heavy for comfortable use. The total weight of each of the earmuffs is not shown but from the weight of the earshells given it is unlikely that any earmuff exceeded 300 grams in weight.

Thiessen (1955) reports the result of an acceptability trial of two models of experimental hearing protectors. A pair was sent to each of six paper mills where they were worn for a minimum period of one shift by each of fifty employees. The Mark I version weighed 560g and 92% of users complained of its weight. The Mark II hearing protector weighed between 260 and 290g and all the employees agreed that the weight of this protector was acceptable.

This judgement may have been affected by the fact that all employees in the study initially used the heavier earmuff. However, their decision is supported by the bulk of literature reported within this section.

On the basis of the evidence discussed above, a maximum weight in the range 400-500 grams should be selected for long term comfort.

4.1.2 Force of earshell application and heaband flexibility

The pressure with which the tensioning headband causes an earshell to be applied to the side of the head is the result of a compromise by the manufacturer between comfort and attenuation. Early earmuff models required high headband tensions to ensure that the materials then used to fill the seals were caused to conform to the contours of the skull. The high headband forces produced the necessary seal stiffness, and reduced the possibility of acoustic leaks forming between the seal and the side of the head.

Zwislocki (1955(b)), calculated that any acoustic leak in excess of that caused by a theoretical cylinder of length 0.5 cm and diameter 0.74 mm would adversely affect the attenuation of an earmuff possessing a 25 cc volume. The need for high headband forces is therefore apparent, given the lack of sophistication of early seal design. However, modern materials have now been developed, and being more compliant than their predecessors, have enabled headband tensions to be lowered (Acton 1971).

However, a need still exists to maintain a relatively high pressure on the side of the head, for a decrease in headband tension will reduce the impedance of the flesh beneath the seals. In turn this effect increases the possibility of the flesh trapped beneath the cushions vibrating as a rigid piston, decreasing the effective attenuation (Zwislocki, 1955(b)).

Evidence of the action of both these mechanisms was reported by Webster (1962), and is shown in figure 4.1. The effect is demonstrated of reducing the headband tension of earmuffs which are identical but for the seal filling material used. The loss of attenuation is more pronounced in the earmuff with the sponge seals than is the case for the earprotector with the liquid filled seals, as these are better able to maintain a good interface with the circumaural tissue under the conditions of reduced headband tension. Additionally the intrinsic stiffness of the liquid filled seal is higher, a point which is discussed in section 4.1.5.

Headband tension is a function of earshell separation. Bolton (1973) used a population of 2000 British aircrew, and demonstrated that the 50^{th} percentile maximum male human head width was 157.3 mm. Hertzberg (1954) gives this width as 153.7 mm, using United States Air Force flying personnel as test subjects. The Canadian and Russian Standards and the British Occupational Hygiene Society documents all make use, approximately, of this earshell separation in specifying the maximum, and in some cases, minimum, headband force. (Canadian Standards Association (1965), British Occupational Hygiene Society (1979), Russian Standards Organisation (1971)).

Russian Standard	Maximum force 800 grams
Canadian Standard	Maximum force 1200 grams
	Minimum force 700 grams
BOHS draft Standard	Maximum force 1200 grams
South African Standard	Minimum force 2039 grams

The South African Standard (South African Bureau of Standards 1973) headband force limits have been included in the above list, but it is difficult to compare the suggested limit with that proposed by the remaining three bodies, as the earshell separation distance at which the tension is to be measured exceeds that of the three by approximately 65 mm. However, the axes of a graph presented by Lupke (1964), relating headband tension to earshell separation for seven earmuff types, can be extended to encompass the range described by the South African Standard.

This extended graph is shown in figure 4.2 and suggests that the South African requirement for a minimum headband tension of approximately 2000 grams at an earshell separation of 215 mm would lead to an unduly high rejection rate of earmuff types.

It is also conceivable that the headbands of many protectors shown, such as the Willson, Riwosa, and DC, which appear to have an acceptable tension at normal earshell separations, might exceed their elastic deformation limit when the earshells are separated by 215 mm. This would result in a measurement of headband tension which bore an uncertain relationship to that exhibited at earshell separations corresponding to the average head width.

Scholer (1975) sets the maximum limit for headband tension at 1000 grams, a figure which is also suggested by Lupke (1971). Zwislocki (1957) states that this force should vary between 500 and 1000 grams, as a result of general experience obtained whilst designing earprotectors.

Table 4.2 shows data drawn from Piesse (1962), and this author comments "With the exception of the CAL Earmuff Heavy, and the Nosonic Mark VI all the devices were considered to be suitable for continuous wear, and all have headband forces on a medium head of less than 992 grams". Problems with excessive headband tension in the Nosonic range had already been noted

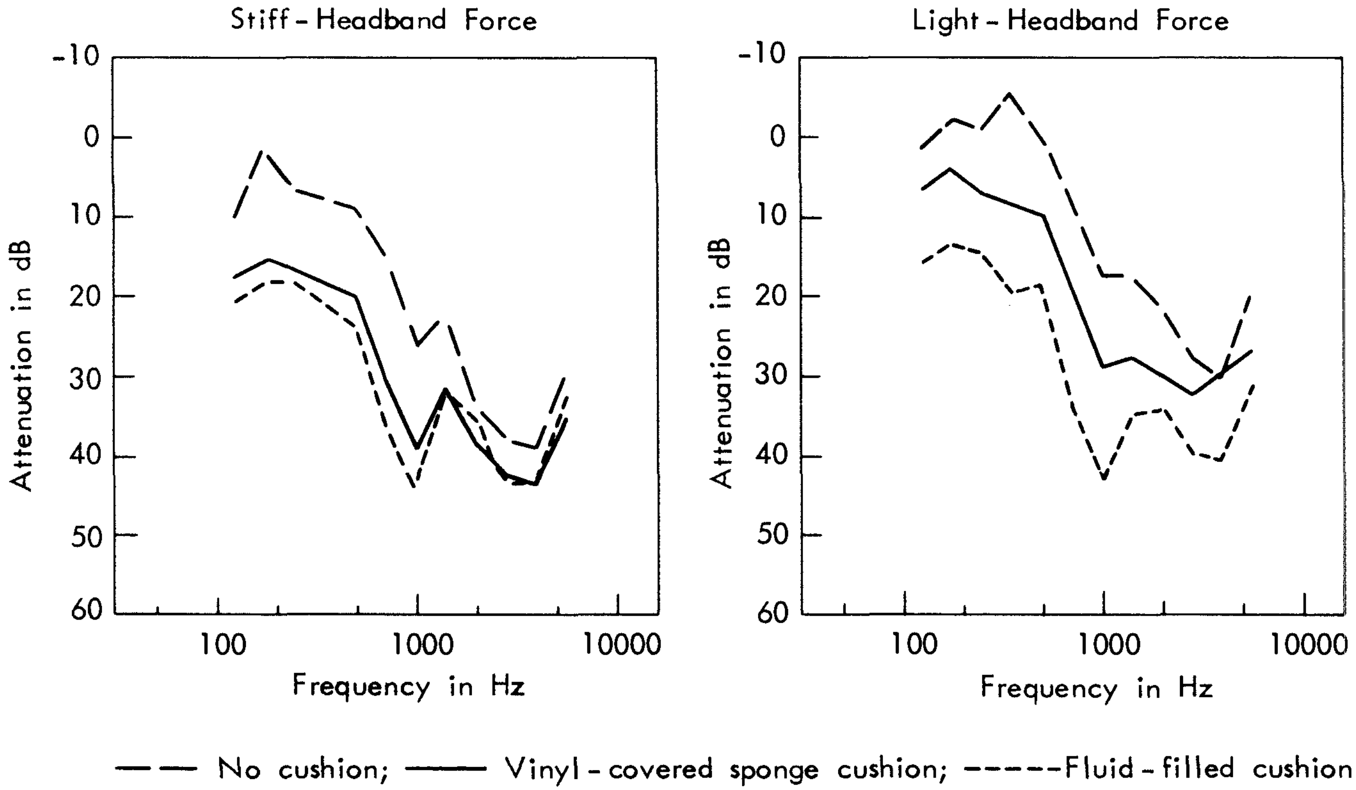


Figure 4.1 The effect of reducing headband tension, and changing the seal material, on earmuff attenuation. Data drawn from Webster (1962).

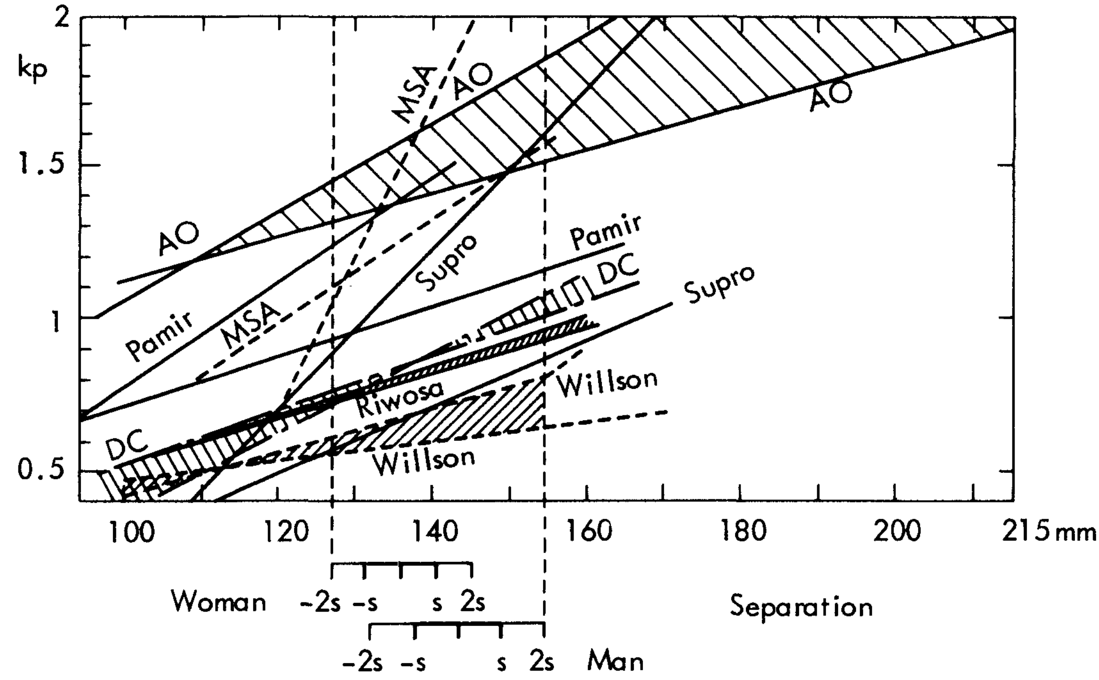


Figure 4.2 A plot of headband tension against earshell separation. Extrapolation of the curves beyond 170 mm is of theoretical interest only as the elastic limit of headband deformation may be passed beyond this point. Data drawn from Lupke (1964).

in Dickson (1954) as shown in table 4.3.

Shaw (1958), suggests, in the course of developing an improved earmuff seal, that a force equal to twice the weight of the earprotector is sufficient, and further comments that a clamping force in excess of 1 kg across the head is unpleasant to some people, and that a 2 kg force can cause severe headache. Piesse (1962) comments favourably on using as a "rule of thumb", twice the weight of the hearing protector as the clamping force of an earmuff. He states that protectors with a clamping force of less than twice their weight failed to maintain a good seal to the side of the head.

Tisserand (1973) calculated the correlations between subjective comfort ratings allocated by ten subjects to 24 protectors, and objective measurements of the hearing protectors. The five parameters measured were; mass, force of earshell application, headband stiffness expressed as an approximation to Youngs Modulus, seal pressure on the side of the head, and a parameter describing the ability of the seal to conform to the contours of the side of the skull.

The correlations between the subjective and objective evaluations are discussed later, but immediate interest lies in headband stiffness which was judged to be of prime importance in the comfort rating of an earmuff.

Tisserand defines headband flexibility in terms of an approximation to Youngs modulus, represented by the ratio of the change in measured force to the change in earshell separation, given by the slope of the lines in figure 4.2.

As can be seen from table 4.5 it was this parameter, rather than force of application which exhibited the highest correlation with comfort. The authors argued that earmuffs with adjustable headbands usually possess high headband stiffness, and consequently a small variation in the separation distance of the earshells results in a large change in the force of application of the earshells on the side of the head. Because small distances are involved, it is difficult to adjust these headbands to a comfortable force of application. Wearers whose heads are wider than the average are subjected to higher headband forces than the minimum deemed

Table 4.5 Correlation coefficients between perceived comfort and measurements of various physical parameters of 24 earmuffs. Data drawn form Tisserand (1973).

Physical parameters	Mass	Force of application of earshells on the side of the head	Stiffness of headband	Average pressure on the side of the head	Ability of the cushion to conform to skull irregularities
Coefficient of correlation with overall comfort	0.10	-0.61	-0.76	-0.63	-0.74

Parameter range	Parameter
148g - 375g	Mass
850g - 1850g	Force of application
48g/cm - 270 g/cm	Stiffness
$19 g/cm^2$ - $91 g/cm^2$	Pressure
$45 g/cm^2$ - $395 g/cm^2$	Conformability

necessary for good attenuation by the designers of the earmuff, who had to specify the headband force for the narrower end of the head width range. Tisserand suggests, therefore, that the flexibility of a headband should be kept high, in order that the force of application might be more independent of the headsize, a comment echoed by Shaw (1958).

Tisserand does modify his conclusions in that he and his co-workers state that the good correlation between headband stiffness and comfort embraces partly the correlation between comfort and force of seal application. They suggest that if force of application had been measured differently from that technique which was actually employed the correlation between force of application and comfort would have been higher.

It is suggested, on the basis of the above evidence, that the maximum headband force developed by an earmuff during use should be 1000 gm or less.

4.1.3 Headband adjustment, earshell mobility and dimensions

The national standards referenced earlier in this chapter all require certain design criteria to be met. Anthropomorphic tables prepared by Bolton (1973) and Hetzberg (1954) show that the headband vertical adjustment needed is approximately 3.25 cm on each side if the 1st-99th percentile of the population is to be fitted.

The headband itself should be designed so that the major proportion of the earmuff weight is distributed over as large an area as possible across the top of the head. The headband should also be light, with the mass of an earmuff being concentrated in the earshells.

A BOHS document (British Occupational Health Society, 1979) considers anthropomorphic data published in Bolton (1973), Aerospace Medical Research Laboratories (1967) and Wright Air Development Centre (1952). The Society recommends that the headband of an earmuff designed to be worn over the head should be adjustable to accommodate a minimum range of head sizes from 320 mm to 385 mm measured in an arc between the upper edges of the ear canals. If the earmuff is designed to be used with the tensioning band behind the neck, the headband should accomodate a minimum range of head sizes from 250 mm to 300 mm measured in an arc between the forwards edges of the ear canals. When designing an earmuff for maximum comfort it is important to ensure that the pinna is not distorted in any way, and that the internal dimensions of the earshell are designed accordingly (Veneklasen 1955, Michael 1965). It is worth noting that one of the most frequent complaints of earmuff users recorded by Damangeot (1973) was that of insufficient clearance for the pinna inside the earmuff shells.

The dimensions to be considered are the protrusion of the pinna from the side of the head, the height, and the width. The British Occupational Hygiene Society (1979) document sets these dimensions as 2.5 cm, 8 cm and 4.5 cm respectively. The width and height limits exceed the Hertzberg (1954) measured values for the 99th percentile by a small margin and those described in Aerospace Medical Research (1967). However, the BOHS document advises hearing protector manufacturers to design earmuffs to accomodate pinnae having a protrusion depth of 2.5 cm, which, according to Hertzberg (1954), will only allow for pinnae up to the 85^{th} percentile and who also suggests a minimum earshell opening of 60 mm by 45 mm.

It is recognised that the sides of the skull are not paralell to one another in any plane. Therefore the BOHS document recommends that the earshells be able to swivel through a conical angel of 15^{o}.

Considering the evidence presented above it is likely that an earmuff will be comfortable to use if the protector possesses the following attributes. The headband in a earmuff designed to be worn over the head should accomodate a range of head sizes fromn 320mm -385mm measured in an arc between the upper edges of the ear canals. If the earmuff is a behind-the-head model the headband should fit head sizes from 250-300 mm measured in an arc between the forwards edges of the earcanals and passing behind the head. The earshells should be capable of rotation through a 15^{o} cone, and a vertical adjustment of 32.5 mm. The earshell should also provide a minimum pinna insertion depth of 25 mm, and an internal opening measuring at least 45 mm by 80 mm.

4.1.4 Seal pressure

Gasaway (1971) states that the pressure of the seal on the skin is one of the most common causes of discomfort experienced whilst wearing hearing protection, while Zwislocki (1955(b)) and Michael (1965), single out the auricle as an especially sensitive area.

In evolutionary terms the skin is the oldest sense organ, containing a plethora of specialised nerve endings, the exact interaction of which is still not fully understood. Pacinian corpuscles, usually situated relatively deep in the skin layers are thought to be the receptors which respond to strong pressure, whilst light pressure affects only the free nerve endings in the skin, and the hair bulbs, (Bliss, 1963). Undoubtedly the sensation of pressure adapts or fatigues with time, as does every other modality of sensation, but only if the initial sensation of pressure is tolerable. If the pressure exerted on the skin lies outside this tolerance band, then increased time of exposure only increases the discomfort felt as indicated by the experiment described below.

Redgrave (1972) investigated the acoustic and comfort properties of several types of flying helmet using subjects who wore the helmets for 2.5 hours. The subjects were required to make a simple scale assessment of the comfort of their helmet on five occasions during this period. The scale used related mainly to the development of pressure points on the skull by the helmet.

Figure 4.3 shows a set of results drawn from one subject and published by Redgrave. It can be seen that although both helmets achieved similar comfort ratings initially, the small difference was apparently sufficient to cause the comfort rating of one type of helmet to decline, whilst the other improved with time.

Damon (1963) and Allen (1968) suggest that localised pressure, or a pressure point, on the skin around the auricle is subjectively more uncomfortable than the same pressure distributed evenly around the ear, although further experimentation would appear necessary if this point is to be confirmed.

Additionally it is suggested that a proportion of the discomfort experienced by earmuff users is due to the restriction of blood flow in the circumaural tissues below the earmuff seal, (American Industrial Hygiene Association 1966, Wheeler 1956).

The British Occupational Society (1975) recommends a maximum permissable seal pressure of 60 g. cm^{-2}, for reasonable comfort. This figure would seem high when compared to that suggested by other authors.

Shaw (1958) recommends that the limit should be 20 g. cm^{-2} to ensure comfort. This view is endorsed by Allen (1968), who designed a "friction spring" earmuff cushion. Schiller (1967), whilst developing an objective technique for ear protector attenuation measurements, obtained a representative sample of earmuffs in current use. Data are shown in table 4.6.

The seal pressures shown range between 11 and 37 g.cm^{-2} at the 50th percentile. This maximum figure agrees with the 40 g.cm^{-2} given in Zwislocki (1955(a)) as being the maximum pressure permissable for comfort. Table 4.7 shows the physical parameters of four earmuffs, including average seal pressures, and a comfort rating on a scale of 1-3 as measured by Damongeot (1973) using a scale developed by Tisserand (1973). These ratings can be placed in perspective by considering table 4.8 drawn from the same work, which shows the distribution of comfort ratings ascribed to 60 types of hearing protector.

As can be seen from table 4.7 a seal pressure of 35 g.cm^{-2} is considered a little high. In view of this, and other evidence discussed earlier, it is recommended that seal pressure should not exceed 30 g.cm^{-2} if earmuff comfort is to be ensured.

4.1.5 Seal materials and sheaths

Two types of earmuff seal are in common usage at the present time. The first type is filled with a liquid, usually glycerine and water, whilst the second contains a plastic foam material.

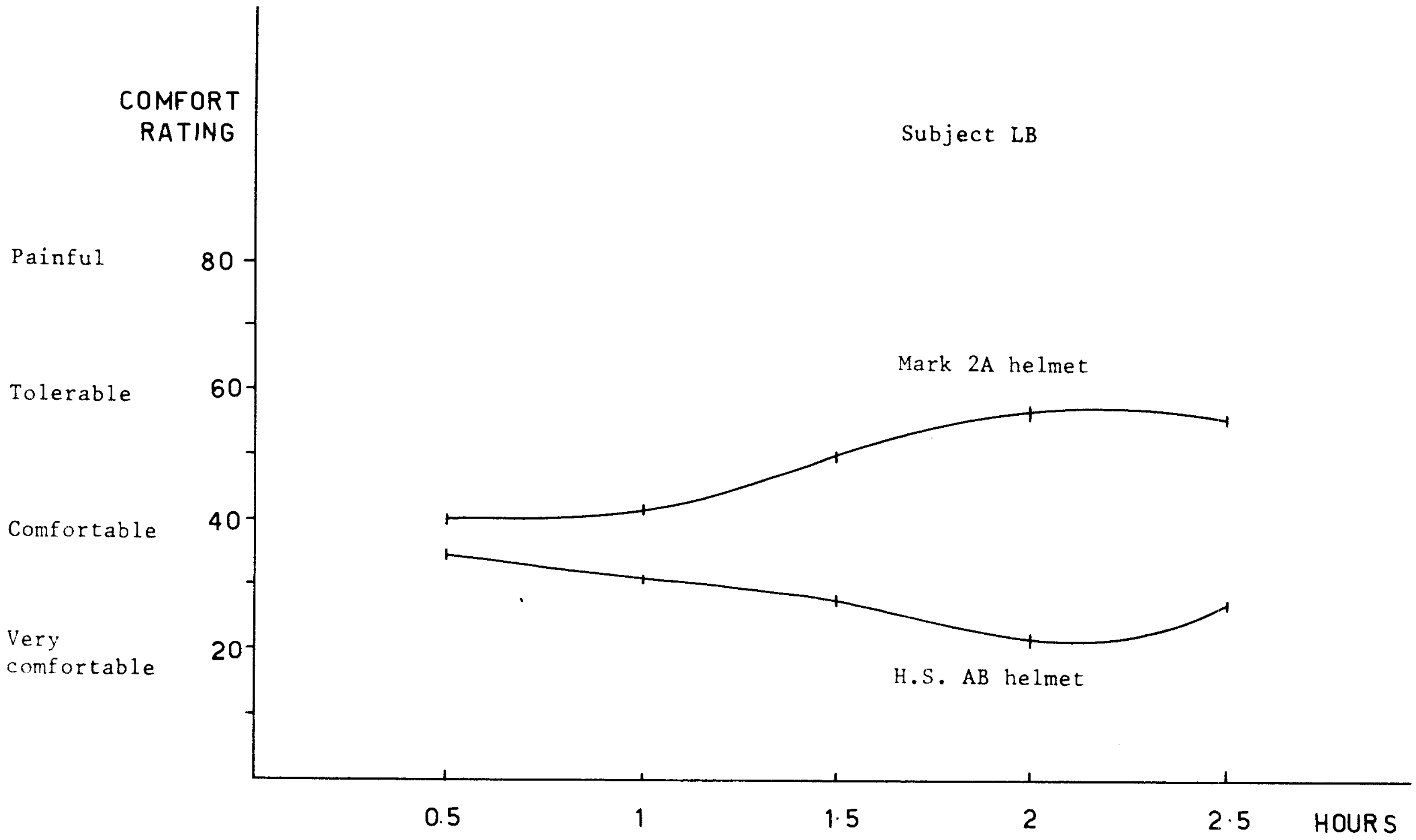


Figure 4.3 Comfort profiles for two types of flying helmet. Data drawn from Redgrave (1972).

Table 4.6 The physical parameters of 9 earmuffs. Data drawn form Schiller 1967

	Ear Protector Manufacturer	Weight	Earcup Volume	Headband Tension			Seal Area	Seal Stress		
Number	Model	kg	m^3 $x10^{-6}$	1% ile kg	50% ile kg	99% ile kg	m^2 $x10^{-4}$	1% ile $kg\ m^{-2}$	50% ile $kg\ m^{-2}$	99% ile $kg\ m^{-2}$
1	DAVID CLARK 62	0.57	185	0.57	0.77	0.91	33	170	230	280
2	DAVID CLARK 19A	0.34	295	0.87	1.22	1.16	33	260	370	350
3	WILLSON 272	0.57	171	0.54	0.65	0.68	63	85	110	110
4	ROANWELL H-158	0.31	75	0.91	1.33	1.48	50	180	270	300
5	US INSTRUMENT SA	0.48	15	0.99	0.97	1.22	80	120	120	150
6	AMERICAN OPTICAL 1200	0.31	160	0.85	1.50	1.50	52	160	290	290
7	DENIS FERRANTI B-1	0.85	90	1.28	1.33	1.36	63	200	210	220
8	PERMAFLUX FDR-8	0.45	25	0.62	0.62	0.51	33	190	190	150
9	WILLSON 258	0.37	171	0.65	0.74	0.74	63	100	120	120

Table 4.7 Showing the physical parameters of 4 earmuffs against their comfort ratings on a scale of 1-3. A rating of 3 denotes high comfort. Data drawn from Damongeot 1973.

Manufacturer model	Mass	Headband Stiffness	Average headband tension	Average seal pressure	Index of seal conformability	Seal filling	Earcup dimensions (external with seals) height	width	depth	Comments	Comfort rating
	g	kg/m	kg	kg/m^2	kg/m^2		cm	cm	cm		
Amplivox Sonogard	375	7.13	0.96	244.7	1019.8	liquid	6.7	5.2	5.2	Seal pressure just acceptable Adequate seal conformability	3
Willson SB258 Sound Barrier	365	5.6	0.95	204	459	liquid	7.3	4.5	5.5	Flexible headband Seal pressure very acceptable Good seal conformability	3
Silenta Comavox	166	8.0	1.2	349	2416.8	foam plastic	10.1	8.1	4.7	Seal pressure a little high Space for the auricle inside the earshell a little restricted	2
David Clark 19A Straight away	346	10.2	1.02	337	2855	foam plastic	6.9	4.4	7.85	Poor scope for headband adjustment Key needed for adjustment	2

Table 4.8 Showing the distribution of the comfort ratings used in table 4.7, for 60 types of hearing protector.

Total tested		Class 3 Most comfortable	Class 2 Average comfort	Class 1 Poor comfort
Helmet earmuffs	4		Not classified	
Earmuffs	32	4	23	5
Earplugs	24	4	18	2

Liquid filled seals usually provide a slightly better attenuation but they are more susceptible to damage and more expensive than foam filled seals, and are accordingly issued less frequently.

Regular earmuff users complain that the plastic seal sheath often becomes hardened with age, and hence uncomfortable. The hardening is usually caused by a combination of body heat and sweat which, over a period of time, leaches the plasticiser from the plastic. This also has the unfortunate consequence in the case of liquid filled seals that the plastic seal sheath can crack and release the liquid from the seals, causing obvious discomfort and irritation to the user.

The length of time elapsing before an earmuff seal becomes hardened and uncomfortable is dependent upon the environment in which the earmuff is used, but in a hot and oily workplace the seals might require to be replaced every 6-8 weeks. In a cooler, clean environment the seals might last two to three years.

Obviously the solution to this comfort problem lies in the frequent checking and replacement of seals. The deleterious effect of seal hardening on earmuff attenuation is discussed in Karmy (1980).

The foam layers inside an earshell, and the seal sheath, can become wet with perspiration very quickly in warm environments, and to such an extent that the earmuff may feel insecure on the side of the head. Absorbant seal covers can reduce this problem by removing sweat from the surface of the skin.

Nealy (1960) found that chamois coverings over liquid filled vinyl sealing rings affected the attenuation of the earmuffs in a very minimal way, and stated that cloth covers behaved in a similar manner. This finding was confirmed in Grose (1981). These covers may also improve wearer comfort in certain cases by acting as a pressure release in the event of sudden changes of barometric pressure as might be experienced by a pilot.

Frequent change of replaceable seal perspiration covers can increase the hygiene of usage in a dirty environment, and thus decrease the reluctance of an employee to wear the earmuffs.

The seal coverings of an earmuff must produce no allergic reaction on the skin. Materials used should be capable of being cleaned and sterilised. They should be non-staining, resistant to sweat, hair oil, cosmetics and skin oil. They should contain no toxic substances, irritants, or be capable of taking up any dermatitic substance in the industrial atmosphere. Neither should the material be prone to picking up mechanical irritants such as grit or fine metal swarf. The seals should not support the growth of moulds or yeasts, or absorb atmospheric moisture.

Zwislocki (1955(b)) points out that the seals are applied to the skin under pressure, and in conditions of some warmth, which can intensify any chemical reaction on the skin. However, Acton (1970), states that earmuffs rarely cause infection or sensitisation of the skin.

Consideration of the earmuff as a vibrating system indicates that the seal filling will be a significant factor in determining the attenuation of an earmuff.

Many modern earmuffs exhibit a resonance around 200 Hz. Acoustic theory would then suggest that below 200 Hz the attenuation is controlled by the stiffness of the system, whilst above 200 Hz the acoustic attenuation is controlled by the mass of the cup. The volume enclosed by the earshell would have an effect on attenuation in both frequency regions. Close to the resonant frequency, the damping of the system would substantially control the acoustic performance of the earmuff (Thiessen, 1958). Above approximately 1000 Hz, the modes of vibration of the earshell become complex, and have not been satisfactorily described theoretically at the present time. The maximum attenuation in these higher frequency bands is limited by the bone conduction thresholds. These comments neglect the effects of acoustic leakage, mentioned earlier, and assume the earshell materials to be rigid at low frequencies.

From the brief descriptions given above, it can be seen that the filling of the seals will be a significant factor in determining the attenuation of an earmuff in the stiffness controlled region. Shaw (1958) also suggests that the design of the earcushions may also be of importance above the resonance frequency, in that correct design may reduce the acoustic coupling between the flesh outside the earcup and the flesh inside the earmuff.

The requirements for comfort and acoustic attentuation appear opposed, a subject explored in detail by Shaw (1980). Soft cushions which conform easily to the side of the head offer the best comfort but hard, stiff, materials are needed for good low frequency attenuation. Soft sponge cushions are usually insufficiently stiff unless compressed by a high headband force. A liquid filled earmuff seal, however, overcomes this problem if sheathed in a plastic skin which, although flexible enough to conform well to the contours of the side of the skull, has a high Youngs modulus, making it relatively inextensible. Thus when filled with an incompressible liquid, the cushion will be comfortable, and yet resistant to volume changes which allow the earshell as a whole to vibrate as a piston at low frequencies. (Thiessen 1958, Shaw 1958).

Shaw (1958) shows that in practice it is only necessary to dilate the sheath moderately with liquid, as the stiffness of such a cushion will increase rapidly as a positive acoustic pressure wave attempts to compress it. This partial dilation of an earcushion should improve earmuff comfort, and designed in this manner, liquid seals can reduce the need for high headband forces.

The liquid filled seal also tends to be more comfortable than its foam filled counterpart as it conforms to the contours of the head better, thus ensuring a more even distribution of pressure for a given headband force and seal area.

Zwislocki investigated a semiplastic filling for earmuff seals, choosing a wax as his material. This wax became malleable at skin temperature, conforming well to the side of the head after a short period of use, and ensured an even distribution of pressure over the side of the head, relieving the possibility of pressure points developing. Moreover the wax had a high internal viscosity, ensuring good damping of the earmuff system at the resonant frequency (Zwislocki 1955(b)).

Figure 4.4 shows the paths by which acoustic energy can pass through an earmuff. The compliance, or conversely, the stiffness, of the flesh is of interest in the present discussion.

Skin compliance is discussed by Zwislocki who states that in order to increase the acoustic attenuation of an earmuff at the lower end of the audible frequency range, it is necessary to increase the combined effective stiffness of the skin and the ear cushion. Once the stiffness of the ear cushion has been raised as far as possible, further improvement of attenuation can be made by making the area of contact between the cushion and the skin as large as possible. This means wide ear cushions, conforming well to the side of the head, (Zwislocki, 1955(a)), which would also result in lower seal contact pressures on the skin for a given headband force, thus increasing wearer comfort.

However, in practice other considerations mitigate against wide earmuff seals. These are given below.

Zwislocki (1957) shows the ratio of the sound pressures inside and outside of the earshell to be:

$$\frac{p_1}{p_o} = \frac{S_o}{S_i} \cdot \frac{Z_{bm}}{Z_m + Z_{bm}} \qquad (4.1)$$

where p_o = acoustic pressure outside the muff, p_1 = acoustic pressure inside the muff, Z_{bm} = acoustic impedance behind the muff, Z_m = acoustic impedance of the earmuff, S_o = outer effective area delineated by the external circumference of the ear cushion and S_i = inner effective area delineated by the inner circumference of the ear cushion.

The impedance behind the earmuff, Z_{bm} is inversely proportional to the volume of the air cavity, and directly proportional to the square of the area of the opening leading to the cavity. A low Z_{bm}, and hence a high attenuation, requires a large volume with a small S_i. This means in practice that the inner circumference of the sealing cushion must be as close to the pinna as possible without actually touching it.

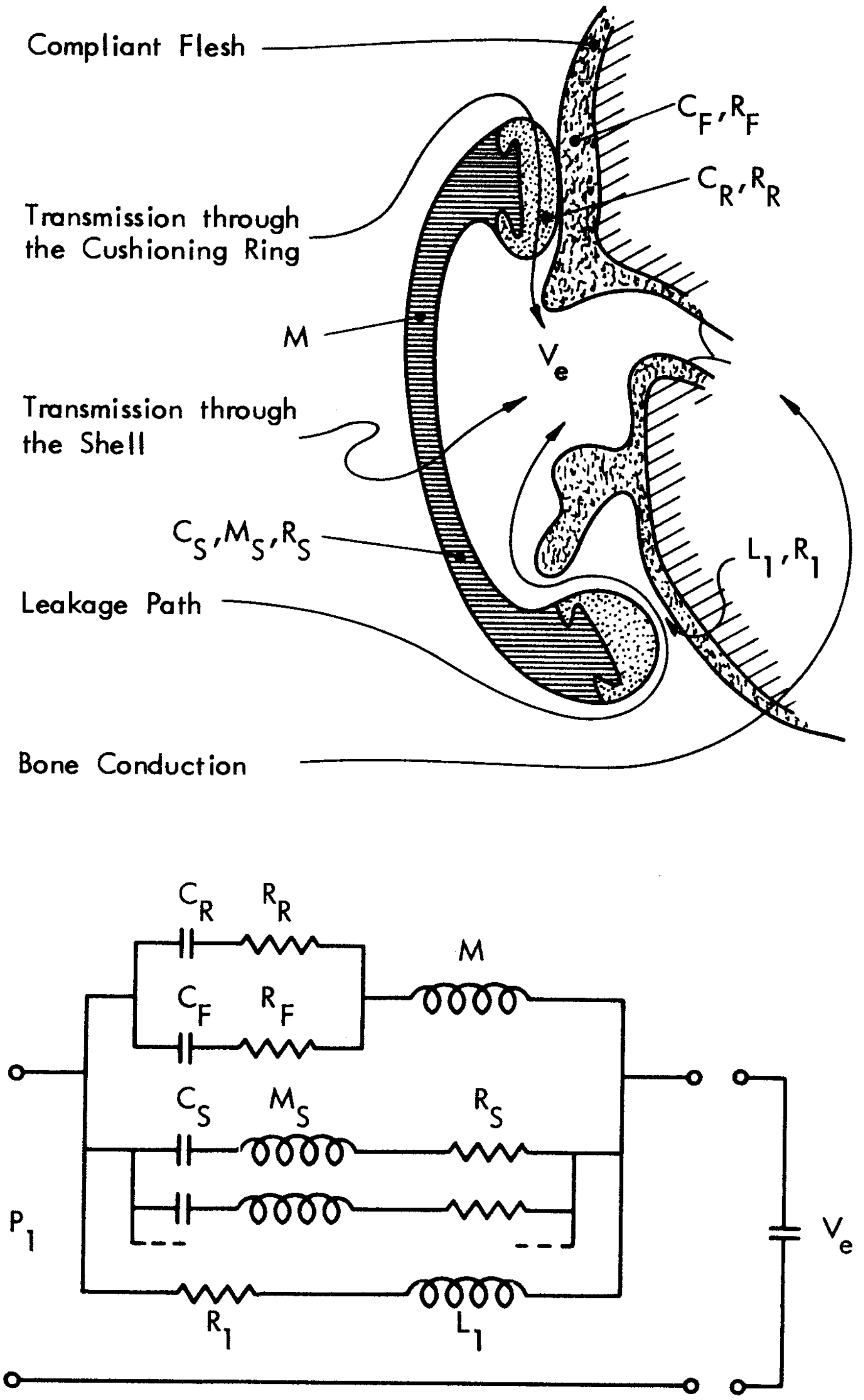


Figure 4.4 Diagram of an earmuff showing leakage paths and an analogue electrical circuit. (Veneklassen, 1955).

Equation 4.1 also shows that the ratio S_o/S_i must be small if the attenuation is to be high.

The preceding two arguments indicate the need for a narrow sealing cushion, which in addition to being potentially uncomfortable, increases the possibility of an air leak forming.

Designing the earcushions to be as close as possible to the base of the pinna is advantageous in that skull irregularities are not as pronounced in this region as they are slightly further away from the ear. However, as described earlier, insufficient clearance of the pinna inside the earshell formed the most frequent complaint of earmuff users recorded in a survey by Damongeot (1973).

It is possible to derive a recommended seal width using the previously defined optimum or maximum values for seal pressure, headband tension, and the minimum suggested size of the seal opening.

Assuming that the seal is elliptical, the width is defined by

$$w = \frac{1}{2}\left(\left(1.2735 + (a+b)^2\right)^{1/2} - a - b\right) \qquad 4.2$$

where (w) represents the seal width, (s) the seal area, and (a) and (b) represent the major and minor axes of the ellipse forming the seal opening respectively.

Using formula 4.2 with the optimum parameter values described earlier yields an optimum seal width of 15 mm.

4.1.6 Temperature

During a study of the user acceptability Thiessen (1955) showed that 70% of the employee's complained of the heat and/or perspiration generated on the skin surface caused by wearing the protectors. Nixon (1959) reported similar findings, as does Veneklasen (1955) who also adds that the potential for mycotic infections of the ear canal must be increased under the conditions of increased humidity and temperature inside the earshell.

Thomas (1975) measured the increase of temperature underneath an Amplivox Audicup headset which is a circumaural muff containing a supraural earphone. The subject was placed in a constant air temperature of 26°C and a humidity enclosure generating an atmosphere with a 52% relative humidity. The temperature behind and in front of the auricles was measured. The results are shown in figure 4.5 and indicate a rise of approximately 4.5°C in front of the left and right auricles, and a rise of 3.3°C at the rear of the right auricle, over a period of 37 minutes. At the end of this period temperatures were still rising slowly.

Thermal radiation is not detected directly by sensors in the skin, but is sensed through a build up of heat in the skin. This information is integrated from all the body surfaces, although the information appears to be weighted, in that hand and face temperatures have a greater effect on sensation than trunk temperatures. Moreover, the sensation of comfort related to temperature functions in a comparative manner with conflicting sensations of temperature from different parts of the body being judged as uncomfortable. The ability of the body to detect differences in temperature is not linear, being at its most sensitive at 34°C.

Figure 4.5 shows that this is approximately the centre of the range of temperature changes measured by Thomas, and caused by wearing the Amplivox Audicups.

It would therefore appear that wearing earmuffs could give rise to a sensation of discomfort due to increased temperature which is out of proportion with the temperature change caused. These conclusions can be further advanced when the problem of sweating is taken into consideration.

In conditions of high ambient temperatures sweating becomes the body's main mechanism of heat loss, achieved through evaporation of sweat from the skin surface. In such working conditions the sweat glands become acclimatised within two weeks such that their liquid output is drastically increased to maintain the body temperature close to normal.

Plastic seals on the earmuffs prevent this sweat from evaporating on a

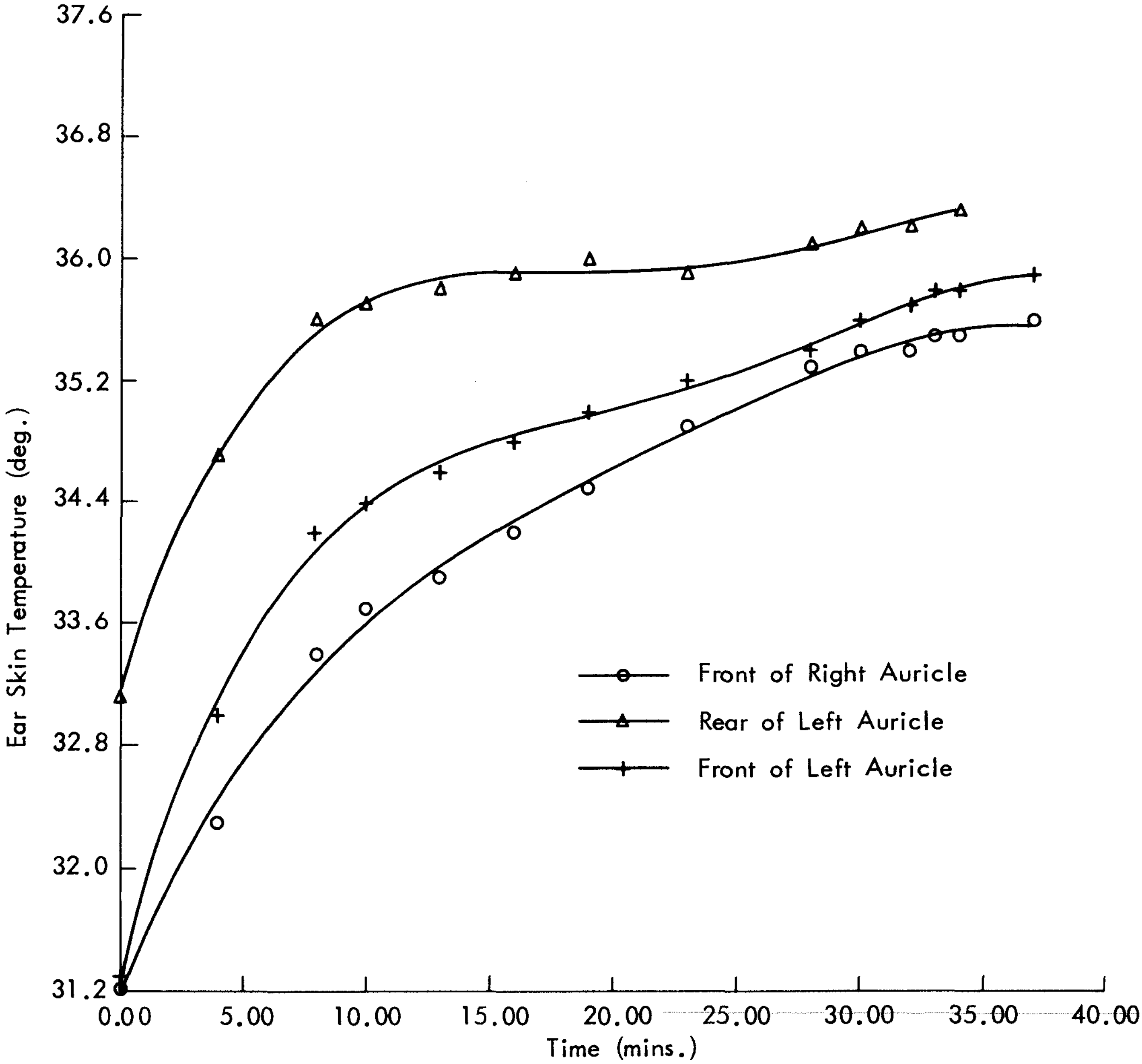


Figure 4.5 The increase in temperature with time at specific points around an ear enclosed by an Amplivox Audiocup type earmuff. Data drawn from Thomas (1975).

significant area of the side of the head, contributing to local heat increases. Moreover the sensation of unevaporated sweat on the skin surface is in itself uncomfortable (Edholm 1967).

Cold as well as warmth can adversely affect the wearer comfort rating of earmuffs, especially if liquid filled earmuff seals are used. In this case employees working in extremely cold environments should not allow their earmuffs to become excessively cooled before use. Although the liquid in the seals would not freeze, the cushions would be unbearably cold when worn. (American Industrial Hygiene Association 1966).

Seal perspiration covers are available which could partially alleviate earmuff discomfort caused by perspiration and cold. These covers will absorb sweat from the surface of the skin and also insulate a cold seal from the side of the face. Heat build-up would still remain a problem.

4.2 Ranking of Comfort Parameters

Arguments developed in earlier sections indicate that the earmuff designer is forced at a very early stage to compromise between acoustic attenuation and comfort. Ranking the physical attributes of earmuffs in order of increasing comfort importance would aid the designer.

Tisserand (1973) undertook this work, calculating correlation coefficients between the comfort ratings and the physical parameters of a range of earmuffs.

The coefficients shown in table 4.5 indicates that the most important parameter controlling wearer comfort is headband stiffness, closely followed by the ability of the cushion to conform to irregularities on the side of the head. However Tisserand states that the coefficient for headband stiffness probably reflects the force of application of the earmuffs to the side of the head, a factor which was judged to be of secondary importance.

The ability of the cushions to conform to the side of the head was shown to be only a little less important than the stiffness of the headband, whilst the average seal pressure on the side of the head was judged to be of only moderate importance. Average seal pressure was calculated by dividing the headband force by the surface area of the seals, but this failed to correlate with the comfort ratings as well as did the parameters describing cushion conformability. This must indicate that most of the earmuff seals used did not distribute pressure evenly over the skin surface, and that a satisfactory comfort rating for an earmuff depends to a large extent on the ability of the protector to avoid developing pressure high spots.

The mass of an earmuff showed the smallest correlation of all with comfort. Tisserand suggests that this occurs because the weight of the protector is much less than that of the head already supported by the neck muscles, and is negligible when compared to the sensation resulting from the force of application of the earshells.

A further explanation for the low correlation between mass and comfort would be that the maximum weight used in the experiment was 125 grams below that shown in section 4.1.1 to be the level above which complaints caused by the weight usually arise (500 grams). As the subjects were asked only to decide if the particular parameter was acceptable or unacceptable in five earmuffs, then the comfort rating of the mass parameter might have been skewed towards the "comfortable" end of the scale for a given earmuff, to such an extent that any potential correlation with mass was reduced. This criticism would not have applied to headband force as the range of protectors tested did encompass the value of 1000 grams shown in section 4.1.2 to be that at which the tension generally becomes unacceptable.

4.3 Conclusions

Table 4.9 show a comparison between the earmuff parameter values recommended within this chapter and those of the two earmuffs most commonly used on the the Wilton site.

It can be seen that the measured headband tensions are close to, or above, the maximum recommended limit, and that this comment applies also to the seal pressure of earmuff B. These observations could explain why a high proportion of interviewed employees participating in the Hearing Conservation study reported in chapter 3 complained of the comfort of their protectors, as shown in figure 3.3(a). Additionally although the two

Table 4.9 A comparison of the two most commonly used earmuffs on the Wilton site with the specifications produced for the British Standards Committee PSS/25, (Karmy 1978) and the standard BS 6344 produced in 1984.

Parameter	Recommended	Specified in BS 6344 1984	Earmuff A	Earmuff B
Maximum weight	400-500 g	400 g	167 g	283 g
Maximum headband force	1000 g	1631 g	970 g	1080g
Maximum seal pressure	30 g/cm^2	40.78 g/cm^2	23.65 g/cm^2	27 g/cm^2
Maximum earshell dimensions. Internal usable dimensions at point of maximum pinnae size:				
width	4.5 cm	3 cm	6.5 cm	7.5 cm
height	8 cm	5 cm	9.7 cm	8.5 cm
depth	2.5 cm	ns	3 cm	3 cm
Minimum earshell adjustment:				
rotation horizontal	15^{o}	$\pm 10^{o}$		
rotation vertical	15^{o}	$+15^{o}$ ($+10^{o}$)* -5^{o} (-10^{o})	35^{o}	25^{o} cone
vertical	3.25 cm	3 cm	5 cm on each side	4 cm on each side
Seal width under reasonable compression	1.5 cm	ns	2 cm	1.5-2.5 cm
Seal Covers	non irritant pliable, non staining	non irritant pliable, non staining	PVC	PVC
Seal fitting	liquid or foam conformable	ns	foam conformable	foam conformable
Head size range to be fitted:				
worn over the head	320-385 mm	320-380 mm**	appeared to give adequate fit to Wilton population	appeared to give adequate fit to Wilton population
worn behind the head	250-300 mm	280-330 mm**		

* Standard specifies $\pm 10^{o}$ rotation. However the planes of origin are such as to equate to the rotation around the vertical shown.

** Graphical derivation from tabular values.

earmuff types appeared to fit the Wilton population, poor fit was also a comfort related problem reported in figure 3.3(a). It is therefore possible that even if the headband appears to fit the contours of the skull, the method of attachment of the earshell to the headband and the resulting design geometry might still give the wearer the impression of a poorly fitting hearing protector.

Table 4.9 shows the earmuff parameter values selected as optimum in sections 4.1.1 to 4.1.5. A summary of the result of the present work was passed to the British Standards Institution Committee PSM/25 and table 4.9 also shows the results of the deliberations of this committee, published as British Standard 6344 (British Standards Institution 1984). Comparisons given in table 4.9 show that many of the findings of the present chapter were adopted.

Use of the information presented in this chapter should permit the selection of an earmuff which will be acceptable to employees, and prevent discomfort from reducing any positive effect which education or programmes of audiometry could have in increasing usage.

CHAPTER 5

THE ATTITUDE QUESTIONNAIRE: DESIGN AND METHODOLOGY

5.0 Introduction

Chapter 2 described the intention to use an attitude questionnaire to monitor the success of the experimental treatments. As gross attitude changes over the experimental period were not expected, it was obvious that great care was needed in the design of the questionnaire, and that a technique should be adopted which allowed for the testing and refinement of the questionnaire before use in the main experiment.

The major choices to be made lay in the decision to use either "interviewer completed" questionnaires, or "self completed" questionnaires sent to employees through the company internal mail systems, and the decision as to the type of questionnaire scaling method to be utilised.

Other factors which required consideration were questionnaire length, exact question wording, and methods of scoring.

Accordingly an appraisal of the literature was completed to ensure that the questionnaire embodied design factors which had been shown to enhance success.

5.1 Postal Versus Interviewer Completed Questionnaire

Field studies have been undertaken to compare the efficiency and possible biases inherent in using either the mail questionnaire or interviewer completed questionnaire. Cannell (1963 and 1968) took this approach and suggested that a respondent may answer quickly rather than accurately when replying to a question posed by an interviewer, a point also emphasised by Ellis (1948). This author also showed that respondents tended to give less radical and more socially acceptable answers to questions presented by an interviewer, than they did when answering the same questions in a postal questionnaire. Frazer (1945) favoured a postal questionnaire for similar reasons, as did Hyman (1954), stating that more extreme, and thus more revealing, responses were to be found in completed postal questionnaires.

However, Sudman (1967) claims that the effect may be restricted only to a subset of the questions, or items, being that requiring a respondee to place himself attitudinally with respect to opinions held by his peer group. This type of question would feature strongly in the proposed research work, and therefore mitigated for the use of postal questionnaires in the main experiment. Hochstim (1967) reinforces the point declaring that the results of a postal questionnaire probably come closer to reflecting the respondents true attitude. It is also of interest to note that Frazen (1945) reported that refusal to reply to a question occurred five times more frequently during surveys conducted using interviewers than was the case in a parallel postal questionnaire.

Furthermore, biases can result from the manner in which different interviewers administer the questionnaire. Moser (1971) comments that dimensions along which interviewers can differ include, honesty, interest in the work, accuracy, adaptability, personality, temperament, intelligence and education. Kish (1962) quantifies the effect as shown in equation 5.1.

$$E = (1 + (k-1)p) \qquad 5.1$$

where E represents the total survey reliability, p equals the proportion of the total variance explained by intra-interviewer variability, and k equals the number of interviews completed by one interviewer. Thus if it was decided as part of the main experiment in the present study to interview a sample of 500 employees distributed between the eight plants, and assuming that the financial resources could be obtained to employ five interviewers, each would conduct 100 interviews. With p set at 0.05, a level found to be typical by Gray (1956) and Kish (1962) equation 5.1 shows that the survey reliability would be degraded by approximately a factor of six. The reliability problem would be further compounded when the 500 interviews were repeated for comparison purposes after the treatment had been completed, as required by the experimental plan.

It was felt that 500 interviews, representing less than one third of the 1716 employees participating in the main experiment, represented the minimum that could be conducted if the research programme was to be concluded successfully. The labour turnover rate was running at 20% per annum throughout the period of the study and would have resulted in only 320 individuals, remaining from the original 500, to be interviewed for the second time after the treatments had been completed. As these 320 employees were distributed amongst 8 plants, it was thought likely that it would be found impossible to conduct the before and after treatment comparison of attitudes on each plant, with sufficient statistical power.

This problem could be avoided by the use of postal questionnaires to take a census of attitudes from every employee participating in the study.

In view of the arguments presented above, it was decided to measure employee attitudes using a postal questionnaire.

5.2 Scaling Techniques

Karlton(1978) discusses the substantial effect which the exact wording of a question has upon the response. He emphasises that questions designed to elicit opinions are the most vulnerable in this respect, especially when the views of the subject are not fully crystalised. However, when several questions are combined together to form a scale, or attitude measuring group, the overall reliability of the measure is increased, with the effects of individual question idiosycrasies tending to cancel out.

Fishbein (1975) discusses the three classical scaling methods, Guttman scaling (Guttman 1944), Thurstone scaling (Thurstone 1929) and Likert scaling (Likert 1932). It is evident from the review produced by Fishbein, that the choice of scale influences the type of analysis which can be undertaken on the data, the amount of developmental work necessary, and the inferences which can be drawn from the final results. Section 5.2.1 describes briefly each of these scaling methods, and justifies the final choice of Likert scaling.

5.2.1. Guttman, Thurstone and Likert scales

Guttman scales are cummulative in nature in that they are comprised of questions which become progressively more extreme. Scores are calculated by awarding a point for each statement with which the respondent agrees. In a perfectly constructed Guttman scale, therefore, the pattern of the response of an employee can be deduced from his total score. A coefficient of reproductability can be calculated to assess the degree to which the actual scale approaches this ideal model, and in addition, the extent to which the scale is measuring one attitude dimension. A well refined scale would measure only one dimension, or one aspect of the employee's attitude towards, in this particular case, hearing conservation measures.

Shaw (1967) states that Guttman scales are both reliable in that they exhibit excellent repeatability, and valid in that they do provide a measure along the desired attitude continuum. However, Oppenheim (1968) criticises the use of the reproductability coefficient in defining the purity of the scale, and points out that the result of the Guttman scaling procedure can be a single scale which covers only a very narrow field of interest. Significantly, the scaling technique is laborious, and requires to be repeated on several large samples of respondents to check that a particular scale did not arise by chance. Additionally , Shaw (1967) suggests that a given set of items may scale in one population, but may not perform similarly for a second.

Likert scales, however, are less susceptible to this problem, and can be developed more easily than Guttman scales, thus facilitating the production of many scales exploring various attitude dimensions. A Likert scale is characterised by five categories of permitted response, these being "Agree strongly", "Agree", "Neither Agree nor Disagree", "Disagree", and "Disagree strongly". As scores can be awarded for each of these categories, Likert scales allow a certain amount of useful analysis to be performed on a single item on the questionnaire.

McKennell (1974) discusses the use of factor or cluster analysis to examine the correlation between the item scores, and thus group the questions into unidimensional scales. High scale reliabilities can be obtained using a question rejection method based upon the calculation of Cronbach's "alpha coefficient" as described in chapter 6.

The validity of the Likert scales is generally assessed by examination of the final scale content, and the method used to select the items. Matell (1971) judges the validity of Likert scales to be good.

Both Likert and Guttman scales are ordinal in nature, in that the attitudinal "distance" between "Agree" and "Agree strongly", in the case of Likert scales, is unmeasured although arbitrarily defined mathematically by the scoring system used. This makes statistical analysis of the questionnaire results conceptually difficult.

Thurstone (1929) developed a scaling technique intended to overcome this problem. As described below, an effort is made to ensure that the items, which require a response of either "yes" or "no" are spaced at equal intervals along a particular attitude continuum. During the scale development procedure a panel of judges is required to place the items in groups spaced at equal intervals along a continuum running from an unfavourable to a favourable attitude towards the particular topic. The selection of items for inclusion in the scale, and their final positions, is made on the basis of the frequency with which the particular items appear in the various groups. Green (1954) gives an account of the mathematical model underlying this technique, and Fishbein (1975) describes the practical scaling procedure.

Thurstone scaling, however, offers no direct method by which the scale can be checked for unidimensionality, and therefore was thought in the context of the present study to offer only a blunt tool for the exploration of attitude structures.

Thurstone scales do appear to offer a more rigorous approach to the problem of scale metric but in practice demonstrate intervals which only appear to be spaced along the scale at equal intervals, as dictated by a panel of judges. It is possible that Likert scale scores could be manipulated to impose a psuedo-metric base upon the scale. This could be achieved by transforming the scores to a standard score format, and utilising measures involving the standard deviation of the scores.

However, McKennel (1978) would regard this procedure as being unnecessary and argues strongly in favour of the acceptance of the Likert scale as a metric measure, a sentiment endorsed by Stevens (1968). This author comments "Even the main preponents of fundamental measurement have not been entirely consistent in their belief that rigorous definition of the basic metric will make a substantive difference". They grant, for instance, that the interval scale assumption underlying the continued use of strong measurement models are "sustained in large measure by the pragmatic usefulness of the result obtained". Furthermore Coombs (1964) states "... these results (from fully metric scales) are usually not very different from, or at least not in conflict with, the results which would have been obtained with a weaker model anyway."

Tufte (1969) also comments on this matter, "The distinction between interval and ordinal measurement is usually of little importance in data analysis. The wise assignment of numbers to ordered categories coupled with the use of techniques that exploit the properties of numbers is generally preferable to working with ordered categories". Most importantly it has been shown that scales constructed according to the Likert technique will exhibit a higher coefficient of reliability with fewer items than scales developed according to the Thurstone method. Moreover, despite the apparent difference in base metric, scores achieved on parallel Likert and Thurstone scales appear comparable (Edwards 1946).

Likert scales also offer more elegant development procedures than either Guttman or Thurstone scales. Large item numbers make Guttman scales difficult to develop, whilst Thurstone scales require large panels of judges. Nunnally (1959) recommends panel sizes up to several hundred, whilst Oppenheim (1948) sets a minimum size of 40. Green (1954) also strongly recommends that the judges be drawn from a population similar to that in which the final survey is to be performed, a procedure which could offer some difficulties in the context of the present research programme undertaken on industrial employees.

In summary therefore, it would appear that the Likert scaling procedure would be the most appropriate for use in this research programme.

5.2.2 Scale neutral point

The choice of Likert scales is further justified when consideration is made of the scale neutral point, this being the scale rating at which the response is neither positive nor negative towards the topic under consideration. This does not always occur at the numerical center point of the scale. Knowledge of the neutral point is valuable in studies such as the present research programme, in which an attempt as being made to change attitudes. With a clearly defined neutral point the concept of positive and negative attitudes takes on a meaning. Additionally, any attitude changes caused can be evaluated in the light of whether or not they were originally positive attitudes or negative attitudes.

If Thurstone or Guttman scales are used, the scale centre point can be defined using a method of intensities (Suchman 1950), whereby a respondent, on each occasion on which he endorses an item, is required to indicate the intensity with which he holds this opinion.

Relating the item scores to the intensity of conviction will yield a 'U' shaped curve, with the minimum at the scale neutral point. However, the use of this method doubles the number of questions in the questionnaire, either at the pilot development stage or at the main survey stage. Each item requires an associated "intensity" question. In contrast, the Likert scaling method is more economical in that each item is already associated with a list of intensity alternatives for endorsement by the respondent, these being "Agree strongly, "Agree", "Neither agree nor disagree", "Disagree" and "Disagree strongly". Thus it is possible to identify the neutral point of an item, this being the "Neither agree nor disagree" (NAD) category and possibly the neutral point of the entire scale (Green 1954) although this is more difficult to assess.

If a score of 3 is awarded to the NAD item response, and the scale consists of 5 items, then a scale score of 15 (3x5) is not necessarily the neutral scale score, as a score of 15 can be achieved by several different permutations of non neutral responses to the items.

More importantly, however, Likert scales can be developed so as to be unidimensional. This topic will be developed further in chapter 6, where it will be shown that through the use of a technique known as factor analysis, the scales can be constructed so as to be unidimensional, and highly homogeneous after refining using a parameter known as Cronbach's alpha. As a result of these constructional techniques it is likely that a respondent will score similarly on each item of the scale, and hence the NAD score multiplied by the number of items in the scale should give a reasonable estimate of the scale neutral point.

5.3 Construction of the attitude questionnaire

5.3.1 Selection of the attitude questions.

Following a strategy recommended by McKennell (1974) six informal interviews were conducted with employees from several noisy areas within the site under study. These inverview were tape recorded, with the employee's permission. Statements of opinion on hearing conservation mattters, as articulated by the employees, were later taken from the recordings. This method was used to ensure that the author did not force his concept of the attitude framework upon the survey population by generating biased or unrealistic items. Moreover, the recordings helped to ensure that the items in the questionnaire were couched in terms which were familiar to the employee.

Avoidance of alien phraseology is important, as the presence of unfamilair terms in an attitude statement may cause a respondent to stop and think carefully before answering. This can change the attitude recorded from that which the respondent holds to that which he feels that he ought to hold. In assembling the attitude questionnaire items it was recognised that many statements would be included which would not bear analytical enquiry into their exact meaning, but that respondents would automatically give the question that meaning which was prevalent in that area at that time (Oppenheim 1968). Additionally the interview method of gathering attitude items gave the author a better insight into the meaning of particular items. Finally the informal intervew reduced the possibility of a complete area of interest being overlooked in the preparation of the questionnaire.

Edwards (1957), Oppenheim (1968) and Moser (1971) discuss the type of items to be included in a Likert scale. Their philosophies are embodied in the discussion given below.

Care was taken to ensure that complex items did not appear in the questionnaire. Conditional questions are not advisable in an attitude questionnaire, such as a requirement that the respondent should "answer question 6 if the answer to question 5 or question 3(a) had been "yes" or "sometimes"". Moser in particular stresses that postal questionnaires will only be successful if the questions are straightforward, and when judgement is not required to decide upon what consitutes a full answer. Again, this requirement justifies the choice of Likert scaling for use in the research programme, as Likert items are clear in meaning.

Ambiguous items were avoided, as were opinion statements which were vague or very similar in wording. The latter, if present in the questionnaire, could cause spuriously high levels of item intercorrelation. To prevent the respondent from falling into a simple response rythmn, approximately half the items were worded such that they required a positive response for a favourable reply, whilst the other half required a negative response for a favourable reply.

As the final attitude questionnaire would be required to discriminate between attitudes held by preselected groups of employees, in general items which appeared neutral in nature were avoided, as were items expressing extreme views, again because these items would have lacked discrimatory power. Approximately equal numbers of questions were allowed for each topic under investigation.

The final item set was compiled into a pilot questionnaire, with seemingly related items being placed in close proximity to one another to facilitate continuity of thought on the part of the respondent. This pilot questionnaire was dispatched to a sample of employees on the Wilton site, and the returns subjected to the item analysis method described in chapter 6. The developmental work on the pilot questionnaire to derive the final attitude questionnaire is discussed fully in chapter 7.

5.3.2 Item scoring procedures

A Likert scale consists of a group of questions, or items, which are associated by the fact that they all measure a respondents position along the same attitude continuum. The method by which the scale grouping is established is discussed in chapter 6. Each item exhibits five possible categories of response ranging from "Strongly Disagree" to "Strongly Agree" as described in section 5.2.1. Other numbers of response categories from 3 to 7, have been used with Likert scales with no appreciable benefit. (Moser 1971). Matell (1971) completed a study upon the optimum number of response categories and concluded that both the relability and valdity of the scales constructed were independent of the number of scale points used.

The most favourable item response with regard to the objectives of the research programme, was awarded a score of 5, with the least favourable response being score 1. The scale score for any respondent was the sum of all the item scores included in the scale.

Theoretically, each item score in a scale should be weighted by the value of its intercorrelation with the other items of that scale. The reasons for this procedure can be seen in chapter 6, where the conceptual model of the "attitude space" is reviewed. However, as has been stated by McKennell (1977) and shown by Richardson (1941) and Likert (1932), little benefit is obtained from the introduction of fractional weights in the scoring procedure if the range of possible weights is small, and the correlations between the scale items are positive. These conditions applied to the results of the present study, as is seen in chapter 7, and justified the decision not to use fractional weights in the scoring system.

5.4 Response to Postal Questionnaires

5.4.1 Non-response

The main problem with postal questionnaires is the size of the non -response. A lively discussion exists in the literature, debating the possible biases which non-response can introduce into the survey results. A review of the literature on postal questionnaires and the biasing effects of non-response upon the results is provided by Scott (1961). He presents studies which have sought to identify the characteristics of the non -respondent population, and studies which have also attempted to estimate the biases introduced into the final results due to the lack of data from the non-respondents. Scott concludes that only one descriptor of the non-respondent population has revealed itself consistantly enough to be classifed as established, and that is the level of education. This is not an important parameter in the present study, as there is little reason to suspect that the weekly paid employees on the Wilton site are not educationally homogeneous, in terms of the broad classification suggested by Scott. The present study is also protected from a non-response bias in that it is designed to evaluate change in attitude as defined by the pre-treatment and post-treatment despatches of the attitude questionnaires. It is not unreasonable to assume that in the main those individuals not responding to the pre-treatment questionnaire would also not respond to the post-treatment questionnaire, thus leaving unaltered the extent of any plant attitude change, at least in that portion of the population responding.

However, Scott does state that for a given variable the final total population results can be estimated by a process of extrapolation from the trend noted as returns are obtained over a period of time from employees successively more reluctant to complete the questionnaire, but encouraged to do so by a series of prompts such as the ones employed in this study and described in section 5.4.2. Successive incoming questionnaire "waves" from the test population caused by these prompts can give the basis for the extrapolation.

Scott also examines the case for "within wave" extrapolation and "between wave" extrapolation to remove non-response bias, and concludes that the latter is more successful than the former. However, he states, "As to the extrapolation hypothesis, linear extrapolation of either the within wave or the between wave trend in the manner described appears to bring advantage more often than not. Clearly the hypothesis is not so well substantiated as to provide a reliable test of the presence or absence of a non-response bias, on the other hand, if results must be used from a survey whose reponse rate is modest, the surveyor will probably be wise to estimate the population figure by extrapolation of the early/late bias; the estimate should improve the accuracy of the survey results more often than not".

Hochstim (1967), who also undertook multi-wave questionnaire surveys, also concluded that it was reasonable to use a between wave extrapolative technique to reduce the biasing effect of non-response.

Interestingly, Donald (1960) showed that the more highly a subject was involved with the topic under investigation, the more likely he was to respond to the questionnaire, and to respond favourably. This effect was especially marked for attitudinal data. There exists some indication that a proportion of the non-respondents usually consists of a group of people who feel that the topic of the survey does not involve them but if pressed for a response would give a relatively favourable reply.

Non-reponse also occurs when interviewers are used to complete surveys. Potential respondents may refuse to cooperate, be persistently unavailable, ill, on holiday or in the case of industrial surveys, have exchanged shifts with a colleague, be taking time off in lieu of extra hours worked, be on a rest day, or refuse to be interviewed without a union representative present.

Hochstim (1967) investigated the difference in the size of the returns achieved in parallel mail, telephone and interviewer surveys. He concluded that providing persistent attempts are made to persuade a subject either to complete his questionnaire, or cooperate with an interviewer, then there will be no practical difference in the size of the returns obtained from these three types of survey.

5.4.2 Techniques used to increase the response to questionnaires

Scott (1961) lists eight points which appear to influence the return of postal questionnaires. Only seven were relevant to the present study and are shown below. Point 1 is the only technique which was shown by Scott to have a large effect. However, concepts were drawn from all seven to enhance the return of the questionnaires used in the present study.

1. The follow-up of persons not responding.

2. The presence or absence of particular questions.

3. Official sponsorship.

4. Special delivery or airmail for the outgoing questionnaires.

5. Handwritten postscript on the covering letter urging a reply.

6. A letter on the back of the questionnaire instead of a separate letter.

7. A small payment as an incentive for the return of the questionnaire.

Each of these points is discussed below.

One reminder letter and a questionnaire were sent to employees who had not responded to the pre-treatment questionnaire approximately three weeks after the initial despatch. No further reminder letters were sent, to avoid alienating employees at this very early stage of the research programme. The possibility that this could occur was evidenced from comments made by a proportion of the employees receiving the reminder letter. These ranged from comments concerning the right of a respondent to refuse to reply to a questionnaire, through remarks on the supposed anonymity of the respondents, to the reactions of employees who tore the code number off the questionnaire before returning the document. It was essential at the beginning of the programme that the initial cooperation of site employees and Unions be maintained, and that the project as a whole be permitted to remain in low profile. Hence it was judged unwise to press non respondents further. However, these restraints did not apply during the final round of attitude questionnaires, dispatched after the treatments had been completed. Accordingly the post treatment questionnaire and letter were followed by two reminder letters and questionnaires, spaced approximately two to three weeks apart. These were then followed by an article published in the site newspaper, designed to encourage the completion of the questionnaires. The article was followed in turn by the dispatch of a special, shortened version of the questionnaire to the persistent non respondents. The use of follow up questionnaires and letters produced a substantial increase in the size of the overall response to both the pre-treatment and the post-treatment attitude questionnaires as described later.

The possible effect of the presence, or absence of particular questions upon the overall size of the response, was tested by means of the pilot questionniare used to develop the main questionniare. Apart from a few small exceptions, all the questions used in the research programme were present in the large pilot questionnaire. As the response to this questionnaire at 93% can only be related as excellent, it can be concluded that none of the questions were sufficiently contentious to discourage a reply. Using similar reasoning it would also appear that employees found the questionnaire sufficiently interesting to motivate them to reply.

However, it was decided to design the pre-treatment and post-treatment questionnaires to be shorter than the pilot, to decrease the possibility of interest in the questionnaire being outweighed by the time and effort needed to complete it.

The official standing of the organisation sponsoring the research was identified in Scott (1961) as being important to the size of the final response achieved. Filipello (1958) achieved significantly higher success in his attempts to recruit a panel for wine tasting by mail, when he quoted a University as his sponsor, than he did when his letter stated that the Wine Advisory Board was the supporting organisation. Similar findings have been reported by Watson (1937) and the National Education Association (1930).

Accordingly it was decided to stress the involvement of the University of Southampton in any communication with employees instead of using the company name. The extent to which this strategy was successful would be tested in the main attitude questionnaire itself by means of a few specific questions to employees on this topic.

Delivery of the questionnaires was made through the internal postal system to employees, who usually received the letter from the hands of the foreman or shift clerk. Returnable envelopes were used, in all cases except the final reminder letters for the post-treatment attitude questionnaires. White foolscap envelopes were provided for this final wave of questionnaires, dispatched after the newspaper article had appeared in the "Wilton News". Two envelopes per questionnaire were used. These were specially printed with the University crest, and the name of the Department. One envelope contained within the first, was printed with the address to which the questionnaire was to be returned. Additionally an attempt was made to increase the importance in the eyes of the employee of the post treatment questionnaire returns at the stage of final follow up, by delivering personally to each plant the boxes of questionnaires and follow up letters. A short discussion was also held with each foreman as to the importance of the work, and the necessity for a high total return. It was requested that this message be passed on to the employees.

The colour of the questionnaires is a factor considered by Scott (1961) to be the subject of insufficient research. However, Bender (1957) and Dunlap (1950) performed studies in the area and report results which, although somewhat inconclusive, show some evidence that the order of preference of colour in terms of maximising the response is yellow, blue, white and "cherry". For this reason, questionnaires printed on yellow paper were used in the last reminder dispatch of the post-treatment attitude questionnaires.

The use of a handwritten postscript urging a reply on the letter accompanying a questionnaire, as recommended by Scott (1961) was not thought to be feasible in the light of the number of questionnaires being dispatched at any time. The content, rather than the form of the accompanying letter would appear to be a significant factor in increasing the questionnaire returns. Sirken (1960) reports greater success with the use of a brisk, firm letter than with a more informal version. Following the research findings of Filipello (1958) and Clausen (1947), the several letters used in the attitude questionnaire waves were relatively simple in content, reasonably forthright, and contained information as to why the questionnaires had been despatched and the usefulness of the information which was requested. The letters were signed by the author. However, in the case of the second reminder letter of the final round of attitude questionnaires, the Divisional Medical Officer signed the letter, which was produced with a Wilton Medical Centre letterhead as a device to inject a new factor which could encourage returns of the questionnaires.

The final two recommendations for increasing the response level of a postal questionnaire listed earlier were: the use of incentives, and the printing of the letter accompanying a questionnaire on the rear of the questionnaire itself. Owing to the lack of available space in previous questionnaires it was only possible to position the letter on the reverse of the questionnaire in the last round of attitude questionnaires.

The concept of using some form of incentive to increase the final questionnaire response was considered on two occassions during the research programme. The author initially recommended that a sum of 50 pence be offered for each completed return. The Senior Shop Stewards committee objected, feeling that their members should cooperate for more philanthropic reasons. Moreover both management and unions saw this strategy as setting an unwelcome precedent, which could affect future industrial safety excercises on the site.

The question of a financial incentive was also raised when methods were being considered for raising the number of returns from the final round of post-treatment attitude questionnaires. It was suggested that each employee returning a questionnaire should be entered in a lottery for a £50 prize. However, this strategy was not implemented, as the ICI Medical Department did not feel that it was in keeping with company policy.

5.5 Coding and questionnaire administration

The scale of the research programme, which embraced approximately 2000 employees over a three year period, necessitated the use of computer databases. These were needed, for example, to monitor the despatch of the pre-and post-treatment questionnaires, and the pilot questionnaires, with computer records being kept of those employees who had returned questionnaires, and those who were to be sent reminder letters. The data bases were also needed to administer employee appointments for audiometric tests. Additionally computer databases were required for the acceptance of incoming questionnaire data, and the subsequent large scale analysis. Computer programmes were written to print address labels to faciltate the large scale despatch of questionnaires.

Much time and effort was expended in developing these computerised adminsitration facilities, necessary because of the scale of the research.

As employee attitudes were to be monitored for change occurring over the experimental period, it was necessary to give each individual a unique code number which would allow his pre-treatment and post-treatment attitude questionnaires to be linked. The code numbers were also used as identifiers on the questionnaires in the place of names. The list linking names to code numbers was kept in secure conditions, allowing employees to return the questionnaires, in the first instance, to the site medical centre in the knowledge that their responses were confidential.

It became apparent, as the survey progressed, that some employees realised that their names could eventually be linked to their questionnaires. This was especially noticeable to an employee when he received a reminder letter because he had not returned the original questionnaire. This lack of anonymity could have deterred some employees from completing the questionnaires. Hoppe (1952) and Mitchell (1939) state that lack of anonymity will not deter private individuals from responding to a questionnaire, but that it does have an effect upon the response obtained from business companies. This trend can obviously be extended to employee's working within a company. Empirical evidence for this statement comes from the fact that certain employees in the study obliterated the code numbers from the questionnaires before return. Employees also expressed anxiety over whether or not the company was using the questionnaires to discover potential "troublemakers".

Several elegant methods for maintaining anonymity have been suggested by Larson (1959) and Rollins (1940) amongst others. Unfortunately, as it was required to compare the attitudes of employees before and after they had been exposed to the experimental treatments, each document sent to the employee would of necessity have to bear some identification. The presence of this code number belied any declaration of questionnaire anonymity made by the author even if in fact the coding key and the individual attitude questionnaires were never seen by the same person. It was beyond the resources of the research programme to use a technique of disguising the code number within the questionnaire script. As the only other practical alternative; every opportunity was taken to stress the confidentiality of the questionnaire exercises.

5.6 Conclusions

After consideration of the various factors which influence the success of postal questionnaires and those completed by an interviewer it was decided that more accurate results could be obtained using the former technique. A certain non-response was expected, which would probably bias the results slightly towards the more favourable side of any attitude continuum. Consideration would be given to using between-wave extrapolation to compensate for this small bias if examination of the variable values noted during successive return waves suggested that a bias might exist.

The literature was reviewed in order to select the most appropriate and elegant scaling technique for use in the attitude survey. This was found to be Likert scaling used in conjunction with factor and cluster analysis, and Cronbach's alpha further discussed in chapter 6. The argument that the lack of a sufficiently strong metric hinders the utilisation of Likert scales was dismissed, and the intensity scaling inherent in Likert scales was thought valuable in ascertaining the scale neutral point.

The initial pool of attitude statements were obtained after analysis of tape-recorded interviews. Care was taken over the wording of the items which appeared in the questionnaire. In order to increase the discrimination of the questionnaire, non-neutral items were used in the attitude inventory, but extreme items were excluded. Approximately half the questions were worded in an attitudinally positive manner, whilst the remainder were in a negative format. These items were compiled into a pilot questionnaire which was to be dispatched to a sample of employees. Chapter 7 describes this exercise and the subsequent questionnaire analysis and refinement. Items were scored on a simple unweighted basis, in accordance with the five possible categories of response.

Several techniques were used to increase the total response to all the attitude quesitonnaire returns. These included up to three reminder letters, an article in the site newspaper, the special printing of envelopes, a shortened version of the questionnaire printed on yellow paper, the stressing of University sponsorship, special delivery of the attitude questionnaires and careful consideration of the inventory content. Care was also taken to stress the confidentiality of all research programme exercises in order to reduce problems likely to occur due to the apparent lack of questionnaire anonymity. The follow-up procedures were pursued less vigorously in the first round of attitude questionnaires than in the second, as it was necessary to maintain the cooperation of employees at least at the beginning of the programme, and to keep the research programme in "low profile".

CHAPTER 6

ANALYSIS OF THE ATTITUDE QUESTIONNAIRES

6.0 Introduction

As stated in section 2.3.2, one of the objectives of the treatments used in the main experiment was to change employee attitudes towards hearing conservation matters. It was therefore necessary to develop attitude questionnaires to monitor any such changes. Refinement of the attitude questionnaires was completed using a statistical technique known as factor analysis.

Although pioneered early in the 20th Century, (Spearman 1904, 1932) the method has only recently become attractive with the availability of large computing power necessary for the efficient handling of very large matrices, and the iterative solution of lengthy equations.

This chapter justifies the selection of the type of factor analysis used, and the addition of a further refinement, cluster analysis, to the analytical methodology.

The objective of the factor and cluster analyses of the questionnaire data is to define the attitude dimensions underlying the views held by employees on the topics of noise, industrial deafness and hearing conservation procedures. These dimensions are mapped using attitude scales, or groups of questions, defined by the factor and cluster analyses. The scales permit the position of an individual along an attitude dimension to be measured.

The statistical reliability of the attitude scales generated can also be assessed, and the use of Cronbachs "alpha" coefficient to optimise the length of a scale is discussed.

The development of the attitude scales was undertaken using data obtained from the pilot attitude questionnaire, described in chapter 7.

6.1 The concept of the attitude questionnaire

Specificity of attitude measurement was required of the attitude questionnaire, for the research plan demanded that a comparison be made of attitudes held before and after the plant treatments were undertaken. It was expected that the attitude changes would be small, and that they would occur across only certain facets of the general attitude dimension covering employee reaction to noise.

Using methods dependent upon the intercorrelation of scores achieved on questions, or items, large numbers of items in a questionnaire covering the "universe of content" or all reasonable questions on the topic, can be reduced to manageable proportions. The number of items can be condensed to a much smaller number of variables which are more easily interpreted, and grouped into subsets or scales.

Optimally each scale should provide a measure along a particular attitude dimension, or facet of the overall general attitude towards industrial noise, and each scale should be orthogonal to the remainder. In practice this is unlikely to happen, and scales will tend to overlap, or interact, to a degree. It is useful to measure this common conceptual area of interaction between scales. If a large common conceptual area can be observed then it can be assumed that the various scales are measuring aspects of the same idea. The presence of two sizeable conceptual areas each relating only to one subset of the attitude dimensions defined by item analysis would tend to indicate that perhaps more than one basic concept was under investigation, and corresponding care would have to be taken in identifying each of the various attitude dimensions. The method chosen for use in the present research study allowed the size of the common conceptual area to be measured.

6.2 Factor analysis

The starting point for a factor analysis, is usually a correlation or covariance matrix. If interest is centred on the relationship between the 'n' observations of the 'p' variables, or in the present case, the relationship between the 'n' individuals completing the questionnaire, then the correlation coefficients are calculated accordingly and the factor analysis is known as 'Q' type. In the present research, however, the analysis is directed towards the relationship between the 'p' variables, or questions. This variant of factor analysis is known as 'R' type and commences from a pxp correlation matrix.

It is possible to represent such matrices in multi-dimensional space. If the variables, or items, described by the correlation matrix are perfectly inter-correlated, that is the variation of any one item can be completely described by a weighted combination of the variance of other items, then the items can be represented by a unit vector in the multi-dimensional space, with the cosine of the angle between any two such item vectors representing the correlation between the two items. The rank of the original matrix represents the number of dimensions necessary to represent correctly the angular relationships between all the item vectors.

Factor analysis then seeks to construct a small set of unit length orthogonal factor vectors in the item space, such that each of the original item vectors can be described in terms of the projection that it has upon each of the new factor vectors. The projection of the item vector upon the factor vector represents the correlation between these two vectors, and is known as the factor loading. The square of the loading of an item on a factor gives the percentage of the total variance of the item accounted for by the factor. The first factor vector is constructed so as to account for as much of the variance of all the items in the item space, as is possible. The second factor vector is then projected orthogonally to the first, and accounts for a smaller proportion of the total item variance. This is the case for successive orthogonal vectors. Factor extraction is terminated when, in the eyes of the analyst, the existing factors account for an acceptable proportion of the total variance. Oblique rather than orthogonal solutions are possible, but are discussed in section 6.2.4.

6.2.1 The factor model

Each item can now be described by the loading it has upon the various factors, as shown by equation 6.1

$$p_j = b_{j1}F_1 + b_{j2}F_2 + \ldots + b_{jm}F_m + d_jS_j + C_je_j \qquad 6.1$$

where p = number of items

m = number of factors

j = 1,2, ... p

p_j = Variable j, normalised

F_m = Factor m

S_j = Specific factor for variable j

d_j = The loading of p_j on S_j

b_{jm} = The loading of p_j on F_m

e_j = The error term

C_j = The error loading.

The existence of the specific factor, S_j, is based on the assumption which sets the method of factor analysis chosen for use in this study (classical factor analysis) apart from the other major branch of factor analysis: principal components analysis. Equation 6.1 shows that the variation in an item response is caused by a number of (orthogonal) factors which are common to one or more of the other items plus one factor (S_j) which is specific to that item alone. As the specific factor affects only that item with which it is associated, then it can be considered to be orthogonal to each of the other specific factors influencing the remaining items, and the common factors.

The assumption of the existance of both specificity, and trends or attitudes which underlie the data accords with the concepts behind the present research study more closely than those concepts behind principal component analysis. This serves simply to decompose a given variable into a new set of linear variables, without making any assumptions concerning the causation of the data. This results in the terms of d_jS_j and e_j being removed from equation 6.1.

Principal component analysis starts from the item correlation matrix, whilst classical factor analysis starts from an item correlation matrix in which the main diagonal has been replaced by the item communalities. Item communalities are defined as follows.

The square of the factor loading (correlation) of an item upon any given factor represents the amount of variance of the item controlled by that factor. The question of factor defining items is raised later, but in the final solution, an item should load higher upon one of the factors than any of the others in the set, this being the defining factor for this item. However, all items load on all factors, to a greater or lesser extent. The square of the loading of an item on a factor shows the variance which that item holds in common with the factor, and by inference, with the rest of the items in that set, through that factor. It therefore follows that the sum of the squares of the loadings of an item on all the factors shows the amount of variance which that item holds in common with the factor set, and indicates the strength of the relationship of the item with the rest of the items in the set. This sum is known as the item communality $(h_j)^2$ and is expressed in equation 6.2.

$$h_j^2 = (b_{j1})^2 + (b_{j2})^2 \ldots (b_{jm})^2 \ldots \qquad 6.2$$

It was concluded in section 6.1 that the objective of the scale construction excercises was to derive a series of specific attitude scales, linked to a common concept (or general attitude). It therefore follows that items retained for use in the attitude scaling procedure should have adequate communalities, as this would indicate that they hold a large part of their covariance in common with other items in the set, and hence are exploring aspects of the same underlying concept.

By replacing the main diagonal of the correlation matrix with item communalities, as described earlier, classical factor analysis seeks to manipulate only the relationships between the items and hence define the underlying attitude concepts linking the items. This approach is now gaining acceptance, over the older practice of allowing the elements along the main diagonal of the correlation matrix to remain at unity. (Tatsuoka 1971). Furthermore the use of communalities in the main diagonal of the correlation matrix guards against the artificial inflation of the factor loadings which was noted by Nunnally (1970) when the elements of the main diagonal of the correlation matrix remain at unity, and the factor analysis is performed on a small number of items, as was the case for one analysis performed as part of the present research programme and described in chapter 8, when the concept of global attitude is discussed.

As the communality of an item will only be known when the factor solution has been obtained, the final factor solution is approached by a series of iterations, starting with an estimate of item communality. Newly calculated communalities replace the old at each revolution of the iteration until the difference between two consecutive estimates of item communality becomes sufficiently small. (Wrigley 1956). It was thought reasonable to stop the iterations in the present study when the difference between successive estimates dropped to 0.001, i.e. a change of only 0.1% of the variance explained.

Obtaining an initial estimate of item communality is the subject of debate. The upper bound for item communality is 1.0. The lower bound has been shown to be the squared multiple correlation of the item with the rest of the items in the total set. (Dwyer 1939).

Wrigley (1957) favours the use of the squared multiple correlation as an initial estimate of item communality, as this parameter measures the common variance of the items, and provides a good starting point for the iterations. It is this value which is used as the starting point of the factor analysis described in this thesis.

6.2.2 The extraction of factors

Kendall (1950) stresses the importance of the criterion to be used for terminating the extraction of factors.

The square of the factor loading (correlation) of an item upon any given factor represents the amount of variance of the item controlled by that factor. The sum of the squares of all the item loadings on a single factor equals, therefore, the amount of variance controlled by that factor.

$$\sigma_{F1}^{2} = (b_{j1})^{2} + (b_{(j+1)1})^{2} \ldots (b_{p1})^{2} \qquad 6.3$$

The above equation calculates the variance explained by the first factor. This quantity is known as the eigenvalue for factor 1. As each variable in equation 6.3 is normalised, the total variance of each item equals 1.0. It was decided, for the purpose of this study, to terminate the extraction of factors when the eigenvalue of a late factor fell below the variance to be expected from a single item, that is 1.0 (Kaiser 1960).

Other criteria for halting the extraction of factors can be used: one such, ascribed to Barlett, is described in Lawley (1963) and involves extracting one factor from a correlation matrix expected to hold x factors, and then checking if the variance ascribed to each of the remaining (x-1) is equal. If this is not the case, then a further factor can be extracted, and so on. Child (1970) describes a test developed by Cattell, known as the "scree-test" which requires that the eigenvalues of successively extracted factors be plotted linearly, factor extraction halting when the slope of this function approaches zero. However, none of these tests, including others described by Burt (1952) hold any real advantage over the end criterion of a unity eigenvalue, and some possess positive disadvantages such as Barlett's test which strictly should only be applied to random samples; and therefore was not truly applicable to the data in the present study.

The decision as to when to stop factor extraction is important, as the factor loading pattern will depend upon the number of factors extracted. Davis (Economic and Social Research Institute 1980) stresses that application of the unity eigenvalue criterion should not be performed mechanically; factor analysis is a tool to be used to explore data structures and should be used flexibly.

6.2.3 Factor rotation

Lawley (1963) discusses the uniqueness of a factor solution, and shows that the mathematical parameters of any given correlation matrix do not define absolutely the position of the derived factor vectors in the 'n' dimensional space, providing that more than one factor exists. An infinite number of factor solutions can be derived from the same correlation matrix, each with equal statistical validity. The primary factor solution derived is unique only in that the variance explained by the first factor is maximised. If all the items load substantially upon the first factor in the primary solution, then the items share a large common conceptual area, a useful check on the overall validity of the questionnaire design.

As an infinite number of equally valid factor solutions exist for a given correlation matrix, it is possible to rotate the initial factor system in the (n) dimensional space, and thus change the pattern of item loadings upon the factors. The purpose of rotation is to produce a set of factors which are meaningful, in that it is possible to identify the dimensions which the factors represent by considering the pattern of item loadings upon the factors.

Cattell (1944) lists a series of qualitative criteria for use in ascertaining the point at which rotation is to cease. However, for the purposes of this study, criteria developed by Thurstone (1947) were preferred in view of their more quantitative nature. Adopting the Thurstone criteria ensures, as far as the data will permit, that each item does not load upon all the factors, that more than one item loads upon each factor, and that each item loads upon a different combination of factors (Frutchter 1954). The rotational technique which appears to result in the most satisfactory approximation to Thurstone's "simple structure" in the rotated matrix, is known as "Varimax".

Kaiser (1958) describes this technique in detail, and compares it with a second method of rotation, "Quartimax". In his argument Kaiser shows that the Varimax rotational solution may be biased unduly by test items with high communalities. A modified Varimax technique is suggested, which removes this bias. The concept, known as "Kaiser Normalisation", was adopted for use in the analyses in the present study.

6.2.4 <u>Orthogonal and oblique solultions</u>

Discussion has been centred around the use of orthogonal factors to describe the underlying attitude dimensions. Visualisation of the correlation which exists between items has been in terms of test vectors with a given angular separation, in 'n' dimensional space. If this concept is modified by adopting the convention of representing the item as a point at the tip of a test vector, then the items will be represented by points scattered thoughout the 'n' dimensional space, with those items which correlate the most highly tending to cluster in specific volumes of the space.

Orthogonal factor analysis passes orthogonal factor vectors thorugh these clusters in order to obtain a good solution. This procedure implies that the centres of gravity of the various clusters lie upon planes which are mutually orthogonal. This can be viewed as an unnatural constraint, in that in practice, clusters can lie on planes which are oblique to one another. Therefore factor vectors should be projected obliquely and not orthogonally, in order to provide the optimum solution. Adopting this technique is equivalent to accepting the assumption that the attitude dimensions, as defined by the factor vectors are correlated; quite a tenable position in studies such as the one undertaken as part of this research programme. Furthermore, Nunnally (1970) concludes that the item loadings on oblique factors are usually more unambiguous than those found on orthogonally extracted factors. However, oblique factor analysis was not performed for the following reasons.

Firstly providing that the factors are not highly correlated, little practical difference exists between oblique and orthogonal solutions at the final stage of factor interpretation. As stated by McKennell (1974) "... many issues which are raised as fundamental in theoretical writings turn out to be inconsequential in applied research", a comment confirmed by the results of two analyses, one an orthogonal factor solution and the other an oblique factor solution imposed upon the same set of data by Davis (1980). Secondly, an oblique solution is more complex computationally. New parameters also have to be defined to obtain a solution, such as the angle to be permitted between two factor vectors before they are considered to be coincident. Satisfactory criteria for this parameter are not available. Thirdly, oblique solutions tend to be less stable than orthogonal ones, in that the angle between the oblique vectors is influenced to some extent by sampling errors. Thus, different solutions could be obtained from sample to sample. It was considered that this might cause unnecessary problems in the analysis of the questionnaire data as it was intended to compare factor solutions from the pilot attitude study and the main attitude study.

Although it was decided to extract orthogonal factors from the original correlation matrix movement towards relaxing the orthogonality of the factors was made using the technique described in section 6.3

6.3 Cluster analysis

Items which are highly correlated group or cluster in small volumes of the 'n' dimensional space. Ideally, members of a cluster would load highly upon the same factor, and define that factor. Cluster analysis, is a technique which groups items possessing high intercorrelations, and by inference, achieves low intercorrelations between clusters.

It has been stated earlier that only factors extracted from the correlation matrix possessing eigenvalues greater than or equal to unity are retained for rotation. However, it is not unusual to find that after rotation the final factors in the solution each tend to control only a small part of the total variance. This, in part, could be considered to be a consequence of the imposition of orthogonal factors in a non-orthogonal universe. The presence of these "low importance" factors can cause true clusters to be split, on rotation, and thus lose their relevance.

It is also possible that an item may load upon two factors to a similar extent. The item will be assigned to the factor on which it has the greater factor loading, even if the difference between the two loadings is infinitesimal, and smaller than the item sampling error. In cases such as these it is valuable to be able to use a method which could signal such an occurrence, and permit the analyst to assign the particular item to a factor on consideration of the emerging attitude structure, giving a more meaningful solution.

McKennell (1974) describes a technique which will overcome many of the shortcomings of the factor analysis method. His approach also permits the calculation of the reliability of the final scales derived.

In essence the factor solution is used to rearrange and section the original correlation matrix, which in turn is subjected to a cluster analysis. Once sectioned according to the factor solution, most of the computation necessary for performing a cluster analysis has also been completed.

Figure 6.1 demonstrates the factor/cluster technique used in this study. Here a twelve item correlation matrix, obtained early in the process of deriving a factor solution, is shown resectioned with all items which define a particular factor (i.e. show their maximum loading on that factor) being adjacent. This has the effect of throwing the highest correlations into the boxes along the main diagonal. A sequence of high correlations in a box removed from the diagonal indicates an item misplaced in the factor solution, or signals the possibility that two derived factors are really trivial subcomponents of one large cluster. Offending items, or blocks of items, are then relocated in the correlation matix, in such a way that the homogeneity of the group into which the reallocation is made, is not degraded.

In order that any two experimenters might arrive at the same solution, starting from the same factor sectioned correlation matrix, it is necessary to adopt a standard procedure for relocating items.

It was decided that if item reallocation was necessary, then the item would be allocated to the cluster with which it had the highest average correlation. In this way the prime objective of cluster analysis is achieved, that is, the attainment of average intra-group correlations greater than the average intergroup correlations.

It is also possible to reallocate an item to the group with which it exhibits the highest single correlation, as is suggested by McQuitty (1957). However, this method, although speedy, was rejected on the grounds that the first allocation method, described above, was superior on the basis of reliability theory, explained in section 6.4. Reliability was also a consideration in the decision whether or not to merge factors into larger clusters.

6.4 Reliability of the attitude scales generated

The purpose of the techniques already discussed was to define the attitude dimensions which underlie a respondent's views on the topic being

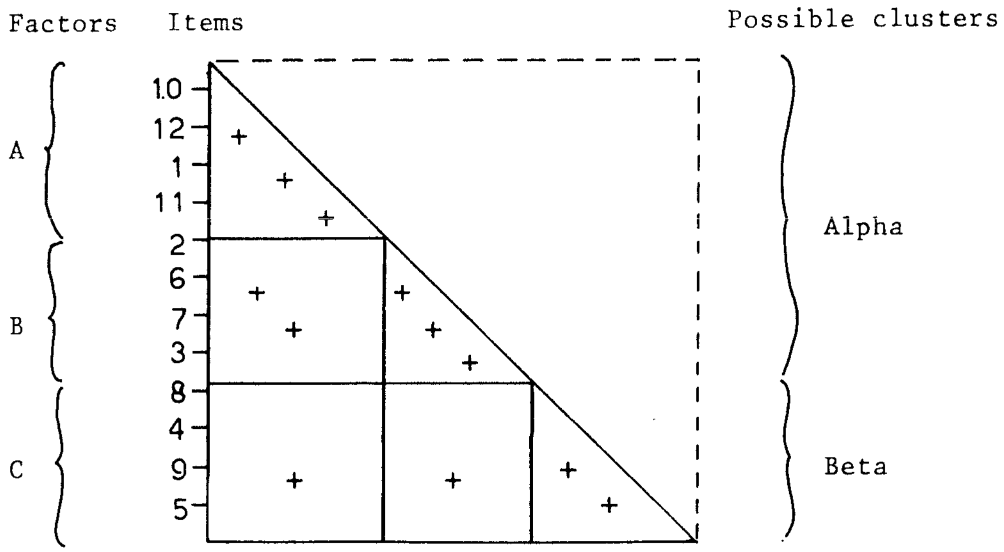


Figure 6.1 Schematic of an item correlation matrix, sectioned according to a factor solution, and also broken down by clusters. The number of (+) signs indicates the strength of the correlations in a particular section.

considered. Each of the groups of items (questions) resulting from the factor and clustering procedure represents one of these attitude dimensions and is known as an attitude scale. A respondent's answers to the questions contained within an attitude scale allow his views to be scored quantitatively and compared with those of other respondents. However, it is useful to know the reliability with which these attitude scales can be used as measuring instruments in this research programme.

Cronbach (1951) reviews this problem and discusses the relative merits of various reliability measures with special reference to the value of the coefficient described as "Cronbach's alpha". The method utilises the "split half" approach by which the total number of items in the test, or scale, are divided into two numerically equal groups. Test scores are computed for each half, and the correlation between the two half scores is determined, with adjustments for the effect of halving.

Cronbach shows that his alpha coefficent is the mean of all possible split-half coefficients in a given group, and is the lower bound for the coefficient of equivalence defined as the correlation of two scores obtained from a pair of identical tests administered simultaneously. This theorem is accurate if initial analysis techniques are designed to produce tests (scales) which are free from pronounced clusters, and if the main factor running through each scale accounts for a large proportion of the scale variance. Discussion throughout this chapter has indicated that the analysis strategy adopted for use in the research programme was orientated in this manner. Cronbach proceeds to show that under these conditions, alpha yields a very close estimate of the proportion of variance accounted for by the principal factor within a scale. In turn the alpha coefficient can be used as a check on scale homogeneity.

McKennell (1970) gives an approximate formula by which alpha may be calculated, shown below. It is particularly suitable for use in scale construction in this format.

$$\text{Alpha} = \frac{v\bar{r}_{ij}}{1 + (v-1)\bar{r}_{ij}} \qquad 6.4$$

v = number of items in the scale

$\bar{r}_{ij}$ = average item intercorrelation in the scale.

The assumptions made in deriving this expression are not sufficently radical to make the approximate alpha coefficient deviate significantly, in the practical sense, from the alpha coefficient calculated using a more exact and time consuming formula.

Equation 6.4 shows that scale reliability can be raised either by increasing v, the number of items in the scale, or by maximising r_{ij}.

The strategy adopted in this research programme; factor analysis followed by a clustering technique, would tend to maximise the average item intercorrelation (r_{ij}) of a scale, and hence its reliability.

As discussed in section 6.2.2 it is not unusual to find that towards the end of factor extraction, a factor is produced that is defined by very few items. Two items is a common number and the factor is known as a 'doublet'. This late factor would probably have a reasonable average item intercorrelation as only two items would be involved, but due to the low number of defining items the scale will have a low alpha coefficient. If the factor in question has a reasonable correlation with a second factor, then it is possible that combining the two factors will yield a scale with an alpha coefficient in excess of that exhibited by either scale separately. The improvement in alpha is a consequence of a small drop in overall scale homogeneity being counterbalanced by the increase in the number of items in the resulting scale. Furthermore Cronbach (1951) has shown that in the case of slightly non homogeneous scales, the calculated alpha may be an underestimate of the true scale reliability. Thus the improvement in alpha, after merging a minor factor with a major one, is likely to be underestimated. However, if the 'doublet' type of factor arises as a result of an idiosycracy of the factor technique, then it is unlikely that overall scale homogeneity would suffer greatly.

The justification for merging two factors can be checked by using a test of "discriminant validity" (Campbell 1959). This procedure investigates the correlation which exists between two scales or factors, (subsets) and indicates whether or not the two are measuring separate dimensions. The form of the test is shown below

$$r_3 < \sqrt{r_1 r_2} \qquad 6.5$$

r_3 = The intercorrelation of the combined subset

r_1 = The reliability of the first subset

r_2 = The reliability of the second subset

If the inequality shown in equation 6.5 does not hold true, then the two subsets are measures of the same variable, and can be combined.

6.4.1 The use of alpha to optimise scale length

A pilot questionnaire was used in this research study so that the scaling procedures described in this chapter could be undertaken , and the main questionnaire so developed by the rejection of unnecessary items.

Cronbach's alpha can be used as a technique for refining the scales by removing redundant questions in a questionnaire, and maximising the coefficient of reliability. The refined scales can then be used in the main questionnaires. Use of refined scales is likely to maximise the volume of complete questionnaire returns, as less work is required from the respondent. Alternatively, the questionnaire length can be maintained, but more of the refined, shorter, scales would fit into the available space. It is worth noting, however, that the inverse relationship between questionnaire length and the size of the total questionnaire return is by no means proven (Scott 1961).

The scales were refined in the following manner.

The average intercorrelation of an item with the rest of the items forming a cluster was calculated. The items were then ordered in descending rank according to the size of these average correlations. By removing the lowest ranked item, the homogeneity of the cluser was raised, at the expense of a reduction in (v), the number of items remaining in the group. A recalaculation of alpha would probably show that the coefficient of reliability had increased. Subsequent removal of the new lowest ranked item and recalculation of alpha would probably show a further change in the coefficient of reliability, which will peak at some stage of the refining process as the effect of reducing (v) predominates.

6.4.2 Methodology chosen for assigning items to scales

Cessation of the removal of items from the scale occurs when the analyst is satisfied with the coefficient of reliability achieved.

The reliability required of a scale before it can be judged to be adequate for use is a function of the use to which a scale is to be put. The literature tends to subdivide scales into two separate types; those used for basic research, and those used for the purposes of making a decision about an individual, such as the state of his mental health, or his educational future. Much lower alpha coefficients can be accepted in the former case than the latter, as the consequences of error are less drastic (Guildford 1954). The study reported in this thesis can be classified as basic research; Nunnally (op.cit) comments that "For basic research it can be argued that increasing reliabilities beyond 0.8 is often wasteful" Guildford sets a lower bound: "As to how high reliability coefficients should be, no hard and fast rule can be stated. ... We are frequently faced with the choice of making the best of what reliability we can get, even though it may be of the order of only 0.5 or of going without the use of the test at all" It will be shown that the scales developed during the present study have satisfactory coefficients of reliability, lying between the above defined bounds.

Although the factors are constrained to be orthogonal , the items will be less rigorously constrained with the result that some items may load almost equally on two, or possibly more, factors. Such an item should be discarded, but this can lead to an unnecessary loss of data if the multiple loading becomes apparent after the pilot stage of attitude scale development. A second solution is to adjust the scale scores for each factor to account for the loading, hopefully small in most cases, of each of the items on each of the factors. This procedure makes some allowance for the fact that the data is not dispersed in truly orthogonal clusters throughout the multidimensional space. However, it is a form of item weighting, which is laborious to perform, and not cost effective, as the procedure rarely causes a significant change in the research results (McKennel 1970). The point has already been discussed in section 6.5.2 where other authors were shown to concur with McKennell (Richardson (1941), Likert (1932)). The technique of weighting is not widely used; a better allocation strategy is described below.

The items can be allocated to the factor on which they have the highest loading, providing that this loading exceeds an arbitrary cut-off point, usually set at 0.30 and providing that no other factor loading for this item exceeds the cut-off point. Items with multiple loadings each exceeding 0.30 are being discarded (Baker 1980). However, a variation of this sytem was introduced for use in the present study, as it was felt that the clustering technique to be used, and described earlier, provided a method of relaxing the constraints of factor orthogonality in a controlled fashion such that multiple item loadings on different factors was no longer a conceptual problem. The clustering technique was used on the final rotated factor solution to associate with the most appropriate factor any item exhibiting multiple, significant, factor loadings. If uncertainty still existed as to the factor to be associated with this ambiguous item, a decision was reached by considering the difference between the item factor loadings on the possible factors and the next highest loadings exhibited by items belonging unambiguously to these factors. The greater the difference, the less likely it was that the item should be associated with that particular factor.

Finally, as item clustering was to be undertaken on the final factor solution, and alpha coefficients for scale reliability calculated, it was not thought necessary to discard items with maximum factor loadings below the cut off point of 0.30. Instead the effect that these items had upon the reliability of the final scales was carefully monitored using the alpha coefficient method described in section 6.4.1.

6.5 Conclusions

This chapter discussed the methods used in developing the attitude scales from the attitude questionnaires, such that the resulting scales would define the attitude dimensions underlying the responses of employees.

Chapter 7 details the practical application of these methods in the pilot attitude questionnaire excercise.

The method of item analysis chosen, and justified, was designed to ensure that only the most relevant questions were included in the final questionnaire, that redundancies were minimised and that the final question pool could be structured to provide scales of known reliability for attitude investigation.

The analysis regime consisted of an "R" type classical factor analysis, with the extraction of orthogonal factors. Factor extraction was terminated when factor eigenvalues fell below unity. Initial estimates of item communality were made on the basis of the squared multiple correlation coefficients of the items with the remaining items in the subset. True communalities were then calculated and inserted in the matrix, using an iterative procedure. Iterations ceased when the difference betwen two successive item communalities fell below 0.001. The factor system was then rotated to achieve an approximation to the simple structure, using Varimax rotation with Kaiser Normalisation. The final factor solution was subjected to a cluster analysis, using a simplified allocation technique. Use was made of a modification of Cronbach's alpha to refine the resulting scales by removing redundant questions, to measure scale reliabilities, and to examine scale homogenity.

CHAPTER 7

DEVELOPMENT OF THE ATTITUDE QUESTIONNAIRE: THE PILOT STUDY

7.0 Introduction

Chapters 5 and 6 have discussed the procedures and statistical analyses selected for use in constructing a valid attitude questionnaire.

Initially, the "Universe of Content" must be defined, that is, the boundary of the area in which the investigation is to proceed must be circumscribed. This was achieved by consideration of the information obtained from the pilot hearing conservation survey described in chapter 3. Informal interviews loosely structured upon the information derived from the definition of the Universe of Content form the next step of the development procedure, and from these the questionnaire items are abstracted. The items are then compiled into a pilot attitude questionnaire, which is dispatched to a sample of respondents. The final step is the analysis of the returns obtained, allowing refinement of the pilot questionnaire to produce the main attitude questionnaire.

This chapter describes the results of the attitude questionnaire development.

7.1 Pilot attitude questionnaire

7.1.1 Development of the pilot questionnaire

After definition of the areas of interested as described in section 7.0, six informal tape recorded interviews were undertaken with men drawn at random from Nylon Outside Services and the Titanium plant. The environment in which these employees worked has been described in chapter 2, and necessitated the use of hearing protection for at least part of the working day.

Figure 7.1 shows the chart used to ensure that each topic was discussed with each interviewee. The pilot attitude questionnaire shown in Appendix

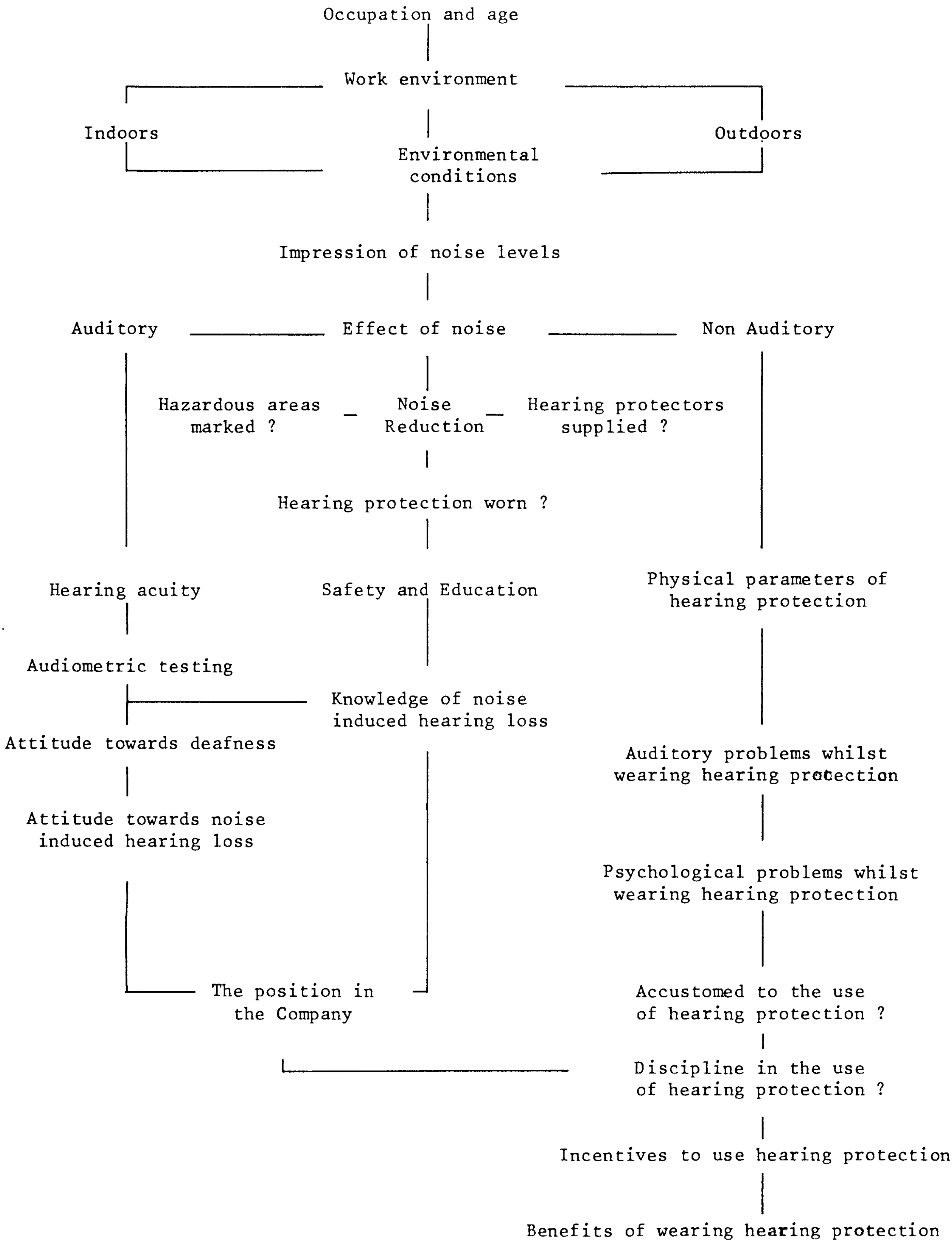


Figure 7.1 The general structure of the informal interviews used to obtain the attitude questionnaire statements and define the Universe of Content .

7.4 consisted of 74 attitude statements taken from comments made by employees interviewed, and restructured in the manner described in chapter 5. Item 75 was a free-format question, allowing the respondee to add any comments of his own, and was not scored.

7.1.2 Dispatch of the pilot attitude questionnaire

The selection of the manufacturing areas and plants to which the pilot attitude questionnaire was dispatched was made on the basis of factory visits, following the examination of noise level records held at the Wilton site Medical Centre. The plants and their associated noise levels were described in chapter 2. All plants and areas exhibited noise levels which were a hazard to hearing, and necessitated the use of hearing protection.

The 17 areas or plants selected included the 8 plants allocated to the main experiment. These latter plants, described as the prime group, are shown together with the remaining 9 plants known as the secondary group, in table 7.1. The sampling rates and employee numbers used in each plant or area are also shown in table 7.1 and indicate that the rate was maintained at between 4% and 6% in the prime group, but that is was more variable in the secondary group, ranging between 1% and 27%. Plant or area process operators were sampled within each plant in the same proportion that each group was present on the factory floor.

The sampling percentage used in the prime group represented a balance between that level which would be low enough to avoid undue stimulation of the population prior to the main study, and yet high enough so as to ensure that the prime group, which would participate in the main study, was reasonably involved in the development of the attitude questionnaires. The sampling percentage was maintained at an approximately constant level across these plants to ensure that at the beginning of the main study, each would have had equal prior involvement with the research programme.

The prime group received 56.5% of the 124 pilot quesitonnaires despatched, whilst the secondary group received the remainder. The letter accompanying the questionnaire is shown in Appendix 7.1 .

Table 7.1 The sampling rate (P) in the prime and secondary groups

Prime group	n	p	Secondary group	n	p
Terylene Spinning	7	5%	E.S.W Maintenance	3	1%
Terylene Drawtwist	12	4%	Nylon Chemical	10	2%
Terylene Drawbulk	6	5%	Polythene Two Four Five Six	15	27%
P.F. Plant	11	4%			
Polythene Finishing	5	4%			
Olefines V	8	5%	Propathene Finishing	4	2%
Nylon Polymer	14	6%	Terylene Polymer North	19	10%
Central Workshops	7	4%	Terylene Polymer C.P.	3	5%

7.1.3 Pilot attitude questionnaire returns

Eight of the 124 questionnaires despatched did not reach the intended recipient for the reasons shown in table 7.2. Of the remainder, 74% were returned completed within three weeks of despatch.

A reminder letter was despatched to the non-respondents, and is shown in Appendix 7.2. However, the reminder letter was delayed by four weeks whilst a problem was resolved, first raised by the Wilton Site Medical Centre which was to despatch the letters. It was noticed that the employee project code number was shown adjacent to his name on the computer printed address labels. Although the author did not feel that this represented a practical breach of the condition of questionnaire confidentiality it was required that the letters should be returned to the University for the project numbers to be deleted.

Two weeks after the reminder letter despatch, the total returns of the pilot questionnaire reached 93%.

7.2 Results

7.2.1 Scale development

The completed questionnaires were scored, except for questions 11, 13 or 14, as it was evident that these items were giving rise to confusion. The remaining 71 variables presented a group which was too large to subject to a single factor analysis as the mainframe computer at the University did not possess an adequate core storage space. To circumvent this problem, the variables were divided into three groups, for analysis on the basis of their probable gross relationships. The validity of this division was checked at a later stage, after arrangements had been completed to use a larger ICL 7600 computer at London University. This check is discussed in chapter 8, which describes the pre-treatment main attitude questionnaires, where the a priori division of the variables into three sections for separate analyses is shown to have been justified.

Reference to tables 7.3, 7.4 and 7.5 shows the sectioning of the variables or questions. These questions are represented in the tables by mnemonics.

Table 7.2 Showing the statistics of the pilot questionnaire dispatch

Number initially dispatched		124
Number returned uncompleted for the following reasons:		
	Deceased	1
	Left plant	6
	Incorrect address	1
Number to be completed		116
Number returned after 3 weeks		86
Number returned after dispatch of the reminder letter		22
Percentage success		93.1%
Rejected: very severely deaf, very few questions completed		1

The key to the mnemonics is given in Appendix 7.4, the pilot attitude questionnaire. The three tables mentioned earlier represent the correlation matrices obtained as the first step of the individual factor solutions. The unrotated factor solutions are shown in tables 7.6, 7.8 and 7.10, whilst the final, rotated, factor solutions are given in tables 7.7, 7.9 and 7.11.

The defining items for a particular factor, that is, those items which show their highest loadings upon this factor, are indicated by an asterisk. The factor eigenvalues are also shown in tables 7.7, 7.9 and 7.11.

The correlation matrices were then resectioned according to the results of the factor analyses, using the method described in chapter 6. Using the clustering technique also described in that chapter, the matrices were further resectioned. The reliability of the putative scales was then calculated using Cronbach's alpha technique. Successive items were discarded until an acceptable level of reliability was achieved, with an acceptable number of items. Scales with reliabilities below 0.5 were rejected. The main diagonal correlations of the resectioned and purified matrices are shown in tables 7.12, 7.13 and 7.14.

These analyses resulted in the development of twelve scales involving 40 questions taken from the original 74. The scales, and their associated reliabilities, are shown in table 7.15.

Identification of the attitude which each scale measured will be discussed in chapter 8 for the following reason. It was decided, as discussed earlier in this chapter, to check the validity of sectioning the pilot questionnaire variables into three groups for individual factor analysis, by performing a single factor analysis of all the variables on a larger computer then installed at Southampton. The data used was drawn from the main pre-treatment attitude questionnaires. This process was advantageous in that the number of respondees was approximately ten times that of the pilot attitude study. As will be seen in chapter 8 the factor solution obtained was almost identical to that achieved in the analysis of the pilot attitude study, with only a few small changes being necessary. However, in order to prevent confusion, the identification of the scales will be shown in chapter 8, after the analysis of the first round of main attitude questionnaires.

Space was available in the final refined, attitude questionnaire for the number of questions to be increased from 40 to 55. The former number represented the space required by the 12 scales. It was not thought that such an increase would discourage employees from replying, but the extra items would greatly increase the yield of information. Accordingly, some questions present in the pilot questionnaire which had been rejected from the scales were nevertheless retained in the final attitude questionnaire as the response of employees to these questions was thought to be of general interest. In the main, extra questions were retained whose scores exhibited standard deviations which were above average in size, or that possessed mean scores which were not extreme in value, that is, approximately 3. Large standard deviations implied that some diversity of opinion existed over the question, whilst scores around 3 increased the scope for attitudinal change over the research period.

Some new questions were also inserted in the questionnaire and the final version is discussed in chapter 8.

7.2.2 Differences between the pre- and post-reminder returns

The mean and standard deviations of the scores achieved on the pilot attitude questionnaire are displayed in table 7.16. Also shown in this table are the question mean scores and standard deviations obtained after an analysis of the 86 questionnaires returned prior to the dispatch of the reminder letters. A similar analysis was completed on the 21 questionnaires returned after the reminder letters had been sent to employees, and also the total response of 107 questionnaires. The three populations are defined here as the "pre-reminder population" the "post-reminder population", and the "total population" respectively.

Comparison of the item means between the populations raises a question which is relevant to many of the analysis procedures undertaken throughout this thesis.

Table 7.3 Correlation matrix. Section 1 variables. Pilot attitude questionnaire.

	NEN	LIKE	USED	NHIGH	SHORT	IRIT	LOUD	WORRY	PRESB	STEPS	SHAND	FAMI	JHAND	WHAND	NDEF	PDEF	ENJ	DAMAGE	IMM	EVID	HEAR	RESUL	XRAY	TBRK	CLINIC	DISCUSS
NEN																										
LIKE	-04																									
USED	11	39																								
NHIGH	27	14	28																							
SHORT	29	11	19	26																						
IRIT	14	24	43	25	20																					
LOUD	04	21	28	13	10	44																				
WORRY	22	-03	12	19	12	16	12																			
PRESB	19	-04	-03	07	31	03	08	15																		
STEPS	07	02	-08	10	23	01	-06	05	52																	
SHAND	22	01	26	25	31	23	07	33	26	12																
FAMI	-04	15	06	03	08	18	16	06	25	12	13															
JHAND	07	-07	05	08	-02	13	09	28	17	04	15	02														
WHAND	14	-02	07	04	11	24	19	17	10	03	20	12	53													
NDEF	18	-04	12	15	14	15	19	38	34	16	23	15	20	16												
PDEF	16	-04	13	07	17	08	01	24	11	03	23	04	07	21	06											
ENJ	23	12	24	30	24	26	20	18	23	22	38	24	18	38	15	21										
DAMAGE	17	17	17	17	37	23	02	14	19	27	25	08	00	10	15	04	27									
IMM	-06	11	20	10	21	17	08	05	08	17	09	11	11	19	11	01	09	32								
EVID	22	06	10	12	22	24	15	25	25	24	19	09	14	16	08	15	24	35	40							
HEAR	16	07	-06	03	09	03	11	16	22	33	14	05	18	06	18	21	24	12	-07	19						
RESUL	09	12	-10	-12	03	03	10	20	09	13	06	09	11	07	05	24	08	01	-08	11	37					
XRAY	15	09	-15	02	10	20	09	21	17	07	18	02	19	08	18	18	18	20	-03	26	25	23				
TBRK	14	15	00	16	03	11	13	07	04	05	08	-03	21	15	11	07	07	-03	11	07	18	23	17			
CLINIC	14	04	01	04	18	-05	07	08	21	09	13	-09	04	11	22	25	22	22	15	24	35	20	23	27		
DISCUSS	18	-05	-03	10	12	09	02	23	03	08	10	15	14	24	19	18	14	09	-10	16	16	21	27	26	45	

Table 7.4 Correlation matrix. Section 2 variables. Pilot attitude questionnaire.

	PAST	WORTH	WASTE	MANAG	THEOR	STON	SEMPLY	BETTER	ATTEN	PRESS	GJOB	ICIH	LEGAL	ENCOU	BENEF	COMPU	RESPON	TALK	FILM	MEMOR	PREF	POST	EDUC
PAST																							
WORTH	21																						
WASTE	55	34																					
MANAG	-11	-18	-08																				
THEOR	-04	.04	03	08																			
STON	15	21	10	08	14																		
SEMPLY	-02	-03	02	47	26	-09																	
BETTER	-08	05	-19	-02	29	14	09																
ATTEN	33	12	33	-11	06	03	-01	-12															
PRESS	36	29	33	13	22	12	20	-03	31														
GJOB	-03	31	-01	-11	13	28	-13	35	-07	05													
ICIH	-02	24	02	-18	13	26	00	25	02	08	55												
LEGAL	-06	18	05	-04	30	18	14	11	-02	06	19	22											
ENCOU	-18	-12	-23	-08	17	13	03	35	-16	-26	21	25	12										
BENEF	14	13	10	-09	24	26	-07	23	09	15	16	20	26	-04									
COMPU	30	18	43	00	14	11	04	-11	24	57	03	08	-04	-30	03								
RESPON	20	14	33	02	15	05	-02	-07	15	48	-01	09	-02	-33	09	79							
TALK	21	17	22	-19	03	08	-26	-07	19	-03	07	-03	04	04	00	21	21						
FILM	34	27	40	-22	-04	18	-16	-07	21	17	24	18	09	01	25	25	25	45					
MEMOR	21	15	36	-14	-02	11	-19	-08	14	12	-15	-08	02	01	24	09	13	22	29				
PREF	-06	02	04	00	-04	-07	06	08	11	07	-14	-11	-04	-01	-13	01	00	-16	-25	-16			
POST	-04	23	-02	-11	07	07	03	17	-14	02	29	50	24	28	05	02	03	-08	05	-04	-07		
EDUC	16	-04	08	-04	-10	01	10	04	-08	-09	06	05	10	10	13	-05	-01	00	22	12	-22	12	

Table 7.5 Correlation matrix. Section 3 variables. Pilot attitude questionnaire.

	NGOOD	SOME	BILS	EFF	ENC	STAM	CONSP	PERCEN	HELM	FIT	HEAV	FORG	SELEC	PUSH	HOT	COLD	DIRT	WET	DANG	COMM	MACH	WARN
NGOOD																						
SOME	19																					
BILS	28	27																				
EFF	17	-20	-30																			
ENC	-03	-11	04	-17																		
STAM	09	16	11	16	17																	
CONSP	23	25	08	-11	25	21																
PERCEN	-01	06	-07	01	03	16	01															
HELM	17	-01	15	-11	02	14	04	-03														
FIT	31	-05	13	16	-02	12	17	-04	27													
HEAV	28	08	29	11	-23	20	06	-11	21	51												
FORG	03	22	10	-22	10	17	20	45	24	-07	-11											
SELEC	24	05	10	00	07	07	09	-13	21	23	22	-01										
PUSH	31	03	22	-03	00	-08	06	-17	21	46	53	-13	34									
HOT	24	00	-05	07	10	05	-01	-05	23	27	18	10	15	39								
COLD	13	19	16	03	06	12	16	-01	02	05	14	02	13	21	07							
DIRT	08	14	01	13	02	00	01	13	-01	16	12	05	01	12	14	47						
WET	19	18	15	12	04	04	10	-06	08	19	15	00	11	28	06	59	56					
DANG	17	01	02	-10	30	33	27	07	24	09	05	28	16	-02	23	18	00	06				
COMM	-11	-25	-21	13	26	03	-16	03	17	09	01	-03	12	11	04	00	04	04	15			
MACH	15	13	-08	03	22	23	23	07	26	02	-12	18	12	01	16	-01	01	06	48	20		
WARN	-04	03	-25	09	07	02	-10	11	06	-20	-19	10	00	-16	07	-01	02	03	29	38	36	

Table 7.6 Unrotated factor solution for section 1 variables. The principal factor is shown as factor 1.

SECTION 1 PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
MEN	-0,38517	-0,06735	0,00213	0,14482	0,14030	0,24028	0,07399	0,00596
LIKE	-0,14356	0,42678	0,02534	0,22504	-0,10763	-0,28122	0,14937	0,15635
USED	-0,31036	0,55821	-0,12298	0,23909	0,05593	-0,00480	0,00722	0,01789
NHIGH	-0,34939	0,26524	0,00795	0,16738	0,12425	0,20343	0,06215	0,16078
SHORT	-0,45415	0,14332	0,25760	0,06685	0,00559	0,19193	0,14032	-0,02937
IRIT	-0,44854	0,43462	-0,20356	0,11320	0,05752	-0,15045	-0,09820	-0,10641
LOUD	-0,51160	0,26121	-0,21119	0,09292	0,00079	-0,33472	-0,10133	0,04331
WORRY	-0,45979	-0,10025	-0,14147	0,03936	0,22251	0,15695	-0,32285	-0,07036
PRESB	-0,47259	-0,16430	0,42146	-0,28647	0,25229	-0,08237	0,00658	0,16660
STEPS	-0,35695	-0,14570	0,48442	-0,21496	0,01760	-0,13073	0,11107	0,08237
SHAND	-0,51025	0,08324	0,01911	0,01523	0,22118	0,19714	0,03989	-0,08739
FAMI	-0,21190	0,17977	0,10238	-0,21080	0,18971	-0,28686	0,00689	-0,07761
UHAND	-0,35936	-0,12913	-0,35205	-0,31395	0,01015	-0,01024	-0,10778	0,09253
WHAND	-0,49265	-0,00125	-0,57417	-0,54288	-0,10453	0,06342	0,26155	0,01337
NDEF	-0,44786	-0,07951	0,01386	-0,05299	0,21016	0,03044	-0,30537	-0,31274
RDEF	-0,33942	-0,14112	-0,10022	0,11343	0,03468	0,06161	0,10577	-0,21492
ENJ	-0,57154	0,11342	-0,03037	-0,04479	0,10449	-0,01074	0,29627	-0,06906
DAMAGE	-0,45149	0,16836	0,30483	0,02424	-0,17721	0,12706	0,01468	-0,11835
IMM	-0,30598	0,32720	0,19224	-0,24780	-0,51630	0,02887	-0,25049	-0,00253
EVID	-0,51411	0,02887	0,17242	-0,04154	-0,26369	0,02372	-0,16347	-0,22890
HEAR	-0,40671	-0,36360	0,09402	0,12465	0,03606	-0,30751	0,10016	-0,02788
RESUL	-0,25595	-0,41721	-0,08397	0,11532	0,02207	-0,29403	-0,04466	-0,24065
XRAY	-0,38278	-0,24707	-0,04896	0,12426	0,00171	-0,03143	-0,14569	-0,14780
TBRK	-0,27740	-0,15105	-0,18023	0,15838	-0,17640	-0,15175	-0,01817	0,22812
CLINIC	-0,43063	-0,34154	0,06737	0,27404	-0,33849	0,00272	0,08834	0,16968
DISCUSS	-0,35985	-0,35705	-0,20759	0,24433	-0,16375	0,15561	0,03059	0,12188

Table 7.7 Varimax rotated factor solution for section 1 variables.

SECTION 1. PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
NEN	-0,00751	0,04105	0,03389	-0,00565	0,44919 ●	0,13805	0,10943	0,14515
LIKE	0,54975 ●	0,06429	-0,10139	0,05958	0,04287	0,12250	-0,13830	-0,18784
USED	0,57431 ●	-0,13599	-0,01750	0,11018	0,32504	-0,03569	-0,11817	0,04549
NHIGH	0,24379	0,02159	-0,00931	0,03028	0,44092 ●	0,09793	-0,15449	0,13519
SHORT	0,08747	0,21017	-0,03677	0,24151	0,48960 ●	0,06141	0,00250	-0,00982
IRIT	0,58873 ●	-0,06930	0,13501	0,17357	0,23198	-0,07107	0,11372	0,14005
LOUD	0,54349 ●	0,02966	0,11757	0,01873	-0,00791	0,03754	0,12449	0,13796
WORRY	0,04719	-0,02067	0,11846	0,07730	0,26488	0,01882	0,25789	0,50596 ●
ARESB	-0,05874	0,69326 ●	0,06199	0,09558	0,20854	0,01150	0,06969	0,23052
STEPS	-0,07221	0,63146 ●	-0,02046	0,19381	0,12388	0,06162	0,07958	-0,01388
SHAND	0,11292	0,12116	0,12102	0,08151	0,51114 ●	-0,03858	0,12868	0,19208
FAMI	0,26844	0,32071 ●	0,10438	0,04213	0,00290	-0,24385	0,09113	0,03359
JHAND	0,03866	0,05677	0,52657 ●	0,03439	0,01095	0,10126	0,10959	0,28856
WHAND	0,08659	0,01332	0,75342 ●	0,10067	0,16488	0,09991	0,04790	-0,02186
NDEF	0,10534	0,25740	0,09116	0,02715	0,15330	0,17580	0,00234	0,55250 ●
RDEF	-0,00119	-0,02195	0,11584	0,02512	0,29057	0,09396	0,34447 ●	-0,00046
ENJ	0,25213	0,23338	0,27336	0,06031	0,46246 ●	0,04654	0,16379	-0,06464
DAMAGE	0,09721	0,18445	-0,05279	0,45486 ●	0,35896	0,05072	0,04865	-0,02265
IMM	0,15528	0,08673	0,12454	0,73825 ●	-0,04294	0,04507	-0,17688	0,04319
EVIO	0,07907	0,12536	0,06432	0,54741 ●	0,20178	0,07321	0,25620	0,09127
HEAR	0,06672	0,34432	0,01088	-0,04082	0,06902	0,28393	0,46517 ●	0,01157
RESUL	-0,00572	0,09893	0,04846	-0,04055	-0,06527	0,15084	0,60274 ●	0,05152
ARAY	0,00686	0,03237	0,04184	0,11305	0,14237	0,16519	0,40483 ●	0,20590
TRRK	0,16869	0,02424	0,11883	0,00755	-0,05000	0,44267 ●	0,12208	0,09415
CLINIC	-0,03910	0,14414	-0,01298	0,18099	0,16704	0,63509 ●	0,22716	-0,01437
DISCUSS	-0,09382	-0,10101	0,12952	0,00273	0,21324	0,52327 ●	0,22996	0,12854
EIGENVALUE	4.10307	1.77613	1.33417	1.03604	0.87082	0.77740	0.5938	0.51800

● Defining item

Table 7.8 Unrotated factor solution for section 2 variables. The principal factor is shown as factor 1.

SECTION 2 PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
PAST	-0,54864	0,14535	-0,11611	-0,17813	-0,19299	0,16659	0,02070	-0,04299
WORTH	-0,43072	-0,21856	-0,00883	0,07817	-0,12797	0,27953	0,01582	0,02872
WASTE	-0,66780	0,19414	-0,07174	-0,14747	-0,24131	0,17045	0,06619	0,06819
MANAG	0,16566	0,17374	0,44643	-0,19716	-0,08158	-0,12852	0,00631	-0,27046
THEOR	-0,15544	-0,26501	0,41834	-0,22275	0,29615	-0,08055	0,28735	0,14659
STON	-0,24953	-0,30665	0,02116	-0,08411	0,09686	0,06299	0,03695	-0,14271
SEMPLY	0,09524	0,34674	0,67561	-0,37390	-0,36336	-0,08293	0,08596	-0,04586
BETTER	0,07093	-0,46994	0,19404	-0,05546	0,16642	0,02879	0,10534	0,01774
ATTEN	-0,38807	0,18485	-0,02800	-0,07450	0,01361	0,23379	0,16988	0,05074
PRESS	-0,58237	0,14060	0,41899	-0,00780	0,01000	0,14735	-0,02295	-0,02305
GJOB	-0,20051	-0,72303	0,03512	0,29028	-0,02557	0,11093	0,07262	-0,42097
ICIH	-0,21562	-0,64030	0,11715	0,21464	-0,11530	0,04361	-0,09138	0,04040
LEGAL	-0,11600	-0,35668	0,13671	-0,17958	0,02174	0,01596	0,00897	0,12400
ENCOU	0,25350	-0,51499	-0,07644	-0,10316	-0,07355	-0,19024	0,28147	0,16819
BENEF	-0,32358	-0,34680	-0,01042	-0,43792	0,43509	0,09726	-0,35276	-0,01066
COMPU	-0,71461	0,24264	0,30952	0,28964	0,05583	-0,20953	-0,00131	0,01320
RESPON	-0,66460	0,22390	0,28575	0,29912	0,17888	-0,35053	-0,12340	0,06284
TALK	-0,37995	0,00083	-0,37211	0,03031	0,06593	-0,21179	0,36322	-0,01455
FILM	-0,61155	-0,16899	-0,37725	-0,13759	-0,11932	-0,17450	0,05880	-0,11993
MEMOR	-0,36747	0,04853	-0,32567	-0,28807	0,03098	-0,07236	-0,03752	0,13836
PREF	0,09851	0,18545	0,19437	0,14242	0,05644	0,33748	0,09120	0,16207
HOST	-0,08051	-0,33973	0,11718	0,19674	-0,30009	-0,05916	-0,18813	0,34713
EDUC	-0,07332	-0,15125	-0,13541	-0,24685	-0,25677	-0,24294	-0,21625	-0,05344

Table 7.9 Varimax rotated factor solution for section 2 variables

SECTION 3. PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
RAST	0,12087	-0,00330	-0,02347	-0,09457	0,02336 ●	0,13516	0,02395	0,05519
NORTH	0,08228	-0,09931	0,23809	0,02659	0,42274 ●	-0,05651	0,28900	0,05871
WASTE	0,21085	-0,01280	0,04426	-0,05899	0,73840 ●	0,09445	-0,03051	0,00202
MANAG	0,07143	0,57313 ●	-0,19006	0,02063	-0,13736	0,00299	-0,02421	-0,01575
THEOR	0,16665	0,14952	-0,01241	0,66619 ●	0,02391	-0,08990	0,06493	0,09622
STON	0,03315	-0,03463	0,01433	0,19575	0,14234	0,10038	0,32347 ●	0,15208
SEMPLY	0,00390	0,82146 ●	0,09821	0,22177	0,05747	0,00184	-0,10759	-0,08598
BETTER	-0,09252	0,03225	0,13851	0,40590 ●	-0,15712	-0,04960	0,27262	0,10766
ATTEN	0,11650	-0,07018	-0,11613	0,05736	0,47671 ●	-0,12694	-0,02317	0,00896
PRESS	0,48754 ●	0,24153	0,02849	0,07070	0,44590	-0,16252	0,10266	0,14686
GJOB	-0,00326	-0,07896	0,20123	0,12572	-0,03513	0,08736	0,87874 ●	-0,01829
ICIM	0,06662	-0,07071	0,51247 ●	0,13244	-0,00020	0,06374	0,47878	0,05301
LEGAL	-0,04020	0,05430	0,21838	0,32960 ●	0,07005	0,07301	0,11560	0,15424
ENCOU	-0,32894	-0,08313	0,22281	0,44189 ●	-0,21570	0,18999	0,09479	-0,20846
BENEF	0,03636	-0,09634	0,00050	0,29080	0,13209	0,20236	0,14027	0,75295 ●
COMPU	0,82884 ●	0,02050	0,01778	-0,00122	0,31787	-0,01109	0,05031	-0,07087
RESPON	0,69693 ●	-0,04823	0,02870	0,01369	0,15527	0,06347	-0,02123	0,02444
TALK	0,14195	-0,39290 ●	-0,20203	0,16127	0,27870	0,27347	0,05644	-0,26098
FILM	0,14522	-0,26576	-0,00544	0,04504	0,46548	0,52536 ●	0,19946	-0,00986
MEMOR	0,02768	-0,23927	-0,04623	0,06442	0,36326 ●	0,31643	-0,17730	0,15916
PREF	-0,01326	0,04565	0,01169	-0,02433	0,05566	-0,48793 ●	-0,09442	-0,02726
ROST	0,02211	-0,03668	0,73965 ●	0,13003	-0,05905	0,08629	0,14885	-0,02771
EDUC	-0,08145	0,19112	0,15317	-0,06029	0,04098	0,47775 ●	-0,02429	0,07792
EIGENVALUE	3.4552	2.50818	1.73764	1.06477	0.79858	0.73192	0.59677	0.53795

● Defining item

Table 7.10 Unrotated factor solution for section 3 variables. The principal factor is shown as factor 1.

SECTION 3 PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
NGOOD	0,50057	0,06226	0,06962	0,16274	0,17759	0,08063	0,16773	0,12235
SOME	0,24938	-0,07605	-0,41242	0,15122	0,10184	0,01385	0,28934	-0,03240
BILS	0,34956	0,17196	-0,30874	0,30536	-0,10737	0,04709	0,00636	-0,21725
EFF	-0,05207	0,12999	0,56130	-0,19448	0,64502	0,16356	-0,04664	0,07170
ENC	0,11657	-0,44194	0,01835	-0,02715	-0,35981	0,30065	-0,35984	0,12841
STAM	0,26893	-0,28631	0,02857	0,16161	0,30078	0,14732	-0,18359	-0,19015
CONSP	0,31599	-0,22137	-0,18546	0,23847	0,08408	0,31416	-0,07876	0,13041
PERCEN	-0,04794	-0,32406	-0,15522	0,03468	0,30665	-0,37916	-0,25705	0,03772
HELM	0,37916	-0,16649	0,17392	0,16860	-0,14150	-0,19691	0,05118	-0,12909
FIT	0,55616	0,23437	0,27998	0,09175	0,04674	-0,07941	-0,20322	0,07344
HEAV	0,57841	0,40686	0,18927	0,14880	0,11232	-0,11927	-0,06854	-0,26665
FORG	0,13912	-0,50253	-0,27645	0,26777	0,14370	-0,39320	-0,10247	0,03350
SELEC	0,37966	0,01544	0,16674	0,04646	-0,12050	0,05987	0,07145	-0,05358
PUSH	0,62295	0,34104	0,21606	-0,00428	-0,25531	-0,09302	0,03497	0,08850
HOT	0,37712	-0,06639	0,29793	0,06136	-0,09047	-0,18530	0,09429	0,38029
COLD	0,46019	0,00440	-0,34239	-0,44556	0,13386	0,18036	-0,05187	-0,11349
DIRT	0,38037	0,00772	-0,32819	-0,50467	0,03085	-0,18713	-0,08066	0,15428
WET	0,53262	0,04330	-0,32900	-0,50293	-0,01450	0,02525	0,05178	0,01753
DANG	0,35696	-0,57641	0,11500	0,09701	-0,02291	0,13784	0,01747	-0,04496
COMM	0,06499	-0,29023	0,45376	-0,36899	-0,21538	-0,12002	-0,15238	-0,24728
MACH	0,25034	-0,57903	0,18253	0,03393	0,02000	0,11507	0,23292	0,04146
WARN	-0,06486	-0,51452	0,22802	-0,29952	0,02168	-0,11484	0,33176	-0,13411

Table 7.11 Varimax rotated factor solution for section 3 variables.

SECTION 3 PILOT STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8
NGOOD	0,43852 ●	0.08451	0,09495	0,34562	0,14729	0,10524	-0,02632	-0,07455
SOME	0,02311	0.19788	0,18540	0,54190 ●	-0,12998	-0,00932	0,11297	0,09492
BILS	0,29920	-0.16645	0,06306	0,31702	-0,32310 ●	0,07053	-0,01154	0,26470
EFF	0,08132	0.04823	-0,05916	-0,10289	0,88644 ●	-0,09154	-0,05884	0,02608
ENC	-0,05926	0.09010	0,05131	-0,25737	-0,16264	0,67011 ●	0,00032	-0,06822
STAM	0,13891	0.14102	0,00993	0,11464	0,19807	0,32945 ●	0,24442	0,31204
CONSP	0,09975	0.01355	0,06371	0,33202	0,00027	0,49004 ●	0,06058	0,03275
PERCEN	-0,12321	0.01853	0,04783	-0,02741	0,07358	0,00960	0,64285 ●	0,00814
HELM	0,43024 ●	0.25769	-0,03230	-0,02962	-0,17252	0,05061	0,14102	0,01811
FIT	0,65972 ●	-0.14652	0,09150	-0,05175	0,13730	0,09279	0,03752	-0,06101
HEAV	0,73040 ●	-0.14879	0,09341	0,06602	0,05698	-0,14532	-0,01861	0,25317
FORG	-0,00251	0.18386	-0,01347	0,17403	-0,21981	0,14319	0,68397 ●	-0,02490
SELEC	0,38672 ●	0.15672	0,05405	0,01548	-0,04412	0,10458	-0,12695	0,00594
RUSH	0,70680 ●	-0.17458	0,19280	-0,02570	-0,09185	-0,03148	-0,19931	-0,17896
HOT	0,42527	0.15915	-0,00336	-0,00243	0,04672	0,07639	0,06551	-0,46555 ●
COLD	0,08047	0.02311	0,71565 ●	0,11089	0,04314	0,13173	-0,04929	0,20151
DIRT	0,06520	-0.03452	0,71933 ●	-0,01649	-0,03815	-0,04148	0,16203	-0,14994
WET	0,16670	0.06011	0,77527 ●	0,03462	-0,07974	0,02913	-0,06510	-0,01134
DANG	0,17160	0.48130 ●	0,02001	0,04309	-0,02830	0,40149	0,15570	0,04353
COMM	0,12254	0.38407	0,07359	-0,63094 ●	0,03331	0,04266	0,00291	0,07027
MACH	0,08[illegible]	0.60537 ●	-0,01769	0,09609	0,04543	0,32144	0,07736	-0,08722
WARN	-0,16102	0.69278 ●	0,05261	-0,16710	0,00357	-0,08383	0,00144	-0,03489
EIGENVALUE	2.9460	2.12784	1.66738	1.34455	0.98988	0.78314	0.62359	0.50890

● Defining item

Table 7.12 Section 1 variables. The main diagonal of the resectioned matrix.

	PRESB	STEPS	EVID	IMM	ENJ	LOUD	USED	IRIT	NHIGH	JHAND	WHAND
PRESB											
STEPS	0·515										
EVID											
IMM			0·403								
ENJ											
LOUD					0·200						
USED					0·235	0·283					
IRIT					0·263	0·439	0·433				
NHIGH					0·296	0·124	0·278	0·254			
JHAND											
WHAND										0·531	

Table 7.13 Section 2 variables. The main diagonal of the resectioned matrix.

	PRESS	RESPON	COMPU	WASTE	GJOB	ICIH	SEMPLY	MANAG	ENCOU	BETTER
PRESS										
RESPON	0·479									
COMPU	0·569	0·787								
WASTE	0·326	0·330	0·429							
GJOB										
ICIH					0·550					
SEMPLY										
MANAG							0·469			
ENCOU										
BETTER									0·349	

Table 7.14 Section 3 Variables. The main diagonal of the restructured matrix

	SELEC	NGOOD	HELM	HEAV	FIT	PUSH	HOT	STAM	COMM	WARN	MACH	DANG	CONSP	ENC
SELEC														
NGOOD	0·238													
HELM	0·213	0·170												
HEAV	0·221	0·280	0·206											
FIT	0·224	0·311	0·265	0·508										
PUSH	0·339	0·304	0·210	0·533	0·455									
HOT	0·150	0·241	0·225	0·174	0·267	0·392								
STAM														
COMM								0·027						
WARN								0·018	0·382					
MACH								0·231	0·196	0·354				
DANG								0·328	0·148	0·291	0·481			
CONSP								0·208	-0·155	-0·102	0·229	0·27		
ENC								0·169	0·256	0·074	0·220	0·301	0·250	

	PERCEN	FORG	DIRT	COLD	WET
PERCEN					
FORG	0·450				
DIRT					
COLD			0·472		
WET			0·564	0·586	

Table 7.15 The scales developed, and their associated reliabilities.

Section 1	Section 2	Section 3
SELEC	PRESB	GJOB
NGOOD	STEPS	ICIH
HELM	0.68	0.71
HEAV		
FIT	EVID	ENCOU
PUSH	IMM	BETTER
HOT	0.57	0.52
0.73		
	ENJOY	SEMPLY
STAM	LOUD	MANAG
COMM	USED	0.64
WARN	IRIT	
MACH	NHIGH	PRESS
DANG	0.66	RESPON
CONSP		COMPU
ENC	JHAND	WASTE
0.67	WHAND	0.79
	0.69	
PERCEN		
FORG		
0.62		
DIRT		
COLD		
WET		
0.78		

Table 7.16 Mean score and standard deviation of items in the pre and post reminder waves.

Mnemonic	Mean Pre-reminder 86 cases	Mean Total 107 cases	Mean Post-reminder 21 cases	Standard deviation Pre-reminder 86 cases	Standard deviation Total 107 cases	Standard deviation Post-reminder 21 cases
NEN	4.058	4.037	3.952	0.962	0.961	0.973
USED	3.477	3.523	3.714	1.176	1.152	1.056
LIKE	4.558	4.514	4.333	0.713	0.732	0.796
NHIGH	3.105	3.084	3.000	1.218	1.245	1.378
SHORT	4.326	4.336	4.381	0.710	0.672	0.498
IRIT	3.349	3.364	3.429	0.991	0.975	0.926
LOUD	2.837	2.879	3.048	0.879	0.918	1.071
PAST	4.419	4.402	4.333	0.677	0.671	0.658
NGOOD	4.047	4.037	4.000	1.016	0.990	0.894
SOME	4.047	4.037	4.000	0.932	0.931	0.949
BILS	3.395	3.383	3.333	0.961	0.968	1.017
EFF	3.663	3.673	3.714	0.876	0.898	1.007
ENC	2.663	2.617	2.429	1.058	1.052	1.028
STAM	4.360	4.346	4.286	0.810	0.802	0.784
CONSP	3.779	3.701	3.381	0.817	0.849	0.921
WORRY	3.977	3.907	3.619	0.811	0.875	1.071
PRES B	4.407	4.374	4.238	0.788	0.759	0.625
STEPS	4.337	4.355	4.429	0.849	0.816	0.676
SHAND	4.349	4.355	4.381	0.891	0.838	0.590
FAMI	4.407	4.393	4.333	0.999	1.044	1.238
JHAND	4.012	3.972	3.810	0.744	0.806	1.030
WHAND	3.605	3.607	3.619	1.032	1.053	1.161
NDEF	3.779	3.785	3.810	0.758	0.789	0.928
PDEF	3.105	3.112	3.143	1.106	1.127	1.236
ENJ	4.233	4.224	4.190	0.821	1.816	0.814
DAMAGE	4.698	4.692	4.667	0.533	0.539	0.577
IMM	4.012	4.019	4.048	1.079	1.090	1.161
EVID	4.465	4.411	4.190	0.681	0.776	1.078
WORTH	4.291	4.196	3.810	0.852	0.966	1.289
WASTE	4.547	4.523	4.429	0.546	0.572	0.676

Table 7.16 continued

Mnemonic	Mean: Pre-reminder 86 cases	Mean: Total 107 cases	Mean: Post-reminder 21 cases	Standard deviation: Pre-reminder 86 cases	Standard deviation: Total 107 cases	Standard deviation: Post-reminder 21 cases
MANAG	2.744	2.757	2.810	0.923	0.950	1.078
THEOR	3.372	3.327	3.143	0.783	0.810	0.910
STON	3.244	3.234	3.190	0.612	0.667	0.873
SEMPLY	2.860	2.822	2.667	0.799	0.833	0.966
BETTER	2.953	2.953	2.952	0.718	0.745	0.865
ATTEN	4.349	4.336	4.286	0.647	0.658	0.717
PRESS	3.605	3.561	3.381	1.066	1.092	1.203
GJOB	3.628	3.617	3.571	0.798	0.832	0.978
ICIH	3.919	3.860	3.619	0.739	0.829	1.117
LEGAL	2.814	2.822	2.857	1.046	1.071	1.195
ENCOV	2.523	2.523	2.524	0.942	0.965	1.078
BENEF	3.965	3.907	3.667	0.727	0.734	0.730
COMPU	3.419	3.411	3.381	1.057	1.037	0.973
RESPON	3.209	3.215	3.238	1.064	1.046	0.995
TALK	3.953	4.000	4.190	0.701	0.687	0.602
FILM	4.151	4.168	4.238	0.604	0.606	0.625
MEMOR	4.012	3.972	3.810	0.604	0.621	0.680
PREF	2.465	2.467	2.476	0.715	0.705	0.680
POST	3.291	3.271	3.190	0.879	0.896	0.981
EDUC	3.500	3.449	3.238	1.015	1.057	1.221
HEAR	4.233	4.234	4.238	0.546	0.559	0.625
RESUL	3.860	3.925	4.190	0.722	0.723	0.680
XRAY	3.558	3.533	3.429	0.953	1.003	1.207
TBRK	3.965	3.963	3.952	0.727	0.764	0.921
CLINIC	4.151	4.187	4.333	0.473	0.498	0.577
DISCUSS	3.767	3.785	3.857	0.746	0.777	0.910
PERCEN	3.326	3.327	3.333	1.323	1.323	1.354
HELM	2.488	2.561	2.857	1.015	1.048	1.153
FIT	3.407	3.449	3.619	0.975	0.954	0.865
HEAV	3.256	3.262	3.286	0.897	0.883	0.845

Table 7.16 continued

Mnemonic	Mean			Standard deviation		
	Pre-reminder 86 cases	Total 107 cases	Post-reminder 21 cases	Pre-reminder 86 cases	Total 107 cases	Post-reminder 21 cases
FORG	3.500	3.477	3.381	0.979	1.013	1.161
SELEC	3.023	2.991	2.857	1.095	1.120	1.236
PUSH	3.023	3.047	3.143	1.107	0.994	0.910
HOT	2.826	2.916	3.286	1.008	1.001	0.902
COLD	3.907	3.879	3.762	0.566	0.562	0.539
DIRT	3.860	3.860	3.857	0.535	0.540	0.573
WET	3.895	3.879	3.810	0.435	0.470	0.602
DANG	3.663	3.607	3.381	0.862	0.949	1.244
COMM	2.663	2.636	2.524	1.047	1.050	1.078
MACH	3.337	3.318	3.238	0.989	0.977	0.944
WARN	2.814	2.794	2.714	1.023	1.035	1.102

When examining the relationships between variables using the common parametric statistical tests, the underlying assumption is that the relevant means are extracted from distributions which conform to the accepted statistical criteria of normality. These conditions are rarely completely fulfilled in this type of study as the data is generally 'non-normal' in some form. The use of transformational techniques is fraught with computational and conceptual difficulties. The simplest solution is to adopt non parametric statistics for use in the analysis, but it is a step which is unjustified in many cases. The loss of statistical power, and discriminatory ability experienced when using non parametric statistics would be highly detrimental to the success of some phases of this study, and is to be avoided if at all possible.

Boneau (1960) shows by means of his own work, and that of Norton (1951) that Student's 't'-test and the 'F' test used in analysis of variance are both extremely robust, and affected little by violation of the underlying assumptions of distribution normality. Boneau concludes that these tests are distribution free, but does qualify this statement. It was found that certain violations of the assumption of distribution normality do affect the distribution of the 't' and 'F' statistics.

The most common violation occurs in the case of non-homogeneous variances associated with greatly unequal group sizes. However, as this condition was not encountered in the research study, it was decided that the 't' and 'F' test of analysis of variance could be used sucessfully. Reinforcing this view was the observation that the distributions obtained in this study were not greatly non-normal, as demonstrated by the typical values of skew and kurtosis, given later in this chapter. Moreover the sample size producing each mean in this research programme was approximately an order of magnitude greater than the 5 to 15 cases used by Boneau in his research work. These larger group sizes would mitigate any effects of violating the underlying assumptions of normality. Additionally the bulk of statistical comparisons undertaken in this thesis are made either between mean values achieved by different populations on the same variable or the same populations on a given variable. In both cases, the distributions on a single variable tend to be similar, allowing the statistical comparisons to be made between non normal distributions with similar shapes. This similarity of distribution shapes would tend to reduce, again, the effect of the non normality of the underlying populations on the 't' tests, or 'F' tests in the analysis of variance. (Fields 1977).

Over all distributions, sample sizes, and deviations from normality experienced in this research programme, it is likely that the true probability for the 5% level of significance will lie within 1% of its nominal value, according to data provided by Boneau (1960). That is, an uncertainty of ± 1% exists about the 5% level of significance taken from standard tables.

Examination of the difference in item standard deviations between the pre-reminder and post-reminder populations can be conducted using table 7.16. It is shown that the largest difference in standard deviations between populations for any one item exists for the question with the mnemonic (DANG). However an 'F' test shows this difference to be non-significant at the 5% level, and hence variance (s^2) differences between the two populations for the remaining 70 variables will also be non significant. The F test is shown in table 7.17.

The simple analysis described above does raise an important point concerning the statistical validity of making multiple comparisons, 71 in the case described above.

It was apparent, a priori, that close investigation of the structure of the difference in attitude scale scores between the "pre-reminder" and "post-reminder" populations in this chapter, or the "pre-treatment" and "post-treatment" questionnaires in later chapters, would require multiple comparisons to be made. Complex analyses of variance are used in investigations throughout the remainder of this thesis, which indicate whether or not statistically significant differences exist between groups. Ultimately however, multiple comparisons must be made to investigate the fine structure of the differences delineated.

Such comparisons on groups of unequal size can be performed using Student's 't' tests, or a range of multiple comparison tests such as the Newman-Keuls, LSD Mod, or Sheffe. Unfortunately, multiple 't' tests can result in spuriously high numbers of differences between means being declared statitically significant. The remainder of the tests described above protect, to some degree, from this problem, but the results derived from them were found not to be in a form useful for the present study. John (1982, 1977) suggests two solutions to the problem of spurious significance using multiple 't' comparisons. Firstly, if (n) comparisons are to be made, the significance level (alpha) for each comparison can be set high, so that the significance level over all the (n) comparisons remains at an acceptable level. To attain, for example an overall significance level of 5% for 50 comparisons, each comparison would be performed at the 0.1% level. The second solution uses the same principle, involving first an analysis of variance to determine the likely sources of significant variation, performed at an acceptable level of statistical significance (alpha), with the subsequent 't' tests being performed at a significance level of (alpha/n). This technique is also described in Miller (1966) and Lee (1975) where it is also recommended that the residual mean square be used as the error estimate in the denominator of the 't' statistic fraction.

It was decided that generally this latter technique provided the better analysis method for use in this thesis, although in the case of simple multiple comparisons, such as the one described earlier, the preceding analysis of variance was not always necessary.

However, reverting to the pre-reminder and post-reminder variance comparison described earlier on the variable "DANG", it is now apparent that the conclusion reached that no statistically significant difference exists between the item variances exhibited by the pre-reminder and post-reminder populations can be stated with an even greater degree of certainty, as despite the multiple comparisons made, no statistically significant differences were shown to exist.

In addition to showing homogeneity of variance it is also possible to demonstrate that distribution skew is not a serious problem in the present study, although it does exist in the data.

The item "DANG" can once again be used as an example. Calculation of skew and kurtosis values for this item on both populations shows that the only derivation from normality occurs at the 2% "two-tailed" level in the skew of the pre-reminder distribution. (Skew observed = -1.176, skew tables, 2%=-0.575 for n = 86).

Having demonstrated the validity of conducting certain parametric tests upon the data obtained in this study, the difference in item means for the two populations can now be examined.

The largest difference between the pre-reminder and post-reminder populations exists on the item "HOT". Table 7.18 shows the results of Student's 't' test on the two means. This indicates that no statistical difference exists between the two populations for this item at the 5% level, a conclusion further reinforced by the concept of protection of multiple comparisons discussed earlier, as this particular comparison can be considered to be one of 71 possible. The result can also be applied to the remaining 70 items, as inspection of table 7.16 shows that a larger t value cannot be produced by comparing the mean scores achieved by the two populations on any other item.

Again, the two population distributions of the item "HOT" are slightly non-normal, the kurtosis values exceeding that for normality at the 1% level of significance in both populations. (Kurtosis tables, 1% level = 1.78, lower tail, kurtosis observed = 1.541 for n = 21. Kurtosis tables, 1% level = 2.24, lower tail, kurtosis observed = 1.81 for n = 86).

The tests of significance of distribution skew and kurtosis have been displayed to show that the typical non normalities of the various distributions are not extreme.

Furthermore, as the item mean scores of the post-reminder population are not significantly different from those achieved by the pre-reminder population, then the item mean scores for the total population will not differ significantly from the pre-reminder mean scores. That is, the addition of the post reminder questionnaires did not significantly change the results as demonstrated by the pre-reminder questionnaire.

Table 7.17 Examination of the item variance differences existing between the pre-reminder and post-reminder pilot questionnaire returns

Variable "DANG"

	Mean	S.D.	Variance	Skew	Kurtosis
Pre-reminder 86 cases	3.663	0.862	0.743	-1.176*	4.191
Post-reminder 21 cases	3.381	1.244	1.547	-0.919	2.613

* exceeds the 1 % level for normality

	Variance	df	F ratio
Pre-reminder questionnaires	0.7430	85	2.0826
Post-reminder questionnaires	1.5474	20	

$F_{tables,85,20,5\%} = 2.1950$ $\therefore$ accept the null hypothesis H_o

Table 7.18 Examination of the difference in means existing between the pre-reminder and post-reminder pilot questionnaire returns.

Variable HOT

	Mean	S.D.	Variance	Skew	Kurtosis
86 cases	2.826	1.008	1.016	-0.20	1.81*
21 cases	3.286	0.902	0.813	-0.589	1.541*

* exceeds the 1 % level for normality

't' test. Difference of two means

Pooled variance	=	0.97749
Degrees of freedom (df)	=	105 (85 + 20)
t_{calc}	=	1.8741
$t_{tables,105,5\%}$	=	1.981

$t_{calc} < t_{tables}$ $\therefore$ accept the null hypothesis

7.3 Discussion

Moser (1971) reports that mail surveys with a response rate of 10% have been reported, whilst occasionally reponse rates of over 90% are achieved. The response rate achieved by the pilot attitude questionnaires, is therefore, exceptional, and it is worthwhile to discuss the reasons for this, to put into perspective any response to future questionnaire exercises in the research programme.

It is possible that the site employees felt highly involved in the problem of industrial noise in their place of work, and responded well to any interest shown by outside bodies. If this was the case, a very high response can be expected in the main experiment. That employee's do consider noise to be a problem at work can be seen from the distribution of replies to questions 3, 6, 2 and 29 in particular, and shown in Appendix 7.4. However, if the decision whether or not to respond to the questionnaire was a function of the degree to which the employee felt that noise was a problem, then the later respondents, the post-reminder population, should score less highly on questions such as the ones mentioned earlier, when compared to the scores achieved by the pre-reminder population on these same questions.

As the analysis shown in section 7.2.2 does not indicate that any mean item score difference exists between the two populations, then this hypothesis cannot be substantiated. Because this reasoning also applies to all questions in the pilot attitude questionnaire, then the explanation for the high questionnaire success rate is less likely to be involved with the attitudes and interests of the respondents than with some other, external, factor.

This factor was probably the low sampling percentage used in each area. As only a few employees in each shift received a pilot attitude questionnaire, they could have felt that their views were specially important, thus encouraging a reply. The number of employees involved in each plant was too low for a meaningful analysis to be performed of the correlation between the number of unreturned questionnaires and the sampling percentage in each plant. However, the implication of the hypothesis is that such a high success rate could not be expected in response to the main waves of the attitude survey, when all personnel in the employee groups involved would receive a questionnaire.

As the pre-reminder and post-reminder item scores were not significantly different, it is unlikely that the third population, that which returned no questionnaires, would have exhibited an extreme discontinuity of attitude in that their views would have been entirely different from the other 93% of the population. This, taken with the fact that the non-respondents represented only 7% of the population, meant that the non- response to the pilot attitude questionnaire is highly unlikely to have either biased the generation of the attitude scales, or caused a signifcant bias on the mean item scores.

The similarity of the pre-reminder and post-reminder populations made the between-wave extrapolation of mean scores unnecessary. The mean item scores achieved by 93% of the population can be taken as a good estimate of those that would have been exhibited by the total population.

Factor and cluster analysis of the pilot attitude questionnaire data proved successful, with the techniques used resulting in the development of twelve attitude scales. Reference to tables 7.6, 7.8 and 7.10 showing the unrotated factor matrices for the three variable sections indicates that in each case the first factor loadings are generally high and unipolar. This reveals that a general factor or attitude underlies the fine structure of the variable patterns within each section. It is likely that the three general factors thus defined are manifestations of the same one, a concept which will be explored in chapter 8 where the results of a single factor analysis of the combined variables from the three subsets is undertaken.

Inspection of the factor eigenvalues of the rotated factor matrices in tables 7.2, 7.9 and 7.11 indicates that several are below unity, which underlines the advantage of proceding from the factor solution to the refined scales via a clustering technique, and the use of Cronbach's alpha coefficient.

In this way trivial factors can be removed and overall scale reliabilities improved. The scale reliabilities measured were satisfactory; the average reliability being 0.67. In general a scale reliability of 0.5 would be considered unsatisfactory, whilst a scale reliability of 0.85 is rarely achieved in practice. (McKennell 1977).

The scales themselves were found to consist of logically related items, and were thus readily identifiable, a topic which is discussed in chapter 8.

One of the shortest scales is of particular interest; that represented by the variables "PERCEN" and "FORG", items 60 and 64 respectively in the pilot attitude questionnaire, and reproduced again below.

60. During a working day, I wear hearing protection ; (followed by a series of alternative time periods).

64. I keep forgeting to take hearing protectors onto the job.

It would appear from the correlation between these two items, (r=0.45) that the hearing protector usage in a noisy area is dependent to a large extent upon the employee remembering to bring the hearing protectors with him when he begins a job. This is encouraging, indicating a starting point for the educational campaign and the need to provide storage facilities for hearing protection closer to the site of usage.

During the single large scale factor anlaysis performed simultaneously on all three variable sections and described in chapter 8, a third item became associated with the scale described above. This new variable is related to the employee's subjective impression of the noise environment, and must constitute a second important mechanism by which the usage of hearing protection is influenced.

Appendix 7.4 shows the distribution of item responses obtained from the pilot attitude questionnaire data, and gives a valuable insight into the manner in which the industrial population views noise as a hazard to the hearing. The data also indicate that the population appeared to be well disposed towards the objectives of the research at that stage of the programme.

7.4 Conclusions

The pilot attitude questionnaire was carefully compiled using the procedure advocated by McKennell (1974). Using the Wilton site weekly payroll sheets, a pseudo-random selection of 124 weekly paid employees was made, within a framework which was designed to conform to certain criteria. These criteira were such that a balance was maintained between developing the questionnaire on the specific population to be used in the main study, known as the prime group, and obtaining a wide sampling of attitudes. The sampling percentage was maintained at a low enough level in the prime group of plants to ensure, as far as possible, that this population was not disturbed unduly prior to the commencement of the main study. Fitters and process operators were sampled in the same ratio as they were present on the factory floor.

Each of the selected individuals received a pilot attitude questionnaire through the internal post. Of the 116 questionnaires which reached the addressee, 93% were returned completed. This percentage was considered to be excellent.

An examination of the reasons for the high return rate suggested that it had occurred because the pilot attitude questionnaire was a sampling excercise, and that the returns from the pre-treatment attitude questionnaire despatch could be lower, as this was to be a census. It was decided, therefore, to publicise by word of mouth the advent of the pre-treamtent attitude questionnaires in order to maximise the returns from the excercise.

Examination of the pilot attitude questionaire pre-reminder and post-reminder item response distributions showed a proportion to be slightly statistically non-normal. However, reference to the extent of the non-normality and previous statistical work by other authors showed that these non-normalities would not preclude the use of parametric statistics.

Comparison of the mean item scores achieved by the pre-reminder and post-reminder populations showed that no statistically significant difference existed. Furthermore, as non-respondents totalled only 7% of the population, it was thought reasonable to take the mean item responses in the pilot attitude survey as being a good estimate of the total population mean item scores.

Factor and cluster analysis of the pilot attitude questionnaire data was successful, with twelve attitude scales being identified. The scaling techniques used resulted in a reduction of the total number of questions needed in the final version of the attitude questionnaire, which was compiled using the results of the analyses discussed in the chapter. The reliability coefficients for each of the derived scales was thought to be satisfactory.

Finally it can be concluded that industrial personnel do exhibit a definite structure of attitudes towards noise and associated topics, which can be scaled reliably.

CHAPTER 8

THE PRE-TREATMENT QUESTIONNAIRE

8.0 Introduction

The items comprising the scales defined in chapter 7 were compiled to form the main attitude questionnaire which is shown in Appendix 8.1 . As this refined questionnaire was relatively short, consisting of 40 questions, the opportunity was taken to add 16 further questions, the answers to which were of factual interest to the research programme.

This chapter details the despatch of these pre-treatment attitude questionnaires to the eight prime group plants in the main experiment and the analysis of the subsequent returns.

The development of the attitude scales was described in chapter 7, and was completed by dividing the variables into three groups, as the required factor analysis needed more memory space than was available on the current University computer if the analysis of all variables was to be undertaken simultaneously. However, the installation of a new, more powerful, ICL 2900 computer gave the opportunity for the factor analysis of all variables to be completed simultaneously. The benefits were twofold. Firstly, it allowed a check on whether or not the division by the author of the variables into three subsets had caused any artificial constraints, preventing, for example, a particular item from being associated with its proper scale. Secondly , it was possible to evaluate whether or not the attitude structure delineated in chapter 7 was stable, and could be observed in a fresh population. Thus the second analysis provided a reliability check on the initial Pilot Attitude Questionnaire work.

The factor analysis technique was taken one stage further than is usual during this second analysis. The overall scores attained on each scale were subjected to a further factor analysis to ascertain if "super scales" could be formed describing broad underlying trends, and, furthermore, whether these could be interpreted. The attempt to form "super scales" could be considered a test of the orthogonality of the individual scales, as ideally the scale scores should not be highly correlated.

Finally the analysis of the pre-treatment attitude questionnaires allowed an estimate to be made of the possible biasing effect of the questionnaires which were not returned, and hence the likely effect upon the comparison to be made of pre-treatment and post-treatment attitudes.

A database was designed and implemented on the new ICL 2900 computer, necessitating the transference of many files and records from the 1900 computer, previously used in the research programme. The database was required as it was known that it might be necessary to contact a large proportion of the employees up to as many as six times during the research study. As over 2000 employees participated in the research work, the administration of the programme required computer assistance.

As one example, a program was written to abstract the addresses from the database, and print them on adhesive labels ready for use in the questionnaire despatches. On another occasion the management on the ICI site decided for internal administrative reasons to change the works number of one third of the employees included in the research programme. A computer card listing was obtained from the site, and this was run against the programme database to change efficiently the employee works numbers. A typical database program is shown in Appendix 8.2 .

Pre-treatment attitude questionnaires were sent to 1716 employees in the eight prime group plants participating in the main experiment.

Employees who did not return a completed attitude questionnaire within three weeks were sent a reminder letter together with a fresh questionnaire. This resulted in approximately 78.4% of the questionnaires being returned within a six week period. It was thought unwise to send a second reminder letter to defaulting employees at this stage, as discussion with plant managers, and comment from the Trade Unions suggested that a further reminder letter would be counterproductive, as it was likely to cause a loss of employee cooperation with the whole research programme. Furthermore, if further pursuit of those employees not returning questionnaires occurred this action alone could change attitudes on the test plants, affecting the whole study adversely.

8.1 Validity of the Attitude Structure Defined by the Pilot Attitude Questionnaire Study

The objectives of the study have been defined in section 8.0

8.1.1 Method

The 1716 pre-treatment attitude questionnaires were despatched approximately 9 months after the pilot attitude questionnaires, and 1346 completed, usable, questionnaires were returned. These were coded in accordance with the procedure outlined in chapter 5, and subjected to one, large, factor analysis on the newly installed 2900 computer.

8.1.2 Results and Discussion

Table 8.1 shows the estimates of the communalities of the 40 items, and the eigenvalues of the initial factors which could be extracted. The item communalities are satisfactory; the percentage of the item variance held in common with other items in the set ranged from 57% (WET), to a minimum of 8% (CONSP). It would therefore appear that the items are exploring the same general attitude universe, although attention is given during the final scale development to the relationship to the scale set of the item (CONSP), and possibly (NGOOD), which also exhibited a low communality.

Table 8.1 shows that if the criterion discussed in chapter 4 for terminating the extraction of orthogonal vectors from the correlation matrix is used, 11 factors are defined. Table 8.2 shows the result of extracting these factors, and demonstrates that the early factors are very strong; factor 1, for example explaining approximately 25% of the data variance. It would, therefore, appear that the items are well correlated, and are measuring some sizeable general attitude towards, presumably, occupational health, or safety at work. The late factors such as no 11, explain little of the variance and are likely to be of little consequence even in the final rotated solution. Table 8.2 shows the final item communalities, confirming that items "CONSP" and "NGOOD" are only loosely associated with the other items, which are well correlated.

The 11 factors were rotated using the method described in chapter 6. The factor solution is shown in table 8.3 which gives the final factor loadings. The defining items are shown asterisked. Allocation of an item to a factor was made using the method discussed in chapter 6, which included the decision to retain items even if their maximum factor loading fell below the arbitrary cut-off point of 0.3. This occurred in two items from a total of 40, these being the items with mnemonics "CONSP" and "NGOOD": the full questions and their mnemonics are shown in Appendix 8.1. The items "NGOOD" and "CONSP" could be rejected if appropriate, during the clustering procedure using the alpha coefficient, if it finally appeared that they were not a logical element in the emerging factor structure. The procedure described in chapter 4 which was to be used if an item loaded equally on more than one factor was invoked for 4 items from the total of 40, these being "WASTE", "DANG", "SELEC" and "ENCOU".

The rotated factor solution was then subjected to clustering to achieve the final attitude scales. The elements lying along the main diagonal of the final restructured correlation matrix are shown in table 8.4 together with the new scale reliabilities. These are good, all lying between the bounds for scale acceptability discussed in chapter 6 except for the fourth scale, which has a reliability coefficient of 0.83, slightly higher than that though to be strictly necessary (0.8).

The decision to retain the items 'NGOOD' and 'CONSP' in the factor solution can be justified by considering the alpha coefficients. Despite the relatively low intercorrelation with other items in the scale, removal of "NGOOD" from scale 4 would change alpha from 0.66 to 0.68, an unimportant improvement in reliability considering the loss of meaningful content caused by deletion of this item from the scale.

Removal of the item "CONSP" from scale 8 would have a greater effect upon scale reliability than in the previous case, the improvement in alpha being from 0.64 to 0.71. Again, however, it was thought that the improvement in scale content caused by retention of this item outweighed the small degradation in scale reliability.

The attitude scales developed were identified, and are shown summarised in table 8.5. The attitude scales developed using the 1346 pre-treatment

Table 8.1 Estimated communalities, eigenvalues and proportion of variance, calculated from the unaltered correlation matrix.

VARIABLE	EST COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
JHAND	.32486	1	4.52346	11.3	11.3
WHAND	.31854	2	3.79709	9.5	20.8
ENJ	.16697	3	2.32444	5.8	26.6
LOUD	.28858	4	2.06288	5.2	31.8
NHIGH	.20637	5	1.73713	4.3	36.1
USED	.22885	6	1.60529	4.0	40.1
IRIT	.32780	7	1.39693	3.5	43.6
STEPS	.37973	8	1.32270	3.3	46.9
PRESB	.36169	9	1.28635	3.2	50.1
PRESS	.32828	10	1.17017	2.9	53.1
RESPON	.34930	11	1.01019	2.5	55.6
COMPU	.39480	12	.99097	2.5	58.1
WASTE	.29406	13	.93982	2.3	60.4
GJOB	.42285	14	.89780	2.2	62.7
ICIH	.29582	15	.85856	2.1	64.8
SEMPLY	.31747	16	.84650	2.1	66.9
MANAG	.33243	17	.79864	2.0	68.9
PERCEN	.31885	18	.78003	2.0	70.9
FORG	.27531	19	.77528	1.9	72.8
STAM	.17726	20	.75317	1.9	74.7
COMM	.24722	21	.72903	1.8	76.5
ENC	.24799	22	.68162	1.7	78.2
CONSP	.08480	23	.64698	1.6	79.8
WARN	.28242	24	.61594	1.5	81.4
MACH	.28658	25	.60464	1.5	82.9
DANG	.38980	26	.57708	1.4	84.3
DIRT	.47946	27	.55371	1.4	85.7
COLD	.54597	28	.52739	1.3	87.0
WET	.57893	29	.51855	1.3	88.3
NGOOD	.10375	30	.51370	1.3	89.6
HELM	.20483	31	.50400	1.3	90.9
FIT	.33758	32	.47691	1.2	92.1
HEAV	.35919	33	.46914	1.2	93.2
SELEC	.23838	34	.45489	1.1	94.4
PUSH	.36434	35	.43140	1.1	95.5
HOT	.25233	36	.41697	1.0	96.5
IMM	.28533	37	.39627	1.0	97.5
EVID	.35051	38	.38864	1.0	98.5
ENCOU	.29186	39	.34968	.9	99.3
BETTER	.30421	40	.26606	.7	100.0

Table 8.2 Showing the final communalities and the percentage of the common variance accounted for by unrotated factors.

VARIABLE	COMMUNALITY
JHAND	.50917
WHAND	.49994
ENJ	.18791
LOUD	.41346
NHIGH	.24431
USED	.30489
IRIT	.47113
STEPS	.53280
PRESB	.50607
PRESS	.40880
RESPON	.50245
COMPU	.52751
WASTE	.33127
GJOB	.63420
ICIH	.34610
SEMPLY	.48054
MANAG	.53545
PERCEN	.52173
FORG	.35921
STAM	.19291
COMM	.35033
ENC	.28264
CONSP	.06625
WARN	.44883
MACH	.35957
DANG	.45291
DIRT	.53078
COLD	.66456
WET	.72329
NGOOD	.09017
HELM	.22351
FIT	.44391
HEAV	.43512
SELEC	.24778
PUSH	.48535
HOT	.27995
IMM	.30050
EVID	.42882
ENCOU	.35399
BETTER	.36021

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	3.95345	24.7	24.7
2	3.21097	20.0	44.7
3	1.79283	11.2	55.8
4	1.56389	9.8	65.6
5	1.20837	7.5	73.1
6	1.04849	6.5	79.7
7	.83782	5.2	84.9
8	.78031	4.9	89.8
9	.69537	4.3	94.1
10	.59068	3.7	97.8
11	.35615	2.2	100.0

Table 8.3 The rotated orthogonal factor matrix (terminal solution).

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
JHAND	.07615	-.01044	-.05082	.02618	.02453	-.03954
WHAND	-.03688	.00323	.02286	.05291	-.01460	-.04292
ENJ	.11403	-.03131	.00502	.06845	.02954	-.06406
LOUD	-.02149	-.10670	-.04943	.07723	-.01404	-.09891
NHIGH	.17052	.01593	.02023	.05249	-.04635	.04879
USED	.24600	-.01943	-.06711	-.04473	-.16248	.02136
IRIT	.12984	-.11416	-.07460	.03384	-.10689	-.07059
STEPS	.68349 ●	.03072	.01841	.03514	-.03907	-.04127
PRESB	.66560 ●	.00319	.01276	.07023	-.03594	.01440
PRESS	.20503	.10118	.03781	.56665 ●	.01609	.03404
RESPON	-.01682	.03247	-.03589	.69886 ●	-.05018	.07717
COMPU	.08032	.03468	.06930	.68750 ●	.01655	.10342
WASTE	.35108	.01042	.08569	.36134 ●	.07332	.07601
GJOB	-.08686	.15432	.04812	.04298	.75044 ●	.09687
ICIH	.01774	.09051	.09901	.08456	.52401 ●	.09611
SEMPLY	.14064	-.05551	.03870	.04903	-.06055	-.03255
MANAG	.11464	-.05432	.01356	.02699	-.16879	.01207
PERCEN	.09336	-.05737	.03181	.15087	-.03560	.06836
FORG	.07009	.08296	.04683	.09525	.08625	.12217
STAM	.33391 ●	.03439	.16211	.11061	-.05099	.06296
COMM	-.09936	.10792	-.03585	.07615	.06851	.54428 ●
ENC	.10458	.15899	.05296	-.01224	.02134	.24081
CONSP	.03323	.14727	.04927	.02022	.05201	.17325 ●
WARN	-.01101	.10585	.00672	.09601	.08868	.64433 ●
MACH	.09239	.14442	.11449	.00705	.06960	.49561 ●
DANG	.24741	.14723	.18415	.12487	.10527	.35604 ●
DIRT	.06007	.15317	.68644 ●	.02668	.06640	.07808
COLD	.14099	.07194	.78495 ●	.04138	.07530	-.00725
WET	.11163	.11562	.83190 ●	.01924	.02303	.05127
NGOOD	.19702 ●	.06985	.09203	.06305	.06813	.01917
HELM	-.03127	.42795 ●	-.02105	.01251	.05989	.16613
FIT	-.04689	.60891 ●	.06364	.03965	.19674	.05712
HEAV	.03562	.62686 ●	.12476	.04846	.08335	.07201
SELEC	-.02204	.32425	-.00387	.00240	.34759 ●	.10474
PUSH	-.00879	.68546 ●	.05964	-.01462	.05645	.03926
HOT	.07418	.46291 ●	.12341	.04811	.07083	.08624
IMM	.47087 ●	-.07071	.09497	-.01429	-.05519	-.02093
EVID	.55674 ●	-.02819	.05690	.10283	-.04831	-.01695
ENCOU	-.03795	.13091	-.03259	-.33826	.34384 ●	.04760
BETTER	-.04992	.17585	.03226	-.15170	.51725 ●	.05613

KEY

● Defining item

Table 8.3 continued

	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10	FACTOR 11
JHAND	.10458	.69418 ●	.04639	-.05059	-.01718
WHAND	.07684	.69381 ●	.02659	-.06844	.02307
ENJ	.25048	.31177 ●	-.01488	.06167	-.01670
LOUD	.59855 ●	.10579	-.10573	-.04642	.02101
NHIGH	-.08607	-.01768	.43804 ●	.08576	-.01809
USED	.37082 ●	.00389	.26845	.02364	-.02216
IRIT	.62868 ●	.14931	-.00480	.00674	.02275
STEPS	-.04220	.00524	.10397	.04771	-.21214
PRESB	-.02986	.04079	.04307	.02982	-.22614
PRESS	-.00101	.02409	.10470	.07726	.12276
RESPON	.03300	.01746	.03582	-.01632	-.00091
COMPU	.02957	.06853	.12954	.05494	-.07784
WASTE	.05620	.02797	.22551	.03720	.05162
GJOB	-.01887	.03715	-.02011	-.14589	-.05205
ICIM	-.00626	.06307	-.01877	-.17508	-.04234
SEMPLY	.01438	-.06078	.02304	.66679 ●	-.00073
MANAG	-.01874	-.01860	.04091	.69801 ●	.01500
PERCEN	.04105	.12647	.67190 ●	-.00423	-.10422
FORG	-.00761	-.00297	.54995 ●	-.01545	.10504
STAM	.00004	.00054	.06977	.09179	.14785
COMM	-.04486	-.06974	.03388	-.05039	-.10114
ENC	-.29756 ●	-.12483	.26039	-.03996	.10725
CONSP	-.06085	-.01450	.05606	.02663	.01184
WARN	-.03074	.02220	.04743	.02259	-.03185
MACH	-.07097	-.07258	.15057	-.01069	.18292
DANG	-.20706	-.06724	.30989	-.03429	.19511
DIRT	-.11206	-.03004	.03818	-.01275	.07977
COLD	-.02400	-.00112	.09516	.05566	-.05649
WET	-.03857	.00468	-.00187	.01532	.01088
NGOOD	.02676	.08321	-.02704	.09046	.11162
HELM	-.01634	-.03311	.05983	-.01773	.04842
FIT	-.00249	.02188	.03668	-.06485	-.13156
HEAV	-.09501	-.00081	.03740	.01995	.00565
SELEC	-.04779	.01383	-.01947	-.08616	-.00804
PUSH	-.06515	.04795	-.01308	.00830	-.01165
HOT	-.08557	-.07327	-.04621	-.05679	.11006
IMM	.11534	-.01072	.11729	.08218	.16476
EVID	.19133	.06388	.16660	.04307	.17700
ENCOU	-.18963	-.14599	.01273	.15421	.13498
BETTER	-.11328	-.04559	.05764	.06193	.09972

KEY

● Defining item

Table 8.4 Showing the main diagonal components of the restructured 40 x 40 correlation matrix. 1346 cases.

	PRESS	RESPON	COMPU	WASTE
PRESS				
RESPON	0·410			
COMPU	0·466	0·486		
WASTE	0·312	0·238	0·317	

	NGOOD	STEPS	PRESB	STAM	IMM	EVID
NGOOD						
STEPS	0·132					
PRESB	0·095	0·542				
STAM	0·126	0·186	0·221			
IMM	0·085	0·308	0·236	0·204		
EVID	0·124	0·335	0·340	0·255	0·439	

	DIRT	COLD	WET
DIRT			
COLD	0·560		
WET	0·617	0·681	

	GJOB	ICIH	ENCOV	BETTER	SELEC
GJOB					
ICIH	0·491				
ENCOV	0·235	0·074			
BETTER	0·397	0·233	0·363		
SELEC	0·331	0·252	0·146	0·244	

Table 8.4 continued.

	JHAND	WHAND
JHAND		
WHAND	0·507	

	NHIGH	PERCEN	FORG
NHGIH			
PERCEN	0·334		
FORG	0·244	0·390	

	SEMPLY	MANAG
SEMPLY		
MANAG	0·520	

Table 8.4 continued.

	COMM	WARN	MACH	DANG	CONSP	ENC
COMM						
WARN	0·413					
MACH	0·224	0·361				
DANG	0·197	0·237	0·399			
CONSP	0·120	0·132	0·177	0·169		
ENC	0·176	0·176	0·246	0·312	0·107	

	HELM	FIT	HEAV	PUSH	HOT
HELM					
FIT	0·274				
HEAV	0·245	0·428			
PUSH	0·278	0·434	0·492		
HOT	0·262	0·285	0·309	0·315	

	LOUD	USED	IRIT	ENJ
LOUD				
USED	0·193			
IRIT	0·422	0·298		
ENJ	0·175	0·126	0·239	

TABLE 8.5 SHOWING THE ITEMS CONTRIBUTING TO THE FINAL SCALES. ITEM MNEMONICS ARE ALSO SHOWN

SCALE 1 Measuring the attitude towards belief in noise induced hearing loss as a serious occupational hazard

Scale mnemonic NIHL Alpha coefficient 0.66

		item mnemonic
31	Wearing hearing protection will not prevent my hearing from being damaged by loud noise.	NGOOD
9	Most people go deaf when they get older, so there is no need to worry about a little extra deafness now.	PRESB
8	I only need to take steps to protect my hearing if I think I am going deaf.	STEPS*
39	People who wear hearing protectors have not got the stamina needed to work in noise.	STAM
14	In my experience, most people's hearing appears to be immune to damage from noise.	IMM
15	I have seen no evidence that noise damages the hearing and so do not really believe it.	EVID

*Defining item.

SCALE 2 Measuring the attitude towards the use of industrial discipline to enforce the usage of hearing protection

Scale mnemonic ENF Alpha coefficient 0.70

23	I should not be pressurised into wearing hearing protection.	PRESS
24	Somebody should be made responsible for seeing that we wear our hearing protection.	RESPON
26	Wearing hearing protectors should be made compulsory.	*COMPU
25	Anybody who tries to get me to wear hearing protectors is wasting their time.	WASTE

*Defining item

TABLE 8.5 CONTINUED. SHOWING THE ITEMS CONTRIBUTING TO THE SCALES. ITEM MNEMONICS ARE ALSO SHOWN

SCALE 3 Measuring attitude towards the frequency of use of hearing protection

Scale mnemonic	NONUSE	Alpha coefficient 0.59
		item mnemonic
30	During the working day I wear hearing protection (1) Never (2) Less than a quarter of the time (3) Less than half the time (4) Less than three-quarters of the time (5) Nearly all the time.	*PERCEN
42	I keep forgetting to take hearing protectors onto the job.	FORG
1	I wear hearing protectors only when the noise levels are very high	NHIGH

*Defining item

SCALE 4 Measuring the attitude towards the effect of the environment upon the usage of hearing protection

Scale mnemonic	ENVIR	Alpha coefficient 0.83
37	It is too dirty where I work to wear hearing protectors comfortably.	DIRT
35	It is too cold where I work to wear hearing protectors comfortably.	COLD
36	It is too wet where I work to wear hearing protectors comfortably.	*WET

*Defining item.

SCALE 5 Measuring the attitude towards the comfort of hearing protection

Scale mnemonic	ACCEPT	Alpha coefficient 0.71
27	It is difficult to wear earmuffs with a safety helmet.	HELM
32	Earmuffs are too heavy.	HEAV
33	Hearing protectors usually fit well.	FIT

TABLE 8.5 CONTINUED. SHOWING THE ITEMS CONTRIBUTING TO THE SCALES. ITEM MNEMONICS ARE ALSO SHOWN

		item mnemonic
34	Earmuffs press too much to the side of the head.	*PUSH
29	It is too hot where I work to wear hearing protectors comfortably.	HOT

*Defining item

SCALE 6 Measuring the attitude towards the credibility of Southampton University as an independent and neutral research body

Scale mnemonic CONTROL Alpha coefficient 0.68

16	The management is carrying out this noise safety campaign.	MANAG
17	The Southampton University research team are being employed by the management to carry out this noise safety campaign.	*SEMPLY

*Defining item.

SCALE 7 Measuring the attitude towards the adequacy of the hearing conservation programme

Scale mnemonic PROG Alpha coefficient 0.66

28	There is a wide enough selection of hearing protectors available from which I can choose a pair.	SELEC
20	ICI are making a good job of the noise safety compaign.	*GJOB
19	ICI is concerned about my health.	ICIH
18	ICI should do more to encourage me to wear hearing protection.	ENCOU
21	I think this noise campaign could be run better.	BETTER

*Defining item

TABLE 8.5 CONTINUED. SHOWING THE ITEMS CONTRIBUTING TO THE SCALES. ITEM MNEMONICS ARE ALSO SHOWN

SCALE 8 Measuring the attitude towards the isolation caused by the use of hearing protection

Scale mnemonic ISO Alpha coefficent 0.64

		item mnemonic
38	Wearing hearing protection does not make it any more difficult to communicate with my workmates.	COMM
40	Wearing hearing protectors does not make it any harder for me to hear warning sounds.	WARN.
41	I cannot tell if my equipment is working properly when I wear hearing protectors.	*MACH
43	Wearing hearing protectors makes me forgetful of the dangers from the equipment with which I am working.	DANG
7	Wearing earmuffs does not make me feel conspicuous.	CONSP
6	When I wear hearing protection I feel enclosed in a world of my own.	ENC

*Defining item.

SCALE 9 Measuring the attitude towards the handicap to a normal working life caused by a noise induced hearing loss

Scale mnemonic COMPET Alpha coefficient 0.67

10	The partly deaf person would have difficulty in finding and keeping a job he wanted to do.	JHAND
11	The partly deaf person is a hazard to himself on most jobs around the plant.	*WHAND

*Defining item.

TABLE 8.5 CONTINUED. SHOWING THE ITEMS CONTRIBUTING TO THE SCALES. ITEM MNEMONICS ARE ALSO SHOWN

SCALE 10 Measuring the attitude towards the effect of noise on behaviour

Scale mnemonic BEHAV Alpha coefficient 0.56

		item mnemonic
3	Being partly deaf would ruin the enjoyment I get from most things in life.	ENJ
2	If the noise was not so loud, I could get a lot more work done.	LOUD
4	It does not take long to get used to the noise at work.	USED
5	Working in a noisy area makes me feel irritable or depressed.	*IRIT

*Defining item.

questionnaires can be compared with those defined using the 107 pilot attitude questionnaires. Figure 8.1 compares the two sets of attitude structures. Each mnemonic represents an item, and each group of mnemonics, a scale. The figures given below each scale are the alpha coefficients attained in the two analyses

The arrows on figure 8.1 show the manner in which the questions changed position amongst the scales as a result of the second factor analyisis. It can be seen that only four questions migrated between scales, and they did so across a boundary which represented the artifical separation of the three sections of the analysis performed on the pilot attitude questionnaires. This implies that the questions were only able to occupy their correct positons when it proved possible to analyse all the questions simultaneously.

Two of the short scales developed in the first analysis joined with other scales to yield the ten final attitude scales.

One of the most interesting scales finally developed was that containing the three items PERCEN, FORG and NHIGH. PERCEN effectively measures the subjects admitted use of hearing protection, and of all the available items correlates the most highly with FORG and NHIGH. The former relates to the employee remembering to bring his hearing protection into noisy areas, whilst the latter item relates to the employee's perception of the noisiness of the work environment. These two aspects might therefore indicate the points at which pressure should be exerted to increase the success of a hearing conservation programme.

Figure 8.1 shows very strongly that the attitude structures defined are stable, having been verified essentially on two populations, and measured at two different points of time. The small changes in structure which did occur between analyses and which resulted in the final attitude structure used thorughout the rest of the study, can be ascribed to two reasons. Firstly the analysis was undertaken on all items simultaneously, rather than in three sections as was the case for the pilot attitude study analysis. Secondly, a different number of items were included in the two analyses, causing different numbers of factors to be extracted. Extraction of different numbers of factors can change a factor solution (Baker 1980).

The ten derived scales, their mnemonics and constituent items are shown in table 8.5 and bear the interpretation shown in the scale titles. Interpretation was made after consideration of the trend of the individual questions, with special consideration being given to the defining items.

The scale intepretations are listed here for ease of consideration.

Scale 1 Measuring the attitude towards belief in noise induced hearing
NIHL loss as a serious occupational hazard.

Scale 2 Measuring the attitude towards the use of industrial discipline
ENF to enforce the usage of hearing protection.

Scale 3 Measuring the attitude towards the frequency of use of hearing
NONUSE protection.

Scale 4 Measuring the attitude towards the effect of the environment upon
ENVIR the usage of hearing protection.

Scale 5 Measuring the attitude towards the comfort of hearing protection
ACCEPT

Scale 6 Measuring the attitude towards the credibility of Southampton
CONTROL University as an independent and neutral research body.

Scale 7 Measuring the attitude towards the adequacy of the hearing
PROG conservation programme.

Scale 8 Measuring the attitude towards the isolation caused by the use
ISO of hearing protection.

Scale 9 Measuring the attitude towards the handicap in a normal working
COMPET life caused by a noise induced hearing loss.

Scale 10 Measuring the attitude towards the effect of noise on behaviour.
BEHAV

8.2 The global attitude scales

The population attitude structure was explored further, to investigate the general attitude continua which could be underlying the attitude dimensions measured by the developed scales. Furthermore, although the attitude scales had been developed so as to be orthogonal, it was by no means certain that the attitude scale scores would be constrained thus. Accordingly it was decided that the relationship between the scales could be investigated by means of a further factor analysis.

8.2.1 Method

A computer programme was written to calculate the scale scores from the questionnaire responses from each employee returning a pre-treatment questionnaire. The scale scores themselves were treated as items, and subjected to the type of factor analysis described in chapter 6. Cluster analysis was not undertaken, as the investigation was of a general nature on a small number of items, and not designed to produce calibrated scales.

8.2.2 Results and discussion

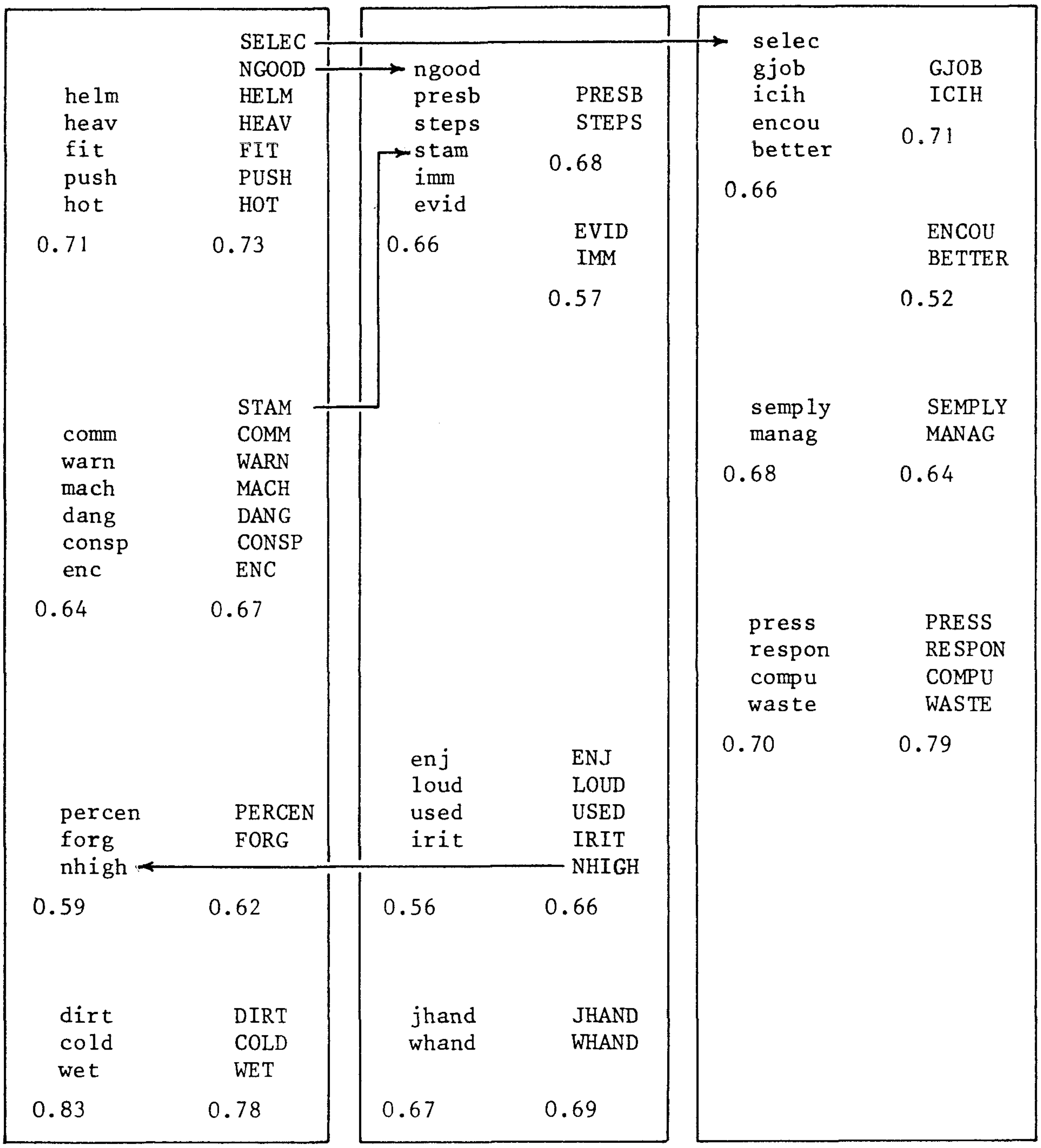
The results of this factor analysis appear in table 8.6 which indicates that the ten scales can themselves be grouped into 3 "superscales". Allocation of the items to the factors was made using the criteria developed in chapter 6.

The variable "ISO" loads almost equally on factors 1 and 2, allocation being made to factor 1 after considering the relationship of this loading to that of other variables loading significantly on factor 1.

It would appear from the groupings that the ten scales are measuring attitudes in three general areas; firstly, the usage of hearing protection and its relationsip with the prevention of noise induced hearing loss; secondly the manner in which the hearing conservation programme is being undertaken and thirdly, the effect of noise upon the ability to work.

This factor analysis provides some measure of the orthogonality of the ten attitude scales developed. Ideally the correlation between the scale

Figure 8.1 The Scale Migration Diagram



Question Mnemonics : Lower case represent the results of one factor analysis of forty questions (1346 cases)

Question Mnemonics : Upper case represent the results of three factor analyses of seventy one questions (107 cases)

Alpha coefficients are given below each scale

Table 8.6 Showing scale associations by means of factor analysis

Variable	Communality
NIHL	0.32943
ENF	0.22960
ISO	0.40702
NONUSE	0.23683
PROG	0.36302
COMPET	0.20684
BEHAV	0.37143
CONTROL	0.17571
ACCEPT	0.37840
ENVIR	0.15574

	Factor 1	Factor 2	Factor 3
NIHL	0.54583	-0.11301	0.13685
ENF	0.46926	0.02331	0.09407
ISO	0.41373	0.40648	-0.26575
NONUSE	0.48338	0.03878	0.04090
PROG	-0.05240	0.59064	-0.10688
COMPET	0.04334	0.00065	0.45273
BEHAV	0.11567	-0.29964	0.51795
CONTROL	0.26144	-0.29834	-0.13545
ACCEPT	0.15281	0.58643	-0.10558
ENVIR	0.30561	0.22542	-0.10740
Alpha	0.664	0.448	0.372

Factor	Eigenvalue	PCT of var	Cum PCT
1	1.37389	48.1	48.1
2	1.08148	37.9	86.0
3	0.39865	14.0	100.0

scores would be zero, with a corresponding zero alpha coefficient. The alpha coefficients for the superscales defined by factors 2 and 3 are satisfactorily small as shown in table 8.6. Factor 1 however, has a reasonably large coefficient of reliability, suggesting that the scales comprising this superscale are inter-related to some extent.

8.2.3 Conclusion

Three general attitude continua were identified by the analysis method described above. Fur thermore, the relationship between the scale scores was found to be such that they could not be described as truly orthogonal, this being most noticeable in the case of those scales comprising the first superscale.

8.3 A Study of the effect of the non-return of a percentage of the questionnaires despatched

Over 78% of the pre-treatment attitude questionnaires were returned. Fifty per cent were received before the reminder letter was despatched (early returns), and 28% after this letter was received by employees (late returns). The return percentage was similar from each plant, and is discussed in chapter 10.

The overall success rate of 78% was deemed to be extremely good for a questionnaire distributed as a census rather than as a sampling exercise, but does mean that the attitudes held by 22% of the population (non-returns) remained undefined. It could be hypothesised that those who responded later, after the reminder letter, or not at all, held views less amenable towards the aims of the hearing conservation programme than those employees who responded immediately. Therefore a lack of data on the 22% of the population not returning questionnaires could cause bias in the estimate of basline attitudes held by the population prior to commencement of the treatments.

The study described in this section estimates the size of any bias which might exist. The early, late and non-return populations are referenced as subpopulations 1, 2, and 3 respectively.

8.3.1 Method

It is reasonable to postulate that if the probability of return of the questionnaires was linked at all to attitudes held towards hearing conservation, then these attitudes would alter progressively moving from subpopulation 1, through subpopulation 2, to subpopulation 3. Therefore if an attitude difference could be measured between subpopulations 1 and 2 this could be extrapolated to subpopulation 3, which did not return questionnaires. Conversely a lack of attitude difference between subpopualtions 1 and 2, or the presence of only a minor difference, could be taken as an indication that the non-return of questionnaires by subpopulation 3 had not significantly biased the population attitude measurement.

Accordingly , a computer program was written to divide the 1346 returned attitude questionnaires into two sections, comprising of the 'pre' and 'post' reminder letter respondents. The questionnaires were scored as described below and the data subjected to a two way analysis of variance using a fixed effects, nested model.

The computer programme described earlier also calculated the scale scores from the individual items for each respondent, allocating scores to question answers in such a manner that each scale encompassed a range of 20 to 100 marks, irrespective of the number of items comprising the scale. This was necessary to facilitate simple comparison between scores on different scales, and to prevent biasing future analyses of variance between scale scores.

Additionally the sense of the scoring of the items was such that the more positive the attained score, the more positive had been the attitude of the respondent to the aims of the hearing conservation programme. The following interpretations of the scale scores can be accepted, as each item has been shown to measure a different facet of the same attitude dimension, and therefore the item scores and overall scale score are correlated. Strongly disagree (20), Disagree (40), Neither Agree nor Disagree (60), Agree (80), Strongly Agree (100).

8.3.2 Results and discussion

The result of the two way analysis of variance described in the previous section is shown in table 8.7. The subject x section x score source of variability is pooled into the residual, for two reasons. Firstly, as this term embraces the interaction of subject performance with the remaining two main effects the natural human variablity between subjects would always tend to generate a statistically significant interaction effect. Secondly, Yates (1937) warns that high order interactions will reach spuriously high levels of statistical significance as a consequence of the number of treatment combinations generated as part of the analysis. This comment is especially pertinent when applied to the analysis of variance used in this chapter in which the subject effect has a high number of levels.

Table 8.7 shows that the section x subject interaction within a block is significant at better than the 5% level, as might be expected from the explanation given earlier. The section x score interaction is also significant at the 1% level, suggesting that a difference exists between the two sections on only some of the attitude scales.

This finding was explored further using 't' tests comparing the mean attitude scale scores attained by the pre and post-reminder letter populations. Following the regime discussed in chapter 7 for the protection of multiple comparison tests from spurious rejection of the null hypothesis, the level of statistical significance for the ten tests was set at 0.1%. The tests were performed using a standard error of the difference between the means generated from the residual mean square calculated as part of the analysis of variance, this being the best error estimate available.

The results of this procedure are shown in table 8.7 as are the mean attitude scales scores for the two sections.

Four scales show significantly different mean scores between the two sections, these being "NIHL", "ENF", "NONUSE" and "COMPET". In all four cases the population which was reluctant to return the attitude questionnaires scored lower on the attitude scales than did the population which was more willing to complete the questionnaires. Thus individuals

Table 8.7 Showing the results of the analysis of variance between the scores achieved on the ten attitude scales by the pre and post reminder letter respondents.

Source of variation	DF	SS	SS%	MS	VR	Level at which the effect is significant
Section	1	8049.8	0.21	8049.8	41.550	1%
Score	9	717701.8	19.15	79744.6	411.615	1%
Section.Subject	1344	664130.4	17.72	494.1	2.551	1%
Section.Score	9	14678.7	0.39	1631.0	8.419	1%
Residual	12096	2343431.0	62.52	193.7		
Total	13459	3747991.0	100.00	278.5		
Grand Total	13459	3747991.0	100.00			
Grand Mean	65.10					
Total number of observations	13460					

Section	Score		NIHL	ENF	NONUSE	ENVIR	ACCEPT	CONTROL	PROG	ISO	COMPET	BEHAV
Pre-reminder	n=858	x_1	79.01	68.82	61.31	74.49	57.28	54.59	60.49	60.39	70.33	70.09
Post-reminder	n=488	x_2	74.92	64.37	57.12	73.33	59.02	52.68	62.02	58.98	67.77	70.49
2 tailed		t	5.18	5.64	5.31	1.47	-2.20	2.42	-1.93	1.79	3.24	-0.51
2 tailed at 0.1% level			sig	sig	sig	nonsig	nonsig	nonsig	nonsig	nonsig	sig	nonsig

returning an attitude questionnaire after receiving a reminder letter were less convinced of the existance of noise induced hearing loss and its significance, were less inclined to wear hearing protection, were less willing to accept the enforced usage of hearing protection, and were less sure that a hearing loss caused a serious handicap at work. A statistically significant difference did not exist between the two population sections on the remaining scales.

In order to estimate the effect of the non return of questionnaires on the attitude scale scores, it was necessary to know whether the differences between the sections observed on the four scales were constant over the 8 plants or whether only some plants exhibited this difference.

Accordingly the difference between the attitude scores of the two sections over the four scales identified earlier were examined by plant. This necessitated the use of 32 single-tailed 't' tests performed at the 0.1% significance level.

The results shown in table 8.8 indicate that the statistically significant difference in attitude scale score which was observed to exist between sections, originated mainly from the Nylon Polymer and Olefines plant results and to a lesser extent, the Terylene Polymer plant. A statistically significant difference between sections occurred on three of the four relevant scales (NIHL, NONUSE, and COMPET) in the case of the Nylon Polymer plant, with the post-reminder letter population or section being less well inclined towards the aims of the hearing conservation programme. A similar comment can be made in the case of the Olefines plant, on two of the attitude scales (NIHL and ENF) and the Terylene Polymer plant on one of the attitude scales, (COMPET).

The results of the preceding analysis indicate that the component of non-response to the pre-treatment attitude questionnaires will not have biased the estimate of pre-treatment population attitudes on 74 of the possible 80 scale scores, the latter comprising 10 measurement scales on 8 plants.

In the case of the six remaining scales, it is possible that the non-response component could have caused the population attitude

Table 8.8 Comparing pre and post reminder letter attitude scale scores on four scales.

Scale		NIHL	ENF	NONUSE	COMPET	n
Terylene Polymer	x_1	79.89	71.28	61.65	72.36*	123
	x_2	74.77	69.34	61.68	64.53	53
Olefines V	x_1	81.47*	70.92*	70.02	73.20	103
	x_2	72.27	61.92	66.15	65.00	26
Central Workshops	x_1	75.95	66.93	56.36	60.80	75
	x_2	74.78	61.73	56.94	67.89	52
PF Plant	x_1	78.52	70.03	58.34	70.27	149
	x_2	75.37	66.62	57.33	70.79	76
Propathene Finishing	x_1	78.80	68.76	58.85	69.50	93
	x_2	73.56	64.50	54.32	69.11	79
Nylon Polymer	x_1	81.59*	70.00	66.06*	73.86*	127
	x_2	74.27	66.43	56.57	66.00	70
Polythene Finishing	x_1	77.78	66.21	52.68	70.92	76
	x_2	74.15	59.68	50.92	68.09	47
Power Station	x_1	75.68	63.97	61.70	68.24	102
	x_2	78.36	63.98	58.09	68.29	76
Unnumbered	$x_1 + x_2$					19
Total						1346

x_1 Pre-reminder letter attitude scale score

x_2 Post-reminder letter attitude scale score

* Significant difference: 't' test at 0.15% level

measurement to be optimistic, although it should be noted that the effect is likely to have been small, as respondents outnumbered non respondents in a ratio of 4:1.

It was not thought justified to progress the above argument to the point of developing correction factors on the three plants in question for application to the one, two, or three scale scores which could be suffering from a small amount of bias. Firstly, as so few scales were affected, insufficient data were available for the development of correction factors. Secondly, the validity of awarding the Likert scale metric properties was discussed in chapter 5 and indicated that little is known of the measurement of the "attitude distance" between two points on the pseudo-metric scale. Therefore, any correction factors developed on the basis of extrapolating the differences between the sections on the six available scales would probably cause greater inaccuracies on application than would exist if the scale scores in question were left unchanged.

It was decided that as the problem affected so few scales and plants, it would be best dealt with by consideration of the likely effect at the stage of evaluating the change in attitude scale score after the plant treatments had been completed.

8.3.3 Conclusion

It was concluded that the amount of bias in the pre-treatment attitude questionnaire results caused by non-response was very small, to such an extent that the generation of correction factors would be a meaningless finesse.

8.4 Overall Conclusion

The pre-treatment attitude questionnaires were successfully despatched to the 8 main experiment plants after the development of a computerised administrative database. Returns from the despatch were very good with 4 out of 5 potential respondents completing a questionnaire.

The scale development work completed using the pilot attitude questionnaire data was checked using a larger factor and cluster analysis of the pre-treatment attitude questionnaire returns than had been possible using the pilot data.

This second analysis was in excellent agreement with that performed on the pilot data, only small modifications to the derived scales being necessary. Moreover this confirmation of the attitude questionnaire by means of a second analysis showed it to be a stable construct. The respondents' scale scores were themselves subjected to a factor analysis to investigate the degree to which the scales were truly orthogonal, and if any broad underlying attitude structures could be observed.

Five of the scales were satisfactorily orthogonal, with the remaining five showing indications of stronger association. Three underlying, broad, attitude dimensions were shown to exist.

The pre-treatment scale scores were investigated, using increasingly fine scale analyses, to show the extent of any bias which might have been caused by the non-return of questionnaires. Bias was not thought to be a problem in 74 of the possible 80 scales. Small scale bias could exist in the remaining six scale scores, but was not thought a serious enough problem to warrant the calculation of correction factors. It was decided, however, to make some allowance for these biases if thought appropriate, when comparing the pre-treatment attitude questionnaire data with the data from the post-treatment questionnaires.

CHAPTER 9

CHANGE IN HEARING PROTECTOR USAGE DURING THE TREATMENT PERIOD

9.0 Introduction

This chapter details both the audiometry and the education which formed either all or part of the treatments on the plants, and the effect which these treatments had upon the usage of hearing protection on the plants.

A full description of the treatments has been reserved until this point to facilitate discussion of the effects of the treatments upon the behaviour of employees, and the manner in which these treatments were applied.

The treatments were administered with that degree of vigour to be expected in a modern hearing conservation programme, in view of the manpower resources likely to be available to the occupational health department of a company and the constraints under which such a department would be required to operate. This approach was adopted to ensure that the results of the study could be applied generally throughout industry.

The three treatment types consisted of firstly, audiometry, secondly education, and thirdly audiometry with education. Each treatment was applied to one of three pairs of plants. A fourth pair was used as a control as described in chapter 2 which detailed the experimental plan.

In most cases the various treatment components were applied serially to the experimental groups, such as would be the case during a standard hearing conservation programme. As an example, the film was shown a few months after the start of the poster programme during the education treatment, which allowed the effect of posters alone to be assessed. The film was shown initially to only two of the four shifts in the PF plant for a similar reason, allowing a within-plant estimate of the effectiveness of the film to be made. Later, the film was shown to the remaining shifts, after the last measurement of hearing protection usage had been completed in this plant, but one month before the post-treatment attitude questionnaires were despatched.

A minimum of three months was allowed to elapse between the despatch of the reminder letter requesting the return of the pre-treatment attitude questionnaires and the commencement of the treatments on the plants. This was to ensure that any effect the receipt of the questionnaires themselves had upon the usage of hearing protection had decayed prior to the start of the treatments, and also prior to the first full assessment of hearing protector usage on the plants.

Chapter 10 describes the attitude changes measured as a consequence of exposure to the treatments. However, it is not necessarily true that a change in attitude will be followed by a change in behaviour. As an example, it is now a generally accepted attitude that exercise is a part of healthy lifestyle, but only a relatively small minority are willing or able to change their behaviour to the point of taking an adequate amount of exercise. Although it is felt that a long term change in behaviour is usually preceded by a change in attitude, the reverse is less likely to hold true.

Accordingly it was decided to assess throughout the research period the behavioural change caused in employees by the treatments. The manner in which this was effected as described in section 9.3.

9.1 The Treatments

9.1.1 Education

The hearing conservation education programme consisted of a specially produced video film and posters which served as regular reminders that hearing protection was necessary. Five different posters were changed regularly to maintain interest.

The possibility of presenting a series of seminars in the plants was discounted on logistical grounds. As it was possible to release from work only relatively small numbers of employees at a time to attend a safety talk, the number of shifts and plants involved would have necessitated an unrealistically high number of presentations. A video film, however, could be shown to small numbers of men when convenient in a room close to the production area, over a period of several weeks.

The video, "Hear today - Hear tomorrow" was specially created by the author for the research programme, and ran for approximately 22 minutes. The initial and final sections were written and produced by the author and recorded by ICI Wilton Television and the Teaching Media Centre at Southampton University. Both sections featured a direct appeal to employees to use hearing protection, and showed several scenes of plants participating in the study. Additionally some reference was made to the research programme, and the use that was being made of the research results. A segment then followed showing a "typical" employee suffering from a noise induced hearing loss being tested audiometrically at Southampton University. Emphasis was placed on how little, in the remedial sense, could be done for an employee once he reached this stage of industrial deafness.

The centre section of the video was a recording of a commercially available educational film on noise induced hearing loss produced by Bilsom International Ltd. This ran for approximately 10 minutes and was titled "Its nice to hear". A summary of the whole video tape is given in Appendix 9.1 .

The 5 posters were chosen for their ability to attract attention and for their message, which exhorted the reader to wear hearing protection. One was produced by Racal Ltd, two by Bilsom International Ltd, and two by the Royal Society for the Prevention of Accidents (RosPA). Additionally use was made of copies of the yellow "Use Hearing Protection" sign shown in the "Code of Practice for reducing the exposure of employed persons to noise" (Health and Safety Executive 1972).

These posters were changed routinely on each visit made to the company site to assess the usage of hearing protection, as detailed in section 9.2.

The posters were placed on noticeboards in mess rooms, and on noticeboards around the factory walls. These posters were often covered with graffitti within a week, but at least this did indicate that they had been noticed, and possibly the workforce continued to read the poster to ascertain if any fresh comments had been added. Only in one case was the poster actually defaced. This featured a semi-nude woman wearing hearing protectors and evidently offended the sense of morality of at least one employee. The same poster disappeared on two other occasions, although it is difficult to judge if this occurred due to the fact that an employee found it offensive, or whether it had been removed to enhance a collection.

9.1.2 Audiometry

The primary purpose of the routine screening audiometry was to assess the succes of this activity in increasing the usage of hearing protection. Naturally audiometric data was obtained during the exercise and this is analysed in chapter 11.

The audiometry undertaken during this study was intended to encourage employees to use hearing protection by implication, and by direct encouragement from the medical staff performing the task. Although instructed not to commit themselves to an absolute diagnosis, the staff were instructed to use such phrases as "Have you been using hearing protection? No? Well, this is evident from your audiogram" or "This audiogram is not as good as others which I have seen from men of your age - do you use hearing protection?" or "Do you use hearing protection? Yes? Well this has prevented your hearing from being damaged". It was found that comments of this type would often stimulate discussion of problems experienced with hearing protection.

The audiometric tests were undertaken between 09.00 hours and 10.00 hours, and 14.00 hours to 15.00 hours each day as a consequence of the number of medical staff available to undertake the work, and the ramifications of the shift system worked as explained in chapter 11. The audiometry was performed by three ICI medical staff members, trained by the author in the technique of manual audiometry described in Appendix 11. They were also fully briefed as to the objective of the research.

Five persons from the 4 plants in which audiometry was being conducted attended the Medical Centre during each of the one-hour test periods. In this way employees could perceive that the programme of audiometry was a continuing exercise, and thus they received a constant stimulus towards increasing their use of hearing protection. This would not have been the case had the audiometry been performed as an intensive exercise lasting for only a short time in each plant.

Audiometric data was sent back to Southampton University at the end of each week, for in order to reach a working agreement with both trade unions and management, it had been necessary to agree that all research information pertaining to individual employees would be confidential and evaluated only by the author.

Hence employees were not officially informed of the results of their audiometric test, although as stated earlier, some indication as to their hearing ability was given by the audiometrician at the time of the test.

Attendance for an audiometric test was voluntary in accordance with the current ICI policy. However, a computer program was written to administer the appointments, and if an employee did not attend the clinic in response to his initial appointment, he was sent a new appointment time, on average five months later. Employees who had completed their initial audiometric tests received a recall for a retest approximately 12 months later. If this appointment was not kept, a further appointment was made during a later phase of the audiometry approximately 3 months afterwards. The time between the various phases is shown in section 9.1.3. It can be seen that it was necessary to alternate the running of some of the phases to maintain the correct spacing in time between the various audiometric activities outlined above.

After 20 months final appointments were despatched to those individuals who had previously refused all appointments to attend for an audiometric test. The various time scales were compressed by several months in the case of employees of the Terylene Polymer plant. This plant was included in the study at a late date as a replacement for the Terylene Drawtwist plant which closed after the field study had been running for approximately 5 months. This was due to the prevailing economic climate.

9.1.3 Education and Audiometry

Plants receiving this treatment were exposed to both the educational and audiometric programmes run in exactly the same manner as experienced by those plants receiving either of the individual treatments of audiometry or education alone. The timing of the various phases in shown in section 9.2.

9.1.4 Control

Two of the eight plants in the study acted as a control. No treatment was effected in these plants and they were not the subject of any ICI programmes of noise education or audiometry. However, hearing protection had been issued to the workforce, and noise hazardous areas had been delineated three years before the present study began.

9.2 Objective Measurements of the Success of the Treatments

9.2.1 Method

Section 9.0 stressed the need to obtain an objective measurement of the success of the treatments on the plants. Relying upon detecting changes in attitude and using these as an index of treatment success would leave unanswered the question as to whether or not changes in hearing protector usage followed changes in attitude.

To obtain the necesary data 160 visits were made by the author to plants participating in the main study to measure the percentage of employees using hearing protection whilst working in an area containing a noise hazard. An increase in this percentage was used as an index of the success of the relevant plant treatment.

The visits were made to the plants at random times of the day, with the provision that no visit was made to a plant at a time when it was known that a substantial proportion of the workforce would either be taking a meal or a workbreak. Additionally plants were only visited during normal office hours, for to do otherwise would have meant obtaining the permission of the foreman in advance, possibly resulting in a biased measurement.

Thus the shifts observed were those working during normal office hours in a 3-4 day visit to the Wilton Site.

Observation by the author of hearing protector usage was made without prior warning to the employees, and passage around each plant was rapid, following a pre-set path which had been chosen to permit examination, as far as was possible, of all individuals present in an area containing a noise hazard. Any employee who was not wearing earmuffs and had a hair style such that his ear canals could not be observed was deemed not to be wearing ear protection. These individuals comprised less than 2% of the employees actually observed.

9.2.2 Results

The results of the assessment of hearing protector usage in each of the eight plants during the treatment period are given in figures 9.1 to 9.10 in terms of both the absolute levels of protector usage, and the change in hearing protector usage normalised to the first assessment of usage made on the plant prior to commencement of the treatments. Each of the data points plotted represents, on average, the percentage of employees wearing hearing protection on three of the four shifts. One exception is the Central Workshops which employed only day workers. The Workshops were therefore visited twice at different times on a single day to obtain the estimate of hearing protection usage plotted.

The individual data values are tabulated in table 9.1 as the ratio of users to non-users by shift and plant as observed on each visit to the Wilton site. These ratios are converted to percentage usage in table 9.2 and shown together with the plant overall usage during a particular visit to the Wilton site, again expressed as the percentage of protector users in the total population observed on all shifts visited on that particular plant.

The shift observations were amalgamated prior to plotting as the experiment was designed to evaluate the success of the treatments upon hearing protector usage in a plant, and not on the shifts which are only individual components of a plant workforce. This method is analagous to that employed in a conventional medical experiment, which strives to evaluate the

Table 9.1 The ratio of hearing protector users to non users, by shift plant and time.
Key E = education, A = audiometry, C = control

Shift	1	8	10	11	12	14	17	21	Month	
A	4:18			4:11	5:13	8:5	9:6	6:8	Film	PF Plant
B	3:14	3:15	5:14		3:5	6:10	3:5	4:5		
C	5:14		5:10		6:7	5:7	5:8	4:9		
D	2:14	2:11		5:10	5:12	8:7	7:8	3:8	Film	E
	14:60	5:26	10:24	9:21	19:37	27:29	24:27	17:30	Total	
	6:32	2:11	n/a	9:21	10:25	16:12	16:14	9:16	Film	
A	6:12	5:12		10:20			4:6	8:14		Power Station
B	7:11	8:12		7:11	9:12			9:9		
C	6:9	5:10	7:12		6:14		9:18	4:5		
D	4:11		5:10	4:10	9:14		4:9	6:13		C
	23:43	18:34	12:22	21:41	24:40		17:33	27:41	Total	
1		2:20	7:23	6:14	7:19	5:16	1:17	7:16		Central Workshops
2		3:26	4:21	5:18	5:19	6:20	2:21	9:16		E
		5:46	11:44	11:32	12:38	11:36	3:38	16:32	Total	
A	2:6			6:5	5:4	4:5	4:5	5:2		Olefines V
B	2:8	closed		5:5	4:3	4:3	4:3	5:4		
C	2:6		2:4		7:7	4:6	4:6	7:4		
D	2:10		5:9	10:13				6:4		A
	8:30		7:13	21:23	16:14	12:14	12:14	23:14	Total	

Table 9.1 cont.

Shift	1	8	10	11	12	17	21	Month
A	2:7	3:7		3:8		6:7	6:7	Nylon Polymer
B	3:9			5:10	5:11	5:8	4:3	
C	4:11		5:11		5:14	7:7	6:5	
D	2:13		6:8	3:7	4:8	9:8	5:5	A+E
	11:40	3:7	11:19	11:25	14:33	27:30	21:20	Total
A	4:10	3:9		6;6	6:5	2:4	2:5	Terylene Polymer
B	4:9	6:17		3:7	6:7	6:8	4:5	
C	5:9		2:10	7:12	3:7		2:3	
D	3:8	3:8	3:9			3:5	5:7	A
	16:36	12:34	5:19	16:25	15:19	11:17	13:20	Total
A	1:14	1:17		1:12	1:9	2:16	1:11	Polythene Finishing
B	1:10			1:15	1:10	1:9	0:8	
C	0:13		0:15		0:6		0:5	
D	0:12		1:12	1:11		0:13	0:5	C
	2:49	1:17	1:27	3:38	2:25	3:38	1:29	Total
A	1:11	3:11		2:7	2:9	3:8	3:4	Propathene Finishing
B	1:10		4:12	2:7	1:4		4:4	
C	1:13		3:18		4:10	3:6	5:9	
D	2:16			3:7		4:10	4:7	A+E
	5:49	3:11	7:40	7:21	7:23	10:24	16:24	Total

Table 9.2 The percentage usage of hearing protection with time, by shift.

Key E = education, A = audiometry, C = control

	1	8	10	11	12	14	17	21	Month
Shift									
A	25.0			54.5	55.5		44.4	71.4	Olefines V
B	20.0	closed		50.0	57.14		57.0	55.5	
C	25.0		33.3		50.0		40.0	60.0	
D	16.6		35.7	43.4				60.0	A
	21.05		35.0	47.7	53.3		46.2	62.1	Total
A	22.2	30.0		27.2			46.2	46.2	Nylon Polymer
B	25.0			33.0	31.3		38.0	57.1	
C	26.6		31.3		26.3		50.0	54.1	
D	13.3		42.9	30.0	33.3		52.9	50.0	A+E
	21.56	30.0	36.66	30.55	29.7		47.4	51.1	Total
A	28.5	25.0		50.0	54.5		33.3	28.5	Terylene Polymer
B	30.8	26.1		30.0	46.1		42.8	44.4	
C	35.7		16.6	36.8	33.3			40.0	
D	27.2	27.27	25.0				37.5	41.6	A
	30.76	26.1	20.8	39.0	44.1		39.3	39.4	Total
A	6.7	5.5		7.7	10.0		11.1	8.3	Polythene Finishing
B	9.1			6.3	9.1		10.0	0.0	
C	0.0		0.0		0.0			0.0	
D	0.0		7.6	8.3			0.0	0.0	C
	3.92	5.5	3.5	7.3	7.4		7.3	3.3	Total

Table 9.2 cont.

	1	8	10	11	12	14	17	21	Month
Shift									
A	8.3	21.4		22.2	18.1		27.2	42.8	Propathene Finishing
B	9.1		25.0	22.2	25.0			50.0	
C	7.1		14.3		28.5		33.3	35.7	
D	11.1			30.0			28.5	36.4	A+E
	9.09	21.4	18.9	25.0	23.33		29.4	40.0	
									PF Plant
A	18.2			26.3	27.3	61.5	60.0	42.8	Film
B	17.7	16.6	30.0		37.5	37.5	37.5	44.4	
C	23.3		21.7		46.2	42.0	38.5	10.8	
D	12.5	15.4		33.3	29.4	53.0	46.6	27.3	Film E
	18.9	16.1	29.4	30.0	34.0	48.2	47.1	36.2	Total
	15.8	15.38	n/a	30.0	28.57	57.14	53.33	36.0	Film
A	33.3	29.4		33.3			40.0	36.3	Power Station
B	38.8	40.0		38.8	42.8			50.0	
C	40.0	33.3	36.8		30.0		33.3	44.4	
D	26.6		33.3	28.5	39.0		30.8	31.6	C
	34.8	34.6	35.3	33.9	37.5		34.0	39.7	Total
1		9.1	23.3	30.0	26.1	23.8	5.6	30.4	Central Workshops
2		10.3	16.0	21.7	20.8	23.1	9.5	36.0	E
		9.8	20.0	25.6	24.0	23.4	7.3	33.3	Total

reaction of a drug on the whole population rather than the reaction on an individual member of the population, each of which would exhibit individual idiosyncrasies prior to treatment. Although inspection of table 9.2 shows that in some plants two different shifts may show a different level of hearing protector usage at a given point in time, this difference is not marked when the possible errors in the measurement method are considered. Small changes in the count on a particular shift can result in appreciable changes in the calculation of percentage usage making between shift comparisons at a given point in time difficult.

However, multiple observations completed on a plant over a long period of time served to reduce measurement errors such that trends could be identified.

Many of these trends or at least parts of them, were approximately linear in nature and use was made of this fact in selecting a technique to evaluate the statistical significance of any changes in hearing protector usage observed to occur. A linear regression line was fitted to the behavioural data obtained from each of the control plants, and the slope calculated. This slope was then compared statistically with that of similar regression lines fitted to behavioural data obtained from the treated plants. As it is shown in section 9.2.2 that the slopes of the control plant regression lines were not significantly different from zero, the comparison with the regression line slopes of the treated plants was simplified to an examination of whether or not these latter slopes were significantly different from zero, and positive.

The test was performed using the 't' statistic based upon the ratio of the calculated slope to the standard error of this slope. A statistically significant 't' value therefore indicated that the observations were demonstrating a confirmed change in hearing protector usage occurring, presumably, as a result of the treatments.

The regression equations were not generated as predictive tools, or even under the assumption that a linear regression was the best form to fit to the particular data set, but rather as a single method which could be applied to the data from each plant to assess whether or not some change in hearing protector usage had occurred in the plant when compared to that observed in the control plants.

It only proved impossible to use this method in one plant, Terylene Polymer. The linear increase section of the objective data curve from this plant proved too short for the fitting procedure. In this case use was made of the Binomial Theorem to statistically validate the existence of change.

Figures 9.1–9.10 show the time at which each of the various components of the treatments was initiated. The two digit numbers above the usage curves from those plants receiving audiometry as a treatment indicate the start of various audiometric phases, the key being given prior to the figures.

9.2.2.1 The control plants

Figures 9.1 and 9.2 show the hearing protector usage, and change in usage, in the control plants. Application of the statistical technique described at the end of section 9.2.1 yielded a line of slope 0.18 in the case of the Power Station, and 0.04 in the case of Polythene Finishing, with 't' values of 1.43 and 0.27 respectively, neither significant at the 5% level.

Thus no significant change in protector usage can be said to have occurred, and therefore any change in the usage of hearing protection within the treated plants, can be ascribed to the effect of the treatments themselves. It is of value to the study that the Power Station exhibited a relatively high level of initial usage when compared to that of the Polythene Finishing Plant, for both plants in tandem comprised an excellent control group covering the range of initial hearing protector usage on the treatment plants, which ranged from approximately 10% to 30%. The following sections detail the increases, or otherwise, in hearing protector usage caused by the treatments. It is noteworthy that no correlation could be found between the starting level of hearing protector usage and the maximum gains in usage caused by the treatments, using either parametric or non-parametric statistics. (Pearsons 'r', Kendalls rank correlation test).

9.2.2.2 The effect of education on the usage of hearing protection

Figure 9.3 shows the percentage usage of hearing protection in the PF plant and the Central Workshops which both received education as a treatment over the experimental period. Figure 9.4 shows a comparison of the change with time of the percentage usage of protectors in these same two plants. The data describing the PF plant is drawn from all shifts until that measurement made prior to the showing of the film. Subsequent PF plant performance measurements are drawn from shifts A and D alone, as the experimental plan described in chapter 2 required that the film be shown only to half of the shifts, randomly selected, on the PF plant. This was to allow an assessment, by comparison with the remaining shifts, of the effect of viewing the film. The separate performances of shifts A and D, and B and C are shown in figure 9.5.

For this reason the statistical technique described in section 9.2.1 for assessing any increase in protector usage was applied to data drawn from all shifts up to the showing of the film, and then to data from shifts A and D only, up to month 17, after which the usage can be seen to be dropping back.

The linear regression produced a line with slope 4.55, and a 't' statistic of 4.7, significant at the 1% level. A similar regression was performed upon the Central Workshop data, excluding that from month 17 when usage had clearly dropped back prior to the showing of the film, as will be discussed later in this section.

The linear regression produced a line with slope 1.46, and a 't' statistic of 3.4, significant at the 5% level.

As both regression line slopes are positive, and significantly different from the zero slopes exhibited by the control plants, it can be concluded that increases in hearing protector usage have occurred, which can be ascribed to the effects of the treatments.

Figure 9.6 shows the percentage usage of hearing protectors for both shifts A and D, and shifts B and C, with time. Figure 9.5 shows the same data transformed to a change in usage, and normalised to the measurement made immediately prior to the showing of the film to shifts A and D.

It is immediately apparent from figure 9.4 that the poster campaign caused a significant rise in hearing protector usage, with very little latency.

Two weeks after the start of the campaign, usage had increased by approximately 10% in both plants. The usage had increased by approximately 15% on average, in the two plants two months after the commencement of the poster programme.

Hearing protector usage in both plants would probably have been sustained at this level for a further two to three months as suggested by the usage pattern observed in the Central Workshops. It would have declined back to the original level, as indicated by the measurement made in month 17 in the Central Workshops prior to the showing of the film in that plant. However, the film was shown to part of the PF plant at the end of month 13, and hearing protection usage differed interestingly from that observed in the Central Workshops after month 12. The film caused a further rise in hearing protector usage in comparison to that observed in the Central Workshops where the film was not seen until month 18, resulting in a level of protector usage in the PF plant which was approximately 40% above that observed before the treatments commenced. This observation is further reinforced by examining figure 9.5 giving the usage of hearing protectors in shifts B and C, which were the two shifts in the PF plant which did not see the film until several weeks prior to the despatch of the final round of attitude questionnaires. Usage in this case followed a similar trend to that exhibited by the Central Workshops prior to showing the film. The usage of hearing protection was approximately constant after month 12 with no evidence of that rise shown by shifts A and D after those employees had viewed the film. Figure 9.5 shows the change in usage of hearing protection within the PF plant on the two shifts which saw the film, and the two shifts which did not, normalised to the measurement made in month 12. It would appear that showing the film caused a rise of approximately 25-30% in addition to that already achieved by the poster campaign.

Figure 9.5 also shows that this positive effect on behaviour began to decay 2-3 months after the stimulus, which in this case was the viewing of the film. The usage of hearing protection would have decayed back to its pre-film level after approximately 10 months.

Showing of the film was delayed until month 18 in the Central Workshops, by which time the usage of hearing protection had decayed back to the pre-treatment levels. The result of showing the film was, once again, a rise of approximately 25% in the usage of hearing protection, but on this occasion the increase was from a base level equal to the pre-treatment level of usage.

The major difference between the performance of shifts B and C on the PF plant, and the workforce of the Central Workshops was that by comparison with the Central Workshops, it might have been expected that the usage of protection on PF plant shifts B and C would have decayed back to pre-treatment levels by month 21, which did not happen. It is felt that the explanation for this event is that at shift handover time within a plant, the two relevant shifts meet each other briefly. Hence hearing protector usage by employees in shifts B and C might have been sustained by the continual stimulus of seeing their colleagues on shifts A and D wearing hearing protection, given that usage on shifts A and D was higher until month 21 as a result of these shifts viewing the film. The Central Workshops, by comparison, only had one workforce and did not operate a shift system.

It is therefore felt that the impact of the poster campaign on shifts B and C of the PF plant would have decayed back in a time scale similar to that noted in the Central Workshops if it had not been sustained by increased hearing protector usage on shifts A and D, caused by viewing the film.

Several interesting conclusions can be drawn from this work. Firstly any educational stimulus such as a film or poster campaign will immediately be followed by a rise in hearing protector usage. This increase in usage will be followed by a period of 3-4 months during which time the effect will be sustained, and then a further 6 or 7 months during which time the usage will fall back to its original levels. If, during the initial 3-4 month period after the start of a poster campaign, a film is shown , the onset of decay can be arrested, and replaced by an additional increase in usage to achieve a final and maximum, increase of usage in the region of 40%. This would fall back to the pre-film levels within the 10 month period discussed earlier. The 25% increase in usage which might be attributed to the action of the film alone does not appear to be dependent upon the absolute usage starting level. This is evidenced by comparison of the performance of the PF plant and the Central Workshops after months 13 and 18 respectively.

It might, however, be argued that the poster campaign run prior to showing the film in both plants had predisposed the population towards reacting favourably towards the film, and that its success may not have been so pronounced had the order of poster campaign followed by a film been reversed.

The poster campaign commenced from different base levels of usage on the two plants, but the effect was identical. However, this conclusion cannot be pursued too far, as the difference in starting levels was less than 10%.

On the evidence presented in this section, it would appear that a film is a more potent educational stimulus than a poster campaign, and that the effects of the two are additive, probably independent of starting level, and decay within approximately 10 months if the educational stimulus is not renewed.

9.2.2.4 The effect of audiometry on the use of hearing protection

Figure 9.7 shows the change in hearing protector usage from that observed prior to the treatments measured on those plants receiving audiometry as a treatment, whilst figures 9.8 and 9.9 show the data as a percentage usage of hearing protection. The two digit numbers shown on these figures represent the starting dates of different stages in the audiometric survey, as indicated by the key preceding the figures.

Audiometry did not commence in the Terylene Polymer plant until month 9 as until that time the plant formed part of the control group. The change was necessitated by the sudden closure of a plant which had been receiving audiometry as a treatment, as described in section 2.3.2.

The statistical technique described in section 9.2.1 for assessing any increase in protector usage was applied to the hearing protector usage data

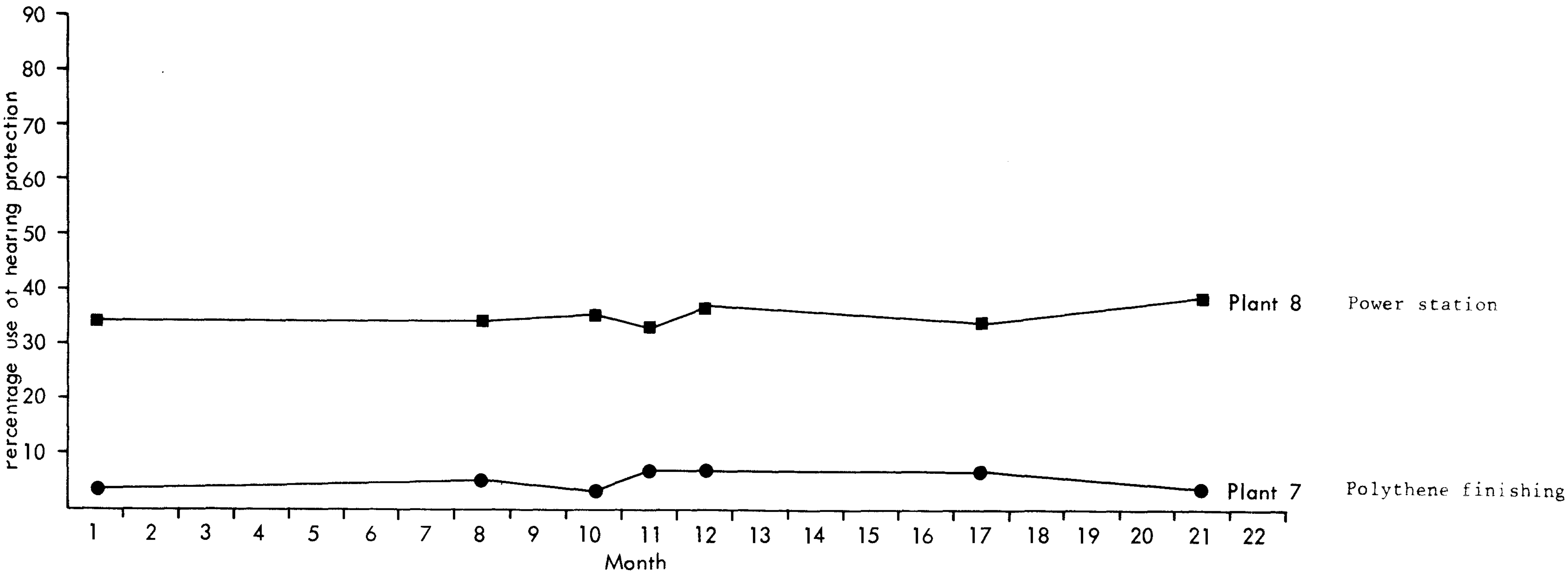


Figure 9.1 The percentage usage of hearing protection in the control plants over the experimental period.

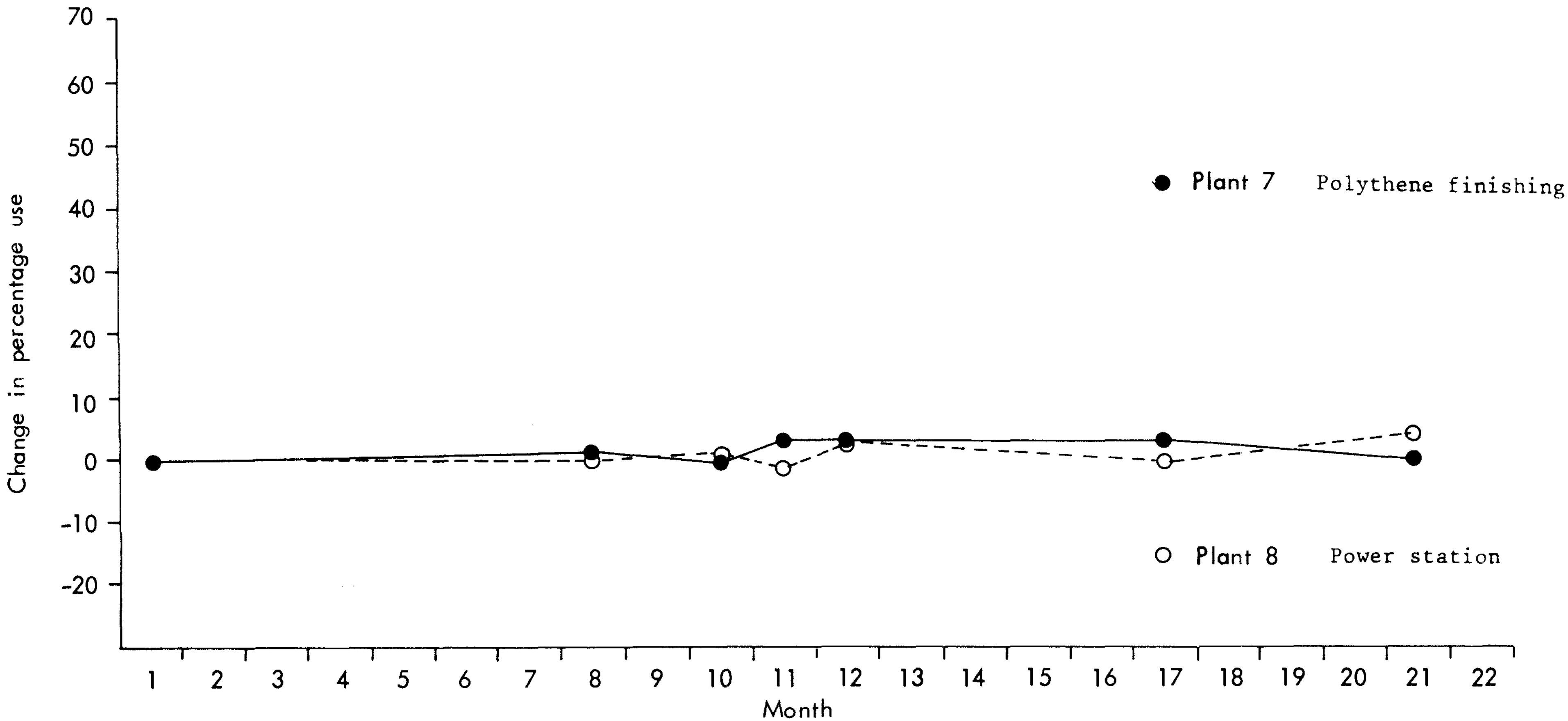


Figure 9.2 The change in hearing protector use in the control plants over the experimental period.

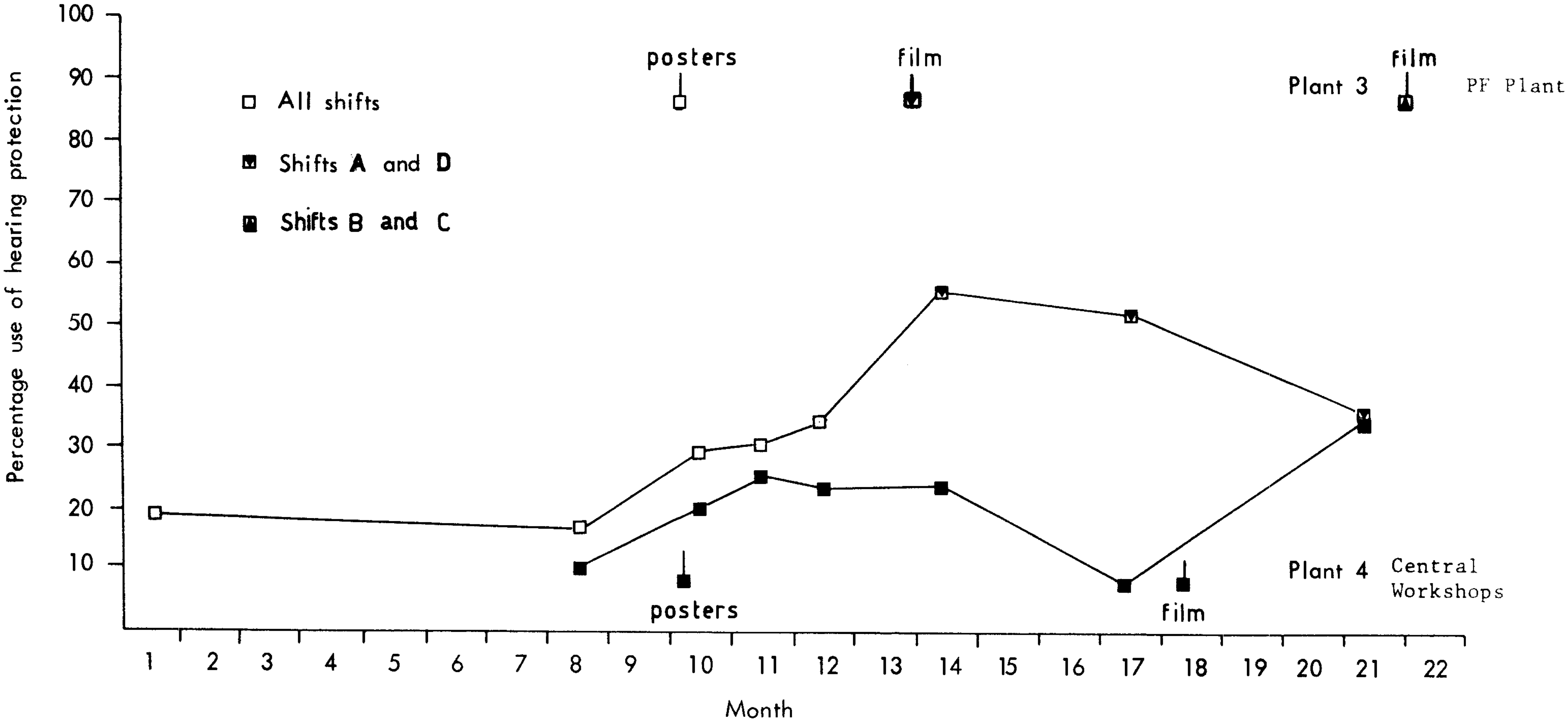


Figure 9.3 The percentage usage of hearing protection in the plants receiving education as a treatment

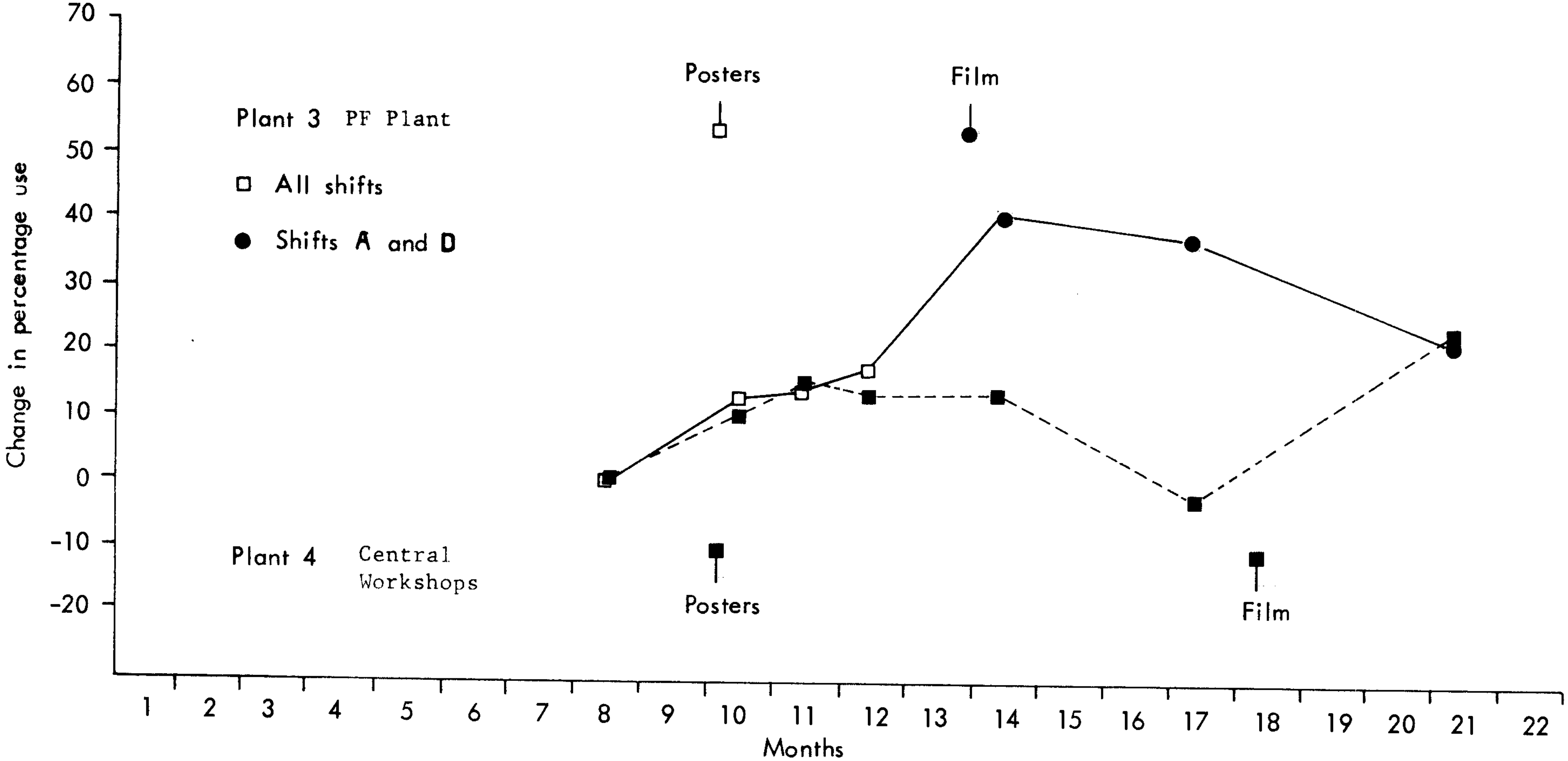


Table 9.4 The change in hearing protector usage in the plants receiving education as a treatment.

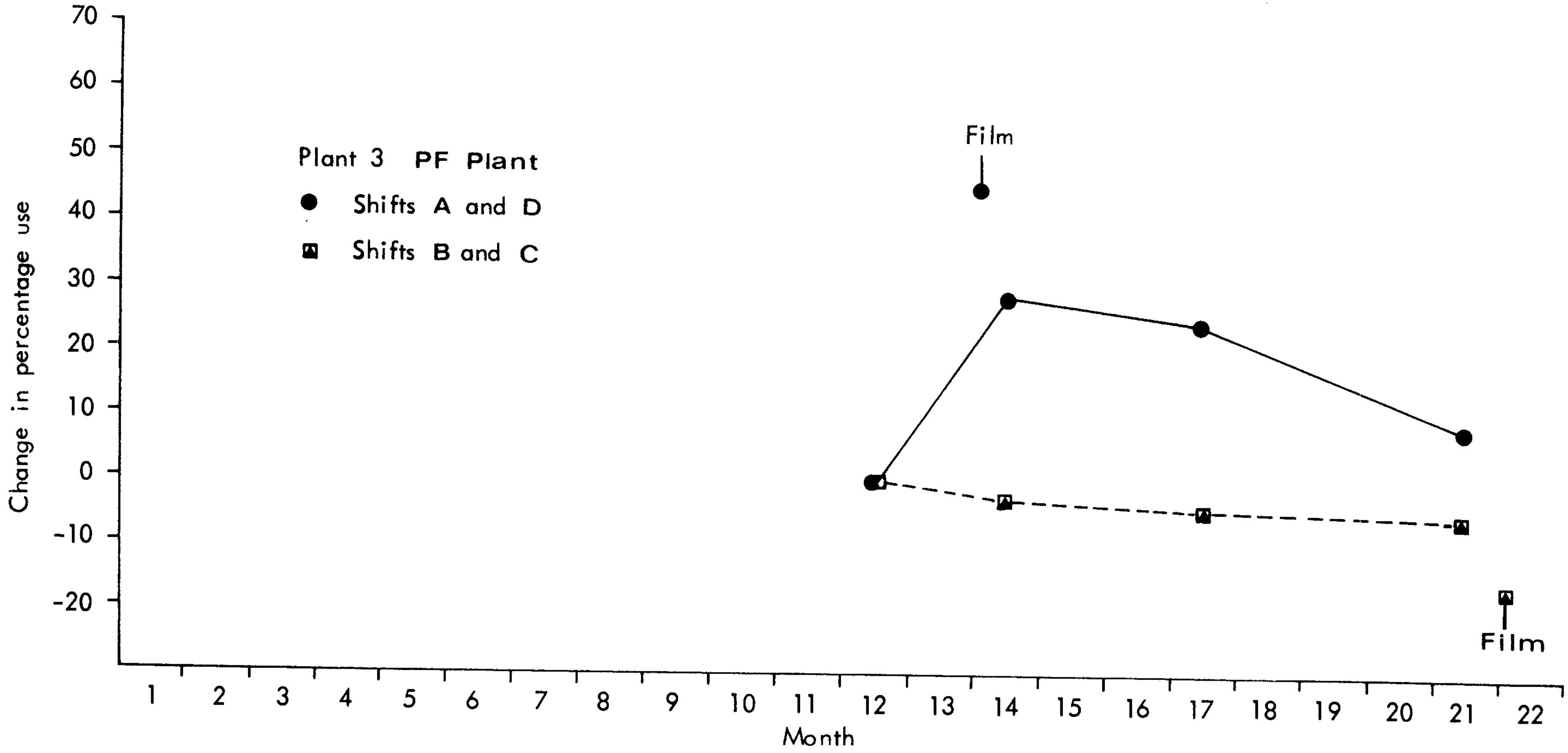


Figure 9.5 The change in hearing protector usage in the PF plant by shift group, normalised to the measurement made in month 12.

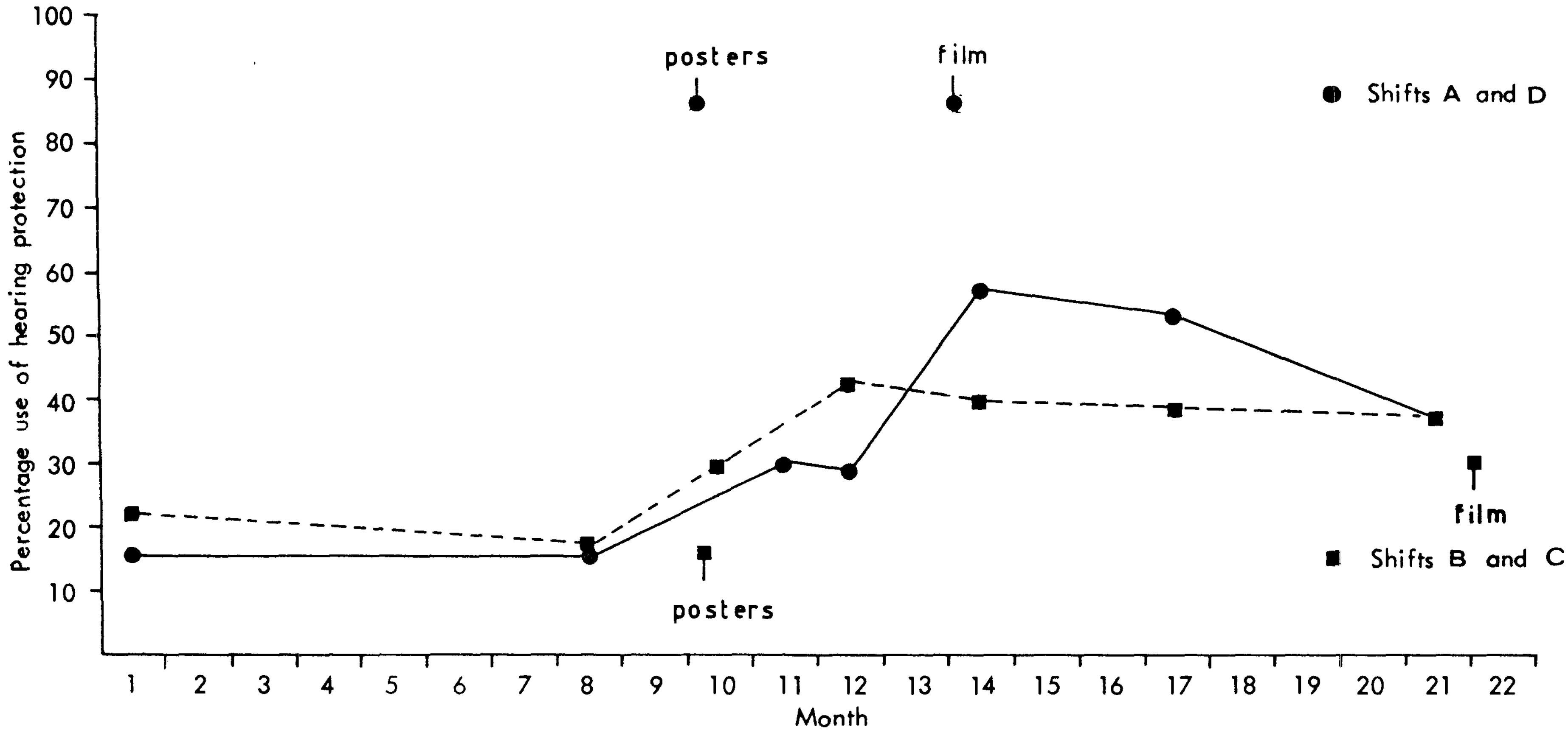


Figure 9.6 The percentage usage of hearing protection in the PF plant by shift group.

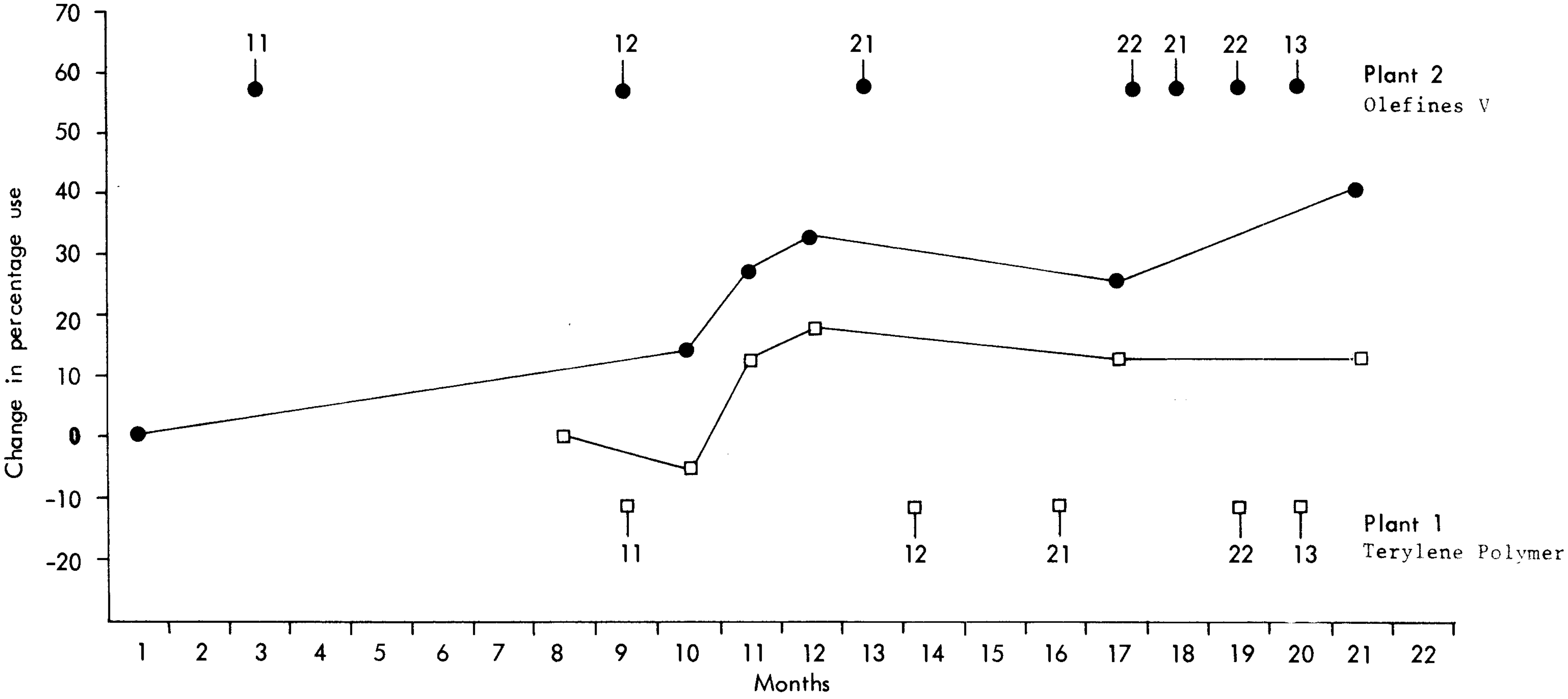


Figure 9.7 The change in hearing protector usage over the experimental period in the plants receiving audiometry as a treatment.

Key to figures 9.7 , 9.8 , 9.9 and 9.10

The two digit numbers used in the above figures represent the starting date of different stages of the audiometric survey.

11 First audiometric test, first appointment

12 First audiometric test, second appointment

21 Second audiometric test, first appointment

22 Second audiometric test, second appointment

13 First audiometric test, third appointment

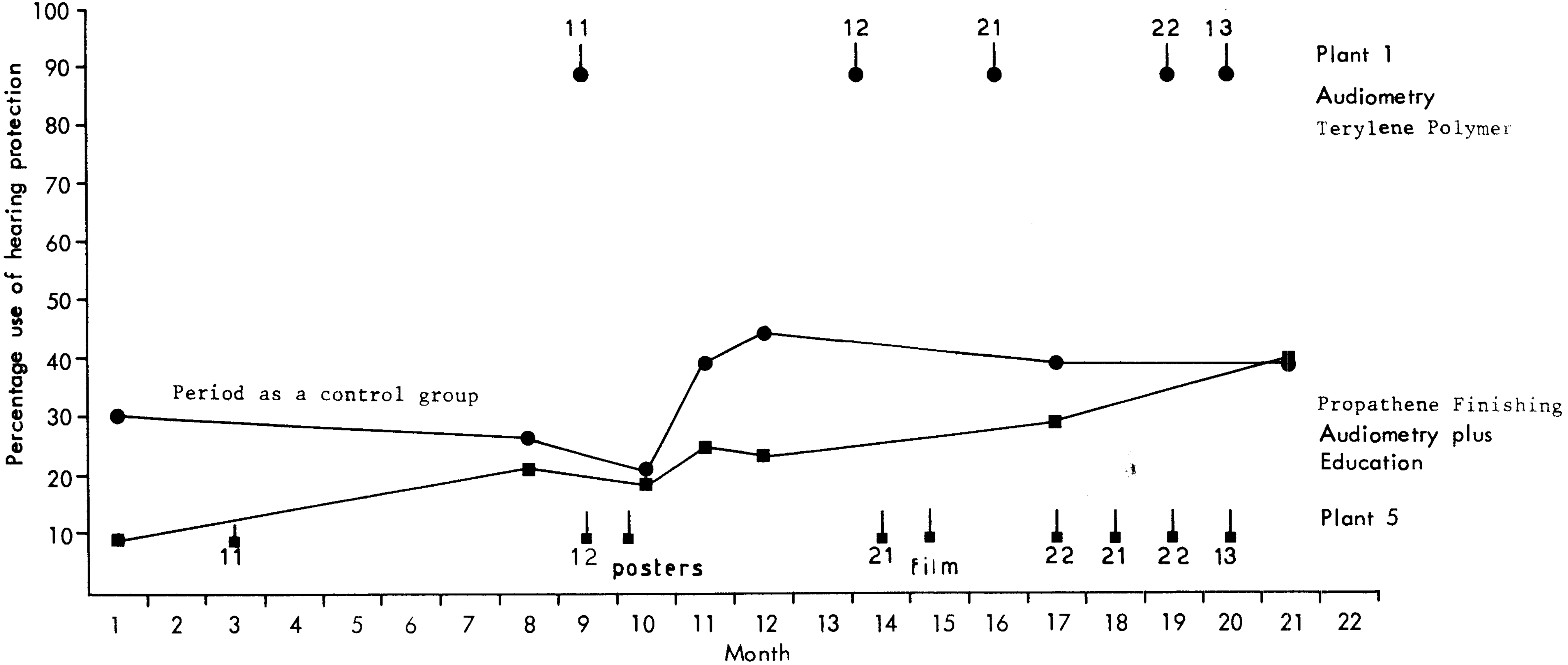


Figure 9.8 A comparison of the percentage usage of hearing protection in a plant receiving audiometry as a treatment with the percentage usage on a plant receiving both audiometry and education as a treatment.

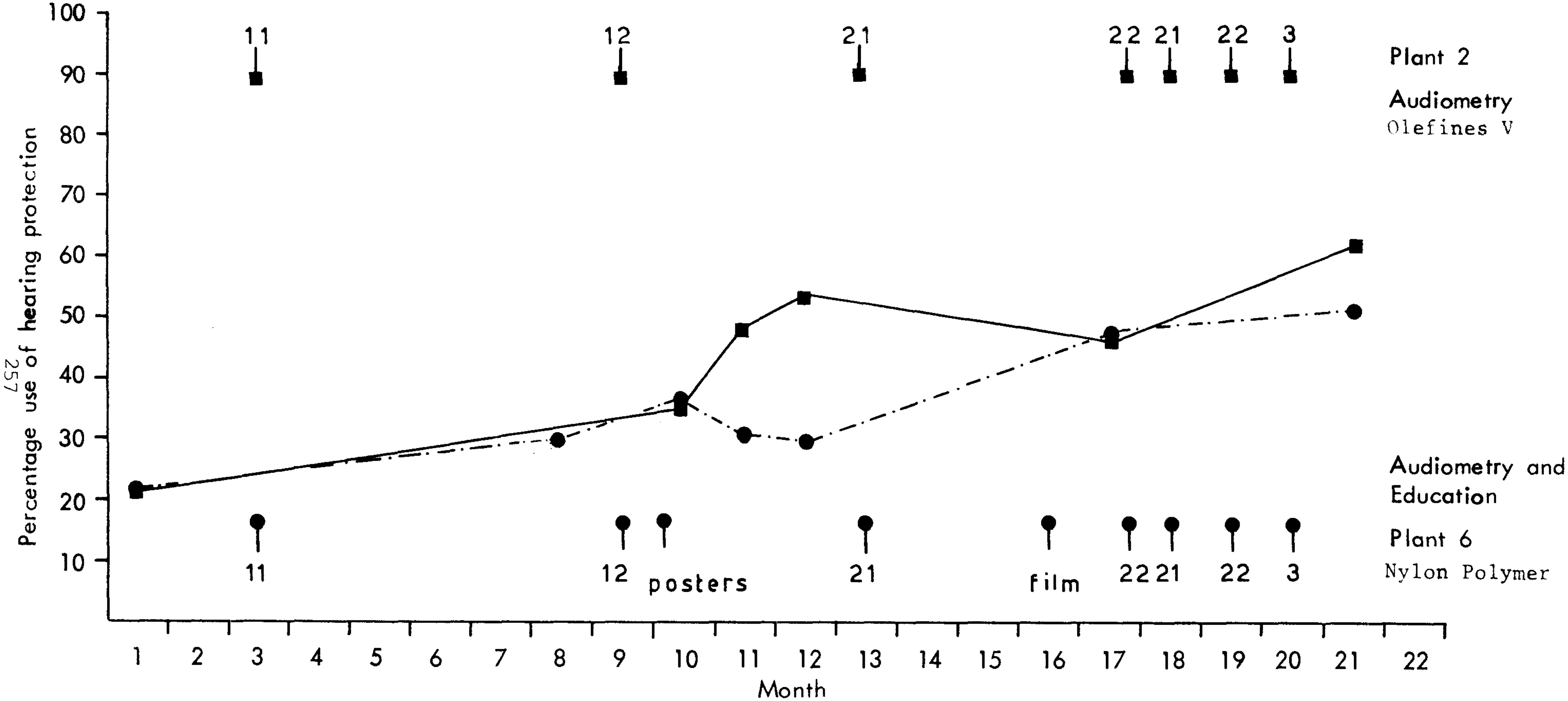


Figure 9.9 A comparison of the percentage usage of hearing protection in a plant receiving audiometry as a treatment with the percentage usage in a plant receiving both audiometry and education as a treatment.

drawn from the Olefines V plant. The regression analysis yielded a line of slope 1.9 and a 't' statistic of 4.06, significant at the 5% level. By comparison of this slope with that of the control plants it is apparent that an increase in protector usage had occurred during the treatment period, and that the increase must be attributed in the first instance to the effect of the treatment.

As explained in section 9.2.1 it was not possible to apply the same technique to the data obtained from the Terylene Polymer plant. This was due to the smaller number of data points arising as a consequence of the late addition of the plant to the treatment group for the reasons described above, and the fact that the increase in hearing protector usage observed occurred over a shorter period of time than was the case for other treated plants, for reasons which are discussed later in this section. Accordingly use was made of the Binomial Distribution.

Use of the Binomial Expansion showed only a 1.8% probability that 12 out of 15 of the shift measurements made after commencement of the treatments on the Terylene Polymer plant could have exceeded the average shift pre-treatment protector usage level of 26.1% by chance alone. As a similar increase in hearing protector usage was not observed in the control plants, it can be concluded that the treatment was causing the increase in hearing protector usage.

Figure 9.7 shows that the growth of hearing protector usage was reasonably steady in the Olefines V plant, with some acceleration of the change in percentage usage being noted immediately after the start of phase 1.2. During this phase individuals who had not attended the clinic in response to an initial appointment were contacted again and given a new appointment time. The new appointments probably helped to convince the workforce in the Olefines plant that the audiometric testing was a serious excercise, and therefore a definite noise hazard must exist within the plant. A similar effect occurred after the commencement of phase 2.2, the second appointment for the second audiometric test in the monitoring programme, but does not appear to have happened in response to the beginning of phase 2.1, when individuals who had been tested once were asked for the first time to attend the clinic for the second test in their monitoring series.

This could have arisen because of the lack of formal feedback of results to the individual after his first test.

The lack of feedback after a substantial period of time might have implied that noise exposure within the Olefines plant was not a serious problem, as no formal evidence had been presented that any employee had sustained a noise-induced hearing loss. It is also possible that this effect could have caused the slight dip in hearing protector usage shown in figure 9.7 to have occurred during months 13-17.

Hearing protector usage rose once again after month 17, probably in response to letters being sent out to individuals within the workforce who had not attended for their second audiometric test as requested or who had already refused all previous appointments made for an audiometric test. As can be seen from figure 9.7 three different audiometric phases were run in close succession during months 17-20 on the Olefines V plant, necessitating 3 different letter types being sent to employees. It is likely that this sustained activity and the audiometric tests themselves, raised employee awareness to the point that hearing protector usage rose to 62%. This figure was the maximum usage observed during the study and represented a gain of 41% during the experimental period.

The change in hearing protector usage in the Terylene Polymer plant followed a similar trend to that observed in the Olefines V plant although it was less pronounced. The maximum gain achieved was 18%, raising the absolute level of protector usage to 44%. The various phases of the audiometric survey were undertaken in the Terylene Polymer plant closer together in time than was the case for the Olefines plant as a consequence of the late entry of the Terlyene Polymer plant into the treatment group. However, it proved possible to make a measurement of hearing protector usage in the Polymer plant in each of the 3 months following the start of phase 1.1 which was the first appointments for the first audiometric tests. The measurements showed a slight drop in hearing protector usage in month 10, one month after the inception of the audiometric testing, followed by a rapid rise with the same characteristic as that observed after the start of phase 1.2 in the Olefines plant.

It is interesting to note that hearing protector usage showed no evidence of rising immediately after audiometric testing commenced in month 9, but that it was not until month 11 that the effect of the audiometry became apparent, with an increase of 13% above the pre-treatment level. This time-lag before the rise in hearing protector usage occured is reasonable when the slow rate of audiometric test is considered, as only two or three employees from the plant could be tested each day. It is possible that a similar rise in hearing protector usage took place immediately after audiometric testing began in the Olefines plant, but if this did occur the effect must have decayed back to the level measured during month 10.

The maximum increase in hearing protector usage in the Terylene Polymer plant was 18%, and observed in month 12. This gain would have been substantially increased, had the Terylene Polymer plant shown the same increase in hearing protector usage after phase 2.2 as did the Olefines plant. That this did not occur could have resulted from the way in which the starts of the various audiometric phases on the Terylene Polymer plant were timed, giving audiometry in Terylene Polymer a different pace and pattern from that of audiometry conducted in the Olefines V plant. The differences are described below.

More individuals were tested each day in the Terylene Polymer plant than was the case in the Olefines plant in order to synchronise the testing on the Olefines and Terylene Polymer plants as soon as was possible. Accordingly the time between the start of the various audiometric phases was also shorter in Terylene Polymer. As an example, the elapsed time between the start of audiometric testing and the second audiometric test in the monitoring series was 30% shorter, being approximately ten months on the Olefines plant, and 7 months on the Terylene Polymer plant. Additionally phases 2.1 (first appointments for the second audiometric test) and 2.2 (second appointments for the second audiometric test) were alternated in the Olefines plant in order to maximise the interval between first and second tests for any employee but this was not thought necessary on the Terylene Polymer plant, as the accelerated testing had already shortened the time between first and second audiometric tests for all employees. It could be hypothesised on the basis of the Olefines V hearing protector response pattern and the evidence of a greater increases in usage in Olefines V, that employees responded to the stimulus represented by the onset of different phases of the audiometric programme, rather than to the content of the stimulus itself. Therefore, it is likely that if an additional stimulus is provided by ensuring that each employee is informed of the results of his audiometric test, the benefit offered by industrial audiometry in terms of promoting the wearing of hearing protection on a plant would be increased.

Furthermore, the accelerated testing rate, and timing of the phases experienced by employees of the Terylene Polymer plant, when compared to those on the Olefines plant were such as to make it apparent to the employees that the Terylene Polymer industrial audiometry was a mass screening exercise with little feedback. The slower test rate, and more complex pattern of audiometric phases made this aspect less apparent on the Olefines V plant and probably contributed to the greater overall success of audiometry in raising the usage of hearing proection in months 17-21. Support might be given to the concept that employees on the Terylene Polymer plant saw the audiometric testing as a routine mass screening exercise by the fact that approximately 95% of available employees attended for a test, whilst only 60% of those in the Olefines plant visited the Medical Centre for a test. This ranking is the inverse of that describing the success of audiometry on the two plants in increasing protector usage.

The results of this section of the study yield the following main conclusions. Firstly industrial screening audiometry will raise the usage of hearing protection in a workforce. Secondly, this increase is characterised by rises in usage after the start of various phases of the audiometric testing, but they are followed by periods of decreasing usage in subsequent months as the effect of the stimulus decreases. It is probable that feedback of the results of the audiometric tests could prevent these decreases from occurring. Thirdly, audiometry is more likely to increase the usage of hearing protection if care is taken to prevent the exercise from being viewed by the workforce as mass screening. Finally a time lag of approximately one month will occur between commencing the audiometric test and an increase in the usage of hearing protection if the test rate is maintained at several each day.

9.2.2.5 The effect of education and audiometry used together to increase the usage of hearing protection.

Figures 9.8 and 9.9 show the percentage usage of hearing protection in the two plants receiving both audiometry and education as a treatment. Figure 9.10 shows the change in hearing protector usage with time.

The statistical technique described in section 9.2.1 for assessing any increase in protector usage was applied to data drawn from the Nylon Polymer plant and the Propathene Finishing plant. The regressions yielded a line of slope 1.5 and a "t" statistic of 5.66 in the case of the Nylon Polymer plant, significant at the 1% level. The regression slope associated with the Propathene Finishing plant data was 1.44, with a 't' value of 9.03, significant at the 0.1% level. It can therefore be concluded, by comparison with the zero slope values associated with the control plant data, that the combination of audiometry and education increased the usage of hearing protection in the Nylon Polymer and Propathene Finishing plants.

It is notable in Figure 9.10 that the rate of increase of hearing protector usage in the two treated plants was approximately constant with time, showing little evidence of the relatively large fluctuations in usage observed in those plants receiving either education, or audiometry alone as a treatment. It would appear that the various extra stimuli such as the poster campaign, or the film served to complement the action of the audiometry, and maintain the awareness of noise as a hazard throughout the experimental period. Further comment on this matter is made in chapter 10 which draws together the behavioural change and attitude change results.

It is not possible to separate out the individual effects caused by components of the education programme from those caused by the various phases of the audiometric programme in the plants receiving both as a treatment. However, it would appear that the effects of the two are not additive. One example of this can be seen in month 10 on figure 9.10. Here it is apparent that the onset of the poster campaign did not cause that increase in hearing protector usage which was observed on those plants receiving only education; the increase which was observed could have been expected as a result of the audiometry alone. It is likely that the

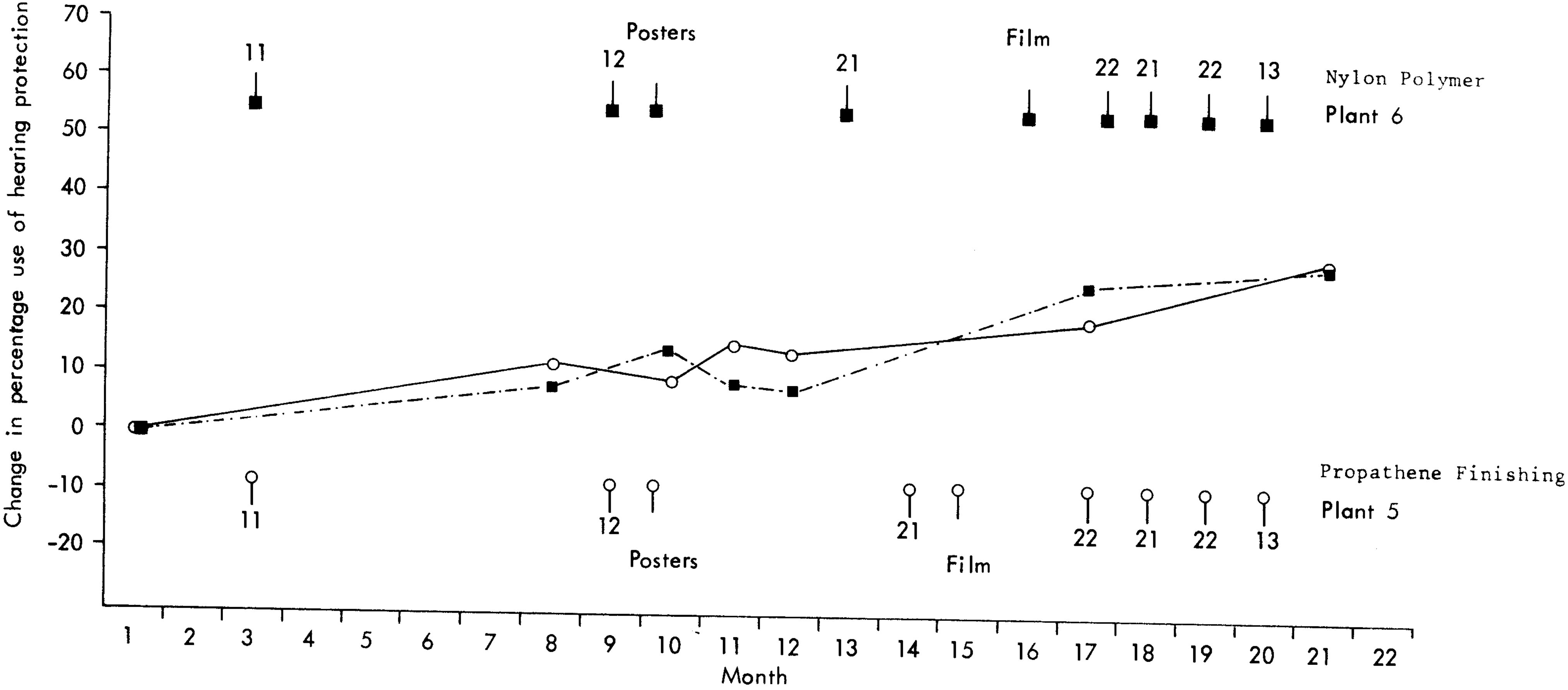


Figure 9.10 The change in hearing protector usage in the plants receiving audiometry and education as a treatment over the experimental period.

initial impact of the poster campaign on the Nylon Polymer and Propathene Finishing plants was diminished because the audiometric programme had been running for 7 months on these two plants, and it is probable that the posters were seen as a relatively minor adjunct to the main audiometric programme. However, it is possible that the presence of the poster programme may have supplemented the effects of the audiometric programme at a later date, and prevented a deterioration in percentage protector usage when interest in industrial noise had diminished during a particular phase of the audiometric testing.

Again, reviewing performance on the Propathene Finishing plant the film does not appear to have added the previously observed related increase in protector usage seen in the PF plant and in the Central Workshop to that increase which could be ascribed to the effect of the audiometry alone. The effect of the film could have been more substantial on the Nylon Polymer plant, but once more the net effect of the audiometry plus the education was no more than results obtained from other plants in the study would suggest could have been achieved by either the audiometry or the education alone.

It might however, be argued that the film and the poster campaign did have the same effect in the Nylon Polymer and the Propathene Finishing plants as they had done in the Central Workshops and in the PF plant, but that the potential increase in usage had been partially nullified by almost equal but opposite changes in protector usage caused by a period of disinterest in the audiometric programme. Although this argument can be advanced, it is less plausible than the following. It is a simpler hypothesis that the various components of the audiometric programme added to the components of the education programme to increase the number of stimuli. This would create a smoother increase in protector usage than that observed in plants receiving a more restricted number of stimuli, that is, either audiometry or education alone.

9.3 Conclusions

The main finding of the work described in this chapter is that a programme of standard industrial audiometry is capable of increasing the usage of hearing protection in a plant. The maximum gain in the usage of protection was approximately 41%, and achieved in Olefines V, a plant receiving audiometry alone as a treatment. The increase with time in the usage of hearing protection was reasonably steady, and was maintained to the end of month 22. This trend, shown in figure 9.7, indicated that this improvement would continue beyond the end of the experimental period.

However, the overall success achieved is dependent upon maintaining the interest of the workforce in the audiometric programme as evidenced by the less substantial gains made in the Terylene Polymer plant, in which the maximum increase reached 18%, and the trend looked less likely to continue at the end of month 22. The audiometric programme in this plant was conducted at a swifter rate and with less variation in type of audiometric phase than was the case for Olefines V, and it is thought that this, together with the fact that the results of the test could not be fed back to the employees, resulted in the smaller success of audiometry on this plant.

On both the Olefines plant, and the Terylene Polymer plant it was noted that increases in usage usually followed the start of a new phase of the audiometric testing programme. From this it can be reasoned that the usage of hearing protection within a plant responds more to the occurrence of the various stimuli, than to the content of the various stimuli. Extending this reasoning reinforces the conclusion that feeding the results of the audiometric test back to the employees should form a series of new stimuli which would serve to increase protector usage once again. In terms of increasing the number of stimuli it is also suggested that it should be beneficial in the long term if only a small number of employees are called for test each day, thus maximising the number of days each year on which employees are attending the medical Centre for a hearing test. However, if this policy is effected, the results presented in this chapter would suggest that a time lag of approximately 4 to 6 weeks after the start of the audiometry should be expected before hearing protector usage will increase.

Little latency in the start of the rise of hearing protector usage was observed after the beginning of the poster campaign. Two months after the posters were displayed both plants receiving education alone as a treatment showed a maximum rise of approximately 15% which could be ascribed directly to the effect of the poster campaign. The results indicate that this effect would probably decay back to zero after 6-7 months, unlike the effect of industrial audiometry.

The film appeared to be a more potent influence on hearing protector usage than the poster campaign, causing a rise of 25-30% in both the Central Workshops and the PF plant, but being more short - lived in effect than either the industrial audiometry or the poster campaign. The increased protector usage caused by viewing the film decreased back to zero 2-3 months after the showing and the combined effects of showing the film, and the poster campaign, which appeared to be additive, would have decreased back to zero after approximately 10 months.

This is unlike the increased usage ascribed to the effect of the industrial audiometry which appeared to have a longer lasting effect. However, the combined effect of the film and the poster campaign was capable of causing the same maximum rise of 40% in hearing protector usage as the programme of industrial audiometry, the only problem being one of how to sustain this effect without the repeated showing of films which would, presumably, have increasingly less overall impact. As a guideline, it would appear that any reasonable educational stimulus should be capable of causing an increase in hearing protector usage for 3-4 months, with the stimulus being in need of repeat within a maximum period of 10 months.

One of the significant findings of this study was that the effects of industrial audiometry combined with programmes of education were not additive, to the extent that the maximum gains achieved in the Propathene Finishing plant and the Nylon Polymer plant were 10% less (at approximately 30%) than had been noted in other plants in response to either audiometry or components of the educational programme alone. That audiometry and education are not completely additive in effect should not be surprising, but that each of these two components can provide a better maximum change when used alone, is more so. It is likely that the reason for this is that performing the audiometry and the education programme together gave the employees the overall impression of a very general and all embracing safety programme on industrial noise, and caused them to take less account of each of the individual components than would have been the case had the components been presented on their own. The results described in this chapter would, therefore, suggest that a delicate balance must be preserved between too few and too many stimuli too close in time during a hearing conservation programme.

Nevertheless, the rise in hearing protector usage on the plants receiving both education and audiometry as a treatment was more even than observed in the other treated plants and was continuing to rise at the same steady rate at the end of the treatment period.

As it is apparent that industrial audiometry can be used as a medium for causing behaviour change and that audiometry plus education does not appear to be more effective than a correctly implemented programme of industrial audiometry alone, traditional educational methods such as films or seminars, could be kept in a low key and relatively restricted. The time and cost saved by adopting this suggestion in a hearing conservation programme could be used to offset the cost of the industrial audiometry which has other, additional, medical values. These include its most important use as a final check on the effectiveness of a hearing conservation programme. It is a method of obtaining a physiological measurement which will assist in ensuring that it is safe for an employee to work in a particular function, a mechanism whereby employees with auditory problems can be identified and helped, and an opportunity to check the external auditory meatus for disease or physical problems which can be easily rectified. Additionally serial records of the hearing acuity of an employee can be built up over a period of time, which can be used for the legal protection of the employee and employer alike.

It is not sugested that a hearing conservation programme should not contain an educational component of the conventional type but rather that as industrial audiometry can produce the desired behavioural change in terms of an increased usage of hearing protection, the component of education can be kept in a low key, and informative rather than of the nature of propaganda. Offsetting the cost of the industrial audiometry using the savings made in the education programme improves the results of any cost-benefit analysis undertaken to assess the viability of conducting industrial audiometry in a particular industry.

CHAPTER 10

CHANGES IN ATTITUDE TOWARDS HEARING CONSERVATION CAUSED BY THE EXPERIMENTAL TREATMENTS

10.0 Introduction

Attitude questionnaires were despatched to the eight plants participating in the main study, after completion of the treatments. A comparison of the pre-treatment and post-treatment attitudes measured provided an index of the success of the treatments. A method was required to maximise the returns of the post-treatment questionnaire, for two reasons. Firstly labour turned over on the site at a rate of approximately 13% per year and thus a comparatively large number of respondents to the pre-treatment attitude questionnaire had left the company by the time that the post-treatment questionnaires were despatched. Therefore the returns of the post-treatment questionnaire needed to be maximised if a successful comparison was to be made of attitude changes occurring during the experimental period, in 8 plants. Secondly the questionnaire now lacked novelty value to the employees as they had already completed one questionnaire 18 months previously, at the commencement of the study.

As will be seen in section 10.1, a method was found to maximise returns, but this necessitated further analytical work to ensure that the steps taken had not themselves biased the questionnaire results.

It was also necessary to evaluate whether or not those employees leaving the company had held views or attitudes which were different from those of the segment of the pre-treatment population which had remained on the site. If this was the case, an apparent attitude change could have spuriously arisen as a consequence of the removal from the test population of those employees who had resigned. Analytical work investigating this problem is described in section 10.2.

The factors described above were successfully resolved, permitting an evaluation to be made of attitude change over the experimental period, and hence the relative effectiveness of the various treatments in changing attitudes.

10.1 Post-treatment Questionnaire

10.1.1 Despatch

The computer files containing the addresses of over 2000 employees participating in the study, used to address the pre-treatment attitude questionnaires, were updated using information supplied from the Wilton site. The process was time consuming, and thus preparations began, by necessity, two months prior to the despatch of the post-treatment questionnaires. This had the unavoidable effect that the computer address list still showed a small number of individuals who had left the site by the time that the questionnaires were despatched. The effect upon the final return percentage however was minimal, reaching approximately 0.75% as shown by the number of envelopes returned as undeliverable.

Difficulty was encountered during the amendment of the pre-treatment attitude questionnaire address list as site management had extensively changed employee works numbers since the creation of the original computer address file on the mainframe computer. Several computer programs were written to effect the necessary changes, using data on punched computer cards from the Wilton site.

During the 21 month period between the creation of the address files, 355 employees included in the main study had left their plants. Accordingly 1361 post-treatment attitude questionnaires were despatched, of which approximately 42% were returned within two weeks. A fresh questionnaire and reminder letter were sent to defaulting employees, resulting in a further 10% being returned. The total return percentage of approximately 52% was not as high at this stage, as that obtained from the pre-treatment attitude questionnaires. Further steps were taken to increase the returns, as described below.

10.1.2 Techniques used to maximise the returns

One probable reason for the initial lower response to the post-treatment attitude questionnaire was that employees recognised the post-treatment questionnaire as being that which they had completed two years earlier, and could not see the point of repeating the process. This problem was difficult to counter in the letters which accompanied the questionnaires, without biasing the results by informing the recipient that the need for a completed second questionnaire lay in the requirement to measure a possible change of attitude over the experimental period.

After discussion with Dr A McKennell of the Social Statistics Department of Southampton University, the following solution was adopted. A new questionnaire was prepared, featuring a reduction in the number of questions to 10. Each of the questions selected was the defining item for one of the 10 attitude scales previously developed, in that it exhibited the highest correlation with the other questions in the scale, and was the question to which most weight had been attached when identifying the scale. The questionnaire was printed on yellow paper, as there exists some slight evidence within the literature that this colour encouraged the recipient to make a response (Dunlop, 1950). Sealable white envelopes specially printed with a University crest, and ISVR heading were designed for this exercise, as a contrast to the brown returnable internal mail envelopes which had been used in previous questionnaire despatches.

The new questionnaire is shown in Appendix 10.1 together with the accompanying letter, which is slightly longer than previous such letters. The questionnaires were delivered by hand to each plant, and the importance of the project stressed to the foremen, who were asked to encourage individuals to complete the questionnaires.

In addition, an attempt was made to increase the return percentage by writing an article for "Wilton News" the fortnightly ICI site newspaper which is distributed free of charge to all employees. This article simply reminded employees that an important research study was being conducted, and requested that the questionnaires should be returned. These devices were successful in that they caused a further 23% of the questionnaires to be returned, bringing the total return to 75.5%.

10.1.3 Analysis of the percentage of the pre-treatment attitude questionnaires returned

Table 10.1 shows the numbers of post-treatment questionnaires returned by each of the plants as a percentage of the despatch. The table also shows the pre-treatment attitude questionnaire percentage returns, and plant rankings by percentage return are given as the first step of calculation of the Spearman rank coefficient. (Runyon 1971). As shown in table 10.1, this statistic permits acceptance of the null hypothesis that the rankings of the plants by post-treatment or pre-treatment attitude questionnaire returns are statistically identical at the 2% level. Thus as the changes in attitude which will be shown later in this chapter to have occurred during the treatment period were evident in some plants, but not in others, the constancy of plant ranking by percentage questionnaire return over the experimental period suggests that the questionnaire return yield of a plant is unrelated to the attitudes held towards hearing conservation measures on that plant. The difference in questionnaire percentages exhibited by the plants is therefore more likely to be related to less important causes in terms of the influence they would exert on the results of the research. They could even include such mundane factors as whether or not pencils or pens were easily accessible within a particular plant.

10.2 Possible biases caused by the non-return of questionnaires

One of the objectives of the research was to ascertain if changes could be measured in attitudes held by employees working in plants in which specific treatments had been undertaken, and furthermore, whether or not these changes could be related to the effects of the treatments.

In order to draw conclusions from any change in attitude measured over the treatment period, it was necessary to investigate certain mechanisms other than the treatments themselves by which a change might have occurred.

One such mechanism was that of an apparent population attitude change occurring because employees who had resigned from the treated plants during the experimental period had done so because they disliked the noise. If this had occurred the measurement of attitudes by the post-treatment

Table 10.1 Post treatment and pre treatment attitude questionnaire returns shown as the number, (n), and as a percentage of the despatch.

	Pre-treatment n	%	Rank	Rank	Pre-treatment %	n
Terylene Polymer	176	88.9	1	2	80.6	133
Olefines V	129	73.7	6	7	71.6	96
Central Workshops	127	70.6	8	6	72.2	109
P.F. Plant	225	72.4	7	8	70.9	168
Propathene Finishing	172	76.8	4	3	77.8	140
Nylon Polymer	197	79.7	3	1	82.0	141
Polythene Finishing	123	86.0	2	4	75.8	75
Power Station	178	74.8	5	5	74.0	165

Spearman's rank coefficient r_{rho} = 0.8095 *

* not significantly different at the 2% level

	Pre-treatment n	%		Post-treatment n	%
First returns	858	50.0		42.0	572
Second returns	488	28.4		10.0	136
Third returns	-	n/a		23.4	319
Total	1346	78.4		75.4	1027

attitude questionnaires could have been biased by lack of these individuals from the sample as they had held a very positive attitude against noise at work. The investigation of this concept is described in section 10.2.1.

Secondly, a study was undertaken to ascertain whether the use of the shortened form of the attitude questionnaire could have caused an apparent change in the attitude measurement. The results of this study are described in section 10.2.2.

10.2.1 Possible bias caused by the natural turnover of employees

10.2.1.1 Method

A computer program was written to interrogate the two computer files containing respectively the addresses of employees to whom the pre-treatment and the post-treatment attitude questionnaires were despatched. This computer program also accessed the files holding the results of the returns of these two despatches of attitude questionnaire. The result of this work is given in figure 10.1 as a dispersion chart showing how the various populations had behaved with respect to completion of the attitude questionnaires, or leaving the company during the study. Of immediate interest to this study was whether or not the individuals who had responded to the pre-treatment questionnaire but not to the post-treatment questionnaires differed in attitude to those who had responded to both despatches. That is, did the attitudes of sub-populations (xiii) and (xiv) in figure 10.1 differ from the attitudes in sub-population (xv)?

An initial indication was given by the rate at which individual employees resigned from the company over the experimental period. Inspection of figure 10.1 shows that subpopulation (ii) represents 20.7% of subpopulation (i), whilst subpopulation (xiv) represents 21.3% of subpopulation (xi). That is, individuals left the entire population of the study at the same rate as they did the subpopulation of individuals who completed the first round of attitude questionnaire. This is an encouraging observation, indicating that attitudes held towards industrial noise were not strongly linked to whether an individual resigned from his work even though subpopulation (xi) is itself a subpopulation of (i).

A further analysis was performed. The pre-treatment attitude questionnaire data were subdivided into the three subpopulations described earlier, these being (xiii), (xiv) and (xv), using a further computer program to locate each of the relevant individuals.

The resulting data were subjected to a two-way analysis of variance using a fixed effects, nested model. The pre-treatment attitudes held by the 954 individuals who had stayed with the company and had responded to both questionnaires were tested against those held by employees who had either not responded to the post-treatment questionnaire, or who had resigned from the company prior to despatch of these questionnaires.

10.2.1.2 Results

Table 10.2 shows the results of the analysis of variance described in section 10.2.1.2 investigating the homogeneity of attitude scale scores within the pre-treatment attitude questionnaire results, by population section.

The population section x scale score interaction is not statistically significant at the 5% level; the subject x population section is statistically significant at the 1% level as a consequence of the expected and inherent variablility found within human subjects, and discussed earlier. The scale score main effect is highly significant, as would be expected; scale scores are not likely to be identical. The difference between population sections is non significant, although in a strict sense comment should not be passed upon this main effect as the population section x subject interaction was statistically significant. However the homogeneity of population attitude scale scores can be seen in the comparison of means also given in table 10.2. Even at the 5% level the difference between mean scale scores for the two populations would be required to exceed 1.7 to achieve statistical significance in a 't' test, which clearly does not occur.

Therefore it can be concluded that no discernable difference in attitude structure exists between the 954 individuals who completed both the post-treatment and pre-treatment questionnaires, and the 373 who completed only the pre-treatment questionnaires. It was therefore decided that any change in attitude which might be noted after the treatments had been completed could not be ascribed to the lack of any special views which had been held by the 21.3% of the original population who had left the company during the treatment period, or the 6.8% who failed to complete the post-treatment questionnaire. Secondly, it was concluded that the 954 individuals who had completed both the pre-treatment and post-treatment questionnaires could be used to monitor the success of the treatments, without fear of significant bias.

10.2.2 Possible bias caused by use of the shortened questionnaire

10.2.2.1 Method

A computer program was written to subdivide the 954 post-treatment attitude questionnaire respondents into two sections, those who had completed the full questionnaire, and those who had returned the shortened questionnaire. The data was subjected to a two-way analysis of variance using a fixed effects, nested, model, and the results are shown in table 10.3 and 10.4

10.2.2.2 Results

The population section x subject interaction is significant at the 5% level, as would be expected after consideration of both the inherent variability of the human population, and the high number of levels within the subject factor. The section x score interaction is also just significant at the 5% level indicating that a small difference may exist between the two sections for one or more of the scale scores. This difference can only be minor, as the difference between population sections main effect is not significant at the 5% level. The remaining main effect, scale score, is highly significant as would be desired, showing that the population is attaining different scores on the various scales.

A series of 10 't' tests was then undertaken between the mean scores attained by the two sections on each of the 10 scales utilising the residual mean square as the error estimate. The test was conducted at a significance level of one tenth of that used in the preceeding analysis of variance to protect against spurious significance, as discussed earlier.

Figure 10.1 The dispersion of attitude questionnaire returns

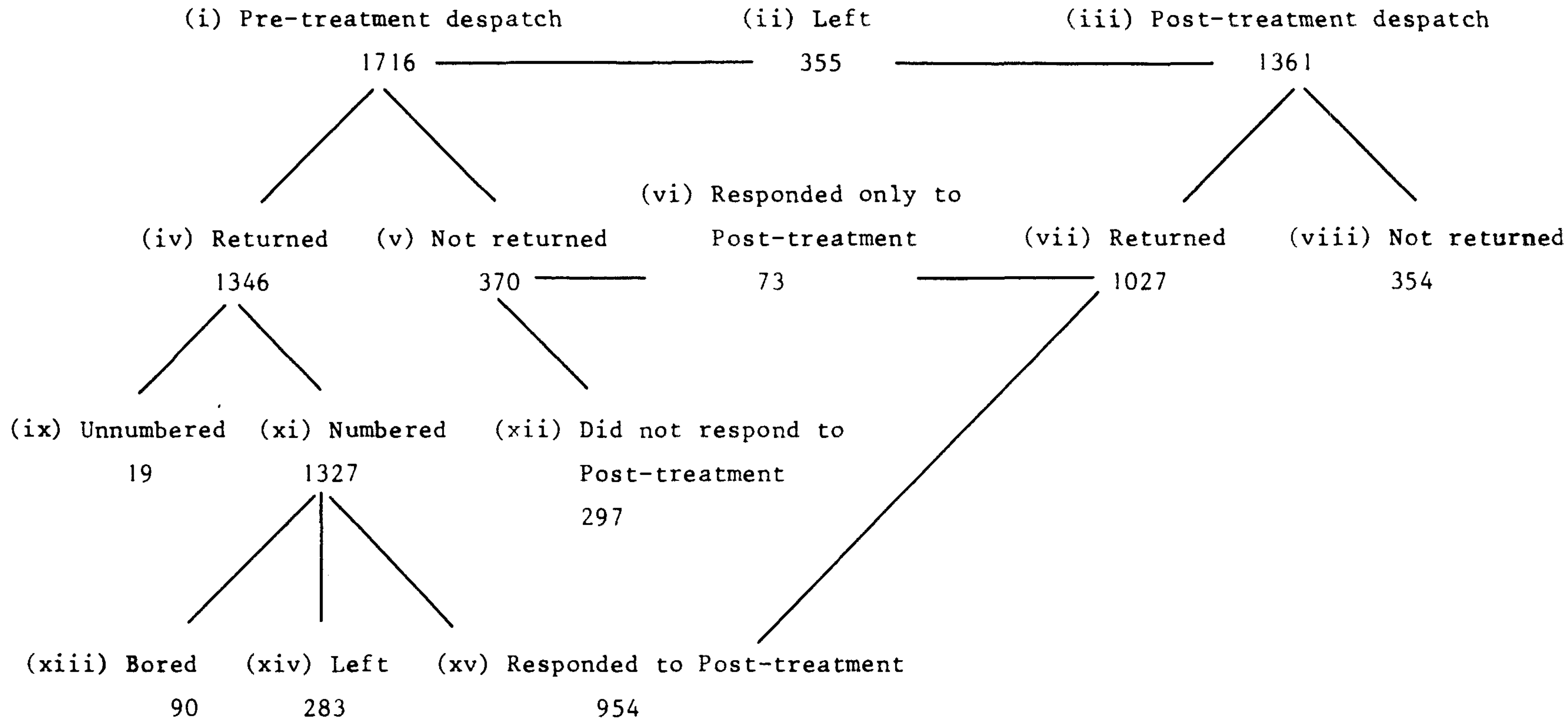


Table 10.2 The results of the analysis of variance of the pre-treatment attitude scale scores subdivided into two populations; those employees who completed both the pre-treatment and post-treatment questionnaires, and those who did not.

Source of variation	df	ss	ss%	ms	vr
Section	1	73.2	0.00	73.2	0.377
Score	9	703224.8	19.12	78136.1	403.132
Section . Subject	1325	662832.3	18.02	500.3	2.581
Section . Score	9	936.0	0.03	104.0	0.537
Residual	11925	2311333.0	62.84	193.8	
Total	13269	3678399.0	100.00	277.2	
Grand Total	13269	3678399.0	100.00		
Grand mean	65.12				
Total number of observation	13270				

* Significant at the 1 % level

** Significant at the 0.01 % level

Section	Scale	NIHL	ENF	NONUSE	ENVIR	ACCEPT	CONTROL	PROG	ISO	COMPET	BEHAV
stay	mean n = 954	77.51	67.18	59.79	74.39	58.30	53.90	50.94	60.14	69.33	70.16
rest	mean n = 373	77.47	67.63	59.53	73.27	57.30	54.05	61.57	59.33	69.73	70.11

Table 10.3 The results of an analysis of the variance of the attitude scale scores attained by the post-treatment respondents who had completed the full or the shortened questionnaire.

	df	ss	ss %	ms	vr
Section	1	904.3	0.03	904.3	3.195
Score	9	486283.3	13.98	54031.5	190.870*
Section x Subject	952	556701.5	16.00	584.8	2.066*
Section x Score	9	9931.9	0.29	1103.5	3.898*
Residual	8563	2425424.0	69.71	283.1	
Total	9539	3479245.0	100.00	364.7	

* Significant at the 5% level

Table 10.04 An examination of the mean scores attained on the full and shortened questionnaires.

n	NIHL	ENF	NONUSE	ENVIR	ACCEPT	CONTROL	PROG	ISO	COMPET	BEHAV	Score
696	78.37	58.24	64.43	75.30	58.46	55.20	67.84	61.64	71.47	71.61	Full
258	76.86	64.73	63.18	73.91	58.10	56.59	70.04	63.22	70.97	71.90	Part
	1.23	-5.29*	1.02	1.13	0.29	-1.13	-1.79	-1.28	0.40	0.24	t

$t_{954,\ 0.5\%} = 2.807$

* significant at the 0.5% level

The results of these tests are shown in table 10.4, where it can be seen that the scale scores attained by the two populations are not significantly different on nine of the ten scales, but that they differ at the 0.5% level on the tenth, ENF.

The scores derived from the shortened questionnaires show a more favourable response to the enforced usage of hearing protection than those obtained from the full questionnaires on the same scale. The mean score attained by the respondents using the full questionnaire falls into the "Neither Agree nor Disagree" category on the five point scale, whilst the mean response from those employees completing the shortened questionnaire falls into the "Agree" scale position, that is they felt that more should be done to compel individuals to use hearing protection.

This difference in attitude score on one scale could have arisen as a consequence of shortening the scale, or because the individuals who completed the shortened questionnaires could be classed as late respondents, with a slightly different attitude than the majority in this one case.

It is not unreasonable to accept the latter hypothesis for if the former was correct, and shortening the scales had caused a change in measured scores, the score differences between scales derived from the full and part questionnaire should have been systematic, arising on more than one scale. However, it will be shown in a later section of this chapter that even if the effect was caused by shortening the questionnaire the result would not affect the outcome of the experiment.

Although it has been concluded that the score on the scale ENF had been slightly affected by those individuals completing the shortened questionnaire, effectively a late response, the data shown in table 10.4 can be used to argue that the effect of non-response must be even smaller in the case of the post treatment questionnaire than has already been shown to be the case for the pre-treatment questionnaire. Table 10.4 indicates that no difference in measured attitude exists between early and late respondees on nine of the ten scales unless the very unlikely hypothesis is accepted that use of the shortened questionnaires caused a bias in a particular direction which was exactly counter-balanced by an equal but opposite bias in opinion held by late respondees. Accepting the more reasonable former proposition and extending it suggests that those employees who did not respond at all to the post-treatment questionnaire would not have changed the post-treatment scale scores significantly had they responded.

10.2.3 Conclusions

Two investigations into possible bias in the post-treatment questionnaire results showed that no significant bias is likely to have occurred either from the use of the shortened questionnaire, or the fact that a proportion of the employees completing the pre-treatment questionnaire had left the company prior to issue of the post-treatment questionnaire.

Finally non-response to the post-treatment questionnaire was also unlikely to have caused any significant bias in the results.

10.3 Homogeneity of the attitudes held on the plants before treatments commenced

Section 10.4 reports the results of the main study of attitude changes caused by the treatments. However, before comment can be passed upon attitude change, and in particular differential attitude changes across the treated plants, an evaluation must be made of whether or not the attitudes held by each of the plants prior to treatment were equivalent.

10.3.1 Method

Work in section 10.1 and 10.2 showed that the questionnaires received from the 954 employees who completed both the pre-treatment and the post-treatment questionnaires could be used to assess the success of the treatments.

A computer program was written to extract the pre-treatment questionnaires completed by these employees, from the 1346 received. The same program generated the scale scores broken down by plant.

10.3.2 Results

The scale scores are shown by plant and scale in table 10.5.

This data were subjected to a two-way analysis of variance, with replication, to investigate the homgeneity of the pre-treatment attitudes across plants. The analysis was too large to perform on the Southampton University ICL 2970 mainframe computer using standard statistical packages, as the number of levels (8x10x954) yielded 76,320 data points and caused the analysis products to exceed the available workspace. Accordingly 10 one way analyses of variance, with replicates, were performed to generate the required means and sums of squares which were then recombined manually to form the final two way analysis of variance using a fixed effects model on a design with unequal cell sizes and replication. During each of the one way analyses the between subjects variance was pooled into the residual, as in this experiment it can be viewed as a form of error, as dicussed earlier.

Table 10.6 shows the results of the reconstructed two way analysis of variance. and indicates that a small interaction effect exists between plants and scale scores at the 0.1% level, but that a much larger effect exists between plants at the 0.1% level, and naturally between the scale scores themselves.

The interaction effect was of interest, showing that some of the plants had attained statistically different scores on some of the scales. This finding is examined in depth later in this chapter. However, it was also of interest to investigate further the difference between the overall pre-treatment plant attitude scores shown to exist. In particular it was desired to ascertain whether a single major effect could be the main cause of the between plants attitude difference. Unfortunatly the analysis described in table 10.5 would obscure this, as the very high number of degrees of freedom resulting from the large number of subjects causes the analysis to have very high discriminatory powers thus revealing the fine structure of any differences existing, and hiding the gross structure which is of main concern.

Table 10.5 Pre-treatment scale scores achieved by the 954 employees completing both the pre-treatment and post-treatment attitude questionnaires displayed by the plant and scale. The upper figure in each box gives the mean score, whilst the variance is shown as the lower figure.

	NIHL	ENF	NONUSE	ENVIR	ACCEPT	CONTROL	PROG	ISO	COMPET	BEHAV
Terylene Polymer	78.4453	70.664	60.4141	75.8047	58.7266	53.5156	62.8281	60.7187	70.00	68.9609
n = 128	156.232	182.428	288.039	157.252	160.3566	284.391	146.0472	165.936	355.6996	182.444
Olefines V	79.2935	70.489	70.3804	76.3804	61.7935	53.5869	58.4783	61.2391	71.5217	71.5761
n = 92	147.2849	270.908	291.4019	180.765	223.087	271.607	173.3066	144.8846	309.746	197.762
Central Workshops	75.0606	64.141	56.0808	71.222	58.9192	52.7273	60.5858	57.5858	63.939	71.4343
n = 99	277.135	275.530	262.706	223.724	170.828	242.484	214.549	118.7533	291.463	240.920
P.F. Plant	77.5776	68.714	57.9068	74.77	58.6149	55.8385	60.2112	59.7391	69.813	69.6335
n = 161	138.469	209.815	309.1196	124.126	166.862	364.447	130.2794	149.906	335.589	173.0934
Propathene Finishing	76.2969	66.367	56.6791	74.1016	61.0078	54.6094	60.820	62.00	68.3594	69.3594
n = 128	188.0354	203.430	296.990	188.972	241.818	289.608	129.2177	154.314	325.633	214.812
Nylon Polymer	79.2143	68.690	64.2778	75.3810	56.50	52.9265	63.3016	62.881	71.1905	71.4365
n = 126	182.9364	229.6701	392.393	202.331	188.746	257.705	127.4415	134.3605	333.767	224.263
Polythene Finishing	76.1389	62.041	50.6389	71.4583	56.0972	51.9444	60.2361	58.0417	71.250	69.1667
n = 72	201.586	229.277	248.403	176.109	204.848	246.87	152.463	146.885	295.596	211.970
Power Station	77.4392	64.378	60.4865	74.4595	55.2432	54.2567	60.3311	58.2095	68.783	70.1554
n = 148	239.7016	257.185	303.146	235.840	162.183	235.497	187.896	141.8647	340.004	261.3945

n = 954

Table 10.6 Two way analysis of variance with replication on the pre-treatment questionnaires completed by the 954 employees returning the "pre" and "post" treatment questionnaires.

	d.f.	Mean square	vr
Plants	7	3013.29	13.61*
Scales	9	52997.66	239.42*
Plants, Scales	63	555.46	2.51*
Residual	9460	221.36	
Total	9539		

*Significant at the 0. 1 % level

Accordingly the data were re-analysed to avoid this problem, as described below.

The data shown in table 10.5 were reconsidered, and each of the mean attitude scale scores within each cell was used as a single datum point representing the overall attitude of that plant on that scale, thus removing the replication or between subjects estimate of error, but also reducing dramatically the number of degrees of freedom. The two way analysis of variance was then reconstructed, and is shown in table 10.7.

This table shows that both the between plants and between scale scores effects are significant at the 0.1% level, as before. The between plant difference is the effect of interest but further investigation requires multiple comparisons betwen the plants to be performed. Use was therefore made of the Newman-Keuls test set at the 1% level both to investigate the contrasts and to group plants with statistically indistinguishable attitudes (Lee 1975).

The plants are shown in table 10.8 ranked by overall scale score. The statistically indistinguishable subsets identified by the Newman-Keuls test are also indicated.

It is notable that the plants taking rankings 1,2, and 3 are those identified in chapter 8 as being the ones in which the non-response factor could have spuriously increased certain of the attitude scale scores. Work in chapter 8 showed that three of the ten scales in the Nylon Polymer plant response were affected, two in the case of the Olefines V plant, and one in ten from the Terylene Polymer plant response. Recalculation of the data shown in table 10.5 suggests that had the scores on the affected scales equalled the mean for all plants on that particular scale, the range of overall scale scores shown in table 10.8 would have been reduced. The reduction would have been such that the majority of plants would have been embraced by a single subset shown as (4) in figure 10.8. This would have indicated general homogeneity of the overall attitude within the experimental plants. Only Olefines V could have then been said to show a more positive attitude than either the Central Workshops or the Polythene Finishing plant, and numerically even this difference would have been small.

Table 10.7 Two way analysis of variance on the attitude scale scores attained by the eight plants on ten attitude scales at the pre-treatment stage.

Variate Y	df	ms	vr
Between plants	7	26.89	5.42*
Between scales	9	472.94	95.43*
Plants . scales residual	63	4.956	
Total	79		

* Significant at the 0.1% level

Table 10.8 Plants ranked by attitude score achieved over all scales as shown in table 10.5. The subsets defined by the Newman-Keuls test are also shown.

Rank	Plant	Overall scale scores	Subset 4	Subset 5	Subset 1	Subset 2	Subset 3
1	Olefines V	674.74		5	1		
2	Nylon Polymer	665.81	4	5	1	2	
3	Terylene Polymer	660.07	4	5	1	2	3
4	PF Plant	652.81	4	5	1	2	3
5	Propathene Finishing	649.61	4	5	1	2	3
6	Power Station	643.75	4	5	1	2	3
7	Central Workshops	631.70	4			2	3
8	Polythene Finishing	627.02	4				3

Key

1 - 3 = subsets defined by Newman - Keuls test
4 - 5 = hypothetical subsets if all employees had returned questionnaires

Newman - Keuls test 1% level of significance

It is now appropriate to investigate the fine structure of the differences between plants by means of a study of the interaction effect shown to exist in table 10.6 based upon an analysis exhibiting a high number of degrees of freedom resulting from the high number of subject levels.

As a first step the plants were ranked by score achieved on each individual scale. A one-way analysis of variance was undertaken on the full data provided by each scale thus ranked, to generate a within groups mean square error for use in the Newman-Keuls test which itself was effected using a harmonic mean to allow for the different sizes of the plant groups. The subsets defined are shown in table 10.9 and indicate clearly that the pretreatment between plants attitude differences have their origins in three scales; ENF, NONUSE, and ACCEPT. No statistical difference between plants at the pre-treatment stage on the other 7 scales can be detected at the 1% level.

The largest variation between plants is observed on the scale NONUSE, which measures the attitude towards the frequency with which use is made of hearing protection on a plant. This finding would be expected if this attitude scale was related to the objective measurements of the plant usage of hearing protection at the pre-treatment stage. This was shown in chapter 9 to differ between plants. Accordingly the usage data given in chapter 9 were used to rank the plants which were then ranked for a second time by mean score achieved on the scale NONUSE. A correlation between these two rankings was shown to exist by calculation of the Spearman Rank Correlation Coefficient. This produced an S_r value of 148, indicating that the hypothesis that no correlation existed could be rejected at a level of better than 5% (3.8% actual). Scores achieved on the remaining 9 scales did not correlate at a level better than 5% with the data on initial protector usage.

This finding is encouraging indicating once again that the attitude scales are functioning as measurement tools, and that certain scale scores can be correlated with physical measurements. Furthermore the pre-treatment difference existing between plants on the scale NONUSE can be related to the difference in the starting levels of hearing protector usage on the plants.

Table 10.9 Plants ranked by scale score achieved on each of the ten scales, at the pre-treatment stage. The subsets shown are calculated using the Newman Keuls test at the 1% level with 946 degrees of freedom.

NIHL	
Olefines V	79.29
Nylon Polymer	79.21
Terylene Polymer	78.45
PF Plant	77.58
Power Station	77.44
Propathene	76.30
Polythene	76.14
Workshops	75.06

ENF	
Terylene Polymer	70.66
Olefines V	70.50
PF Plant	68.71
Nylon Polymer	68.69
Propathene	66.37
Power Station	64.38
Workshops	64.14
Polythene	62.04

NONUSE	
Olefines V	70.38
Nylon Polymer	64.28
Power Station	60.49
Terylene Polymer	60.41
PF Plant	57.91
Propathene	56.68
Workshops	56.08
Polythene	50.64

ENVIR	
Olefines V	76.38
Terylene Polymer	75.81
Nylon Polymer	75.38
PF Plant	74.77
Power Station	74.46
Propathene	74.10
Polythene	71.45
Workshops	71.22

ACCEPT	
Olefines V	61.79
Propathene	61.00
Workshops	58.92
Terylene Polymer	58.73
PF Plant	58.62
Nylon Polymer	56.50
Polythene	56.10
Power Station	55.24

CONTROL	
PF Plant	55.84
Propathene	54.61
Power Station	54.26
Olefines V	53.59
Terylene Polymer	53.52
Nylon Polymer	52.94
Workshops	52.73
Polythene	51.94

Table 10.9 continued.

PROG		ISO	
Nylon Polymer	63.60	Nylon Polymer	62.88
Terylene Polymer	62.83	Propathene	62.00
Propathene	60.82	Olefines V	61.24
Workshops	60.59	Terylene Polymer	60.72
Power Station	60.33	PF Plant	59.74
Polythene	60.24	Power Station	58.21
PF Plant	60.21	Polythene	58.04
Olefines V	58.48	Workshops	57.59

COMPET		BEHAV	
Olefines V	71.52	Olefines V	71.58
Polythene	71.25	Nylon Polymer	71.44
Nylon Polymer	71.19	Workshops	71.43
Terylene Polymer	70.00	Power Station	70.16
PF Plant	69.81	PF Plant	69.63
Power Station	68.78	Propathene	69.36
Propathene	68.36	Polythene	69.17
Workshops	63.94	Terylene Polymer	68.96

The Newman-Keuls test on the scale ENF, as shown in table 10.9, indicates that attitude differences exist between plants towards the enforced usage of hearing protection. The plant attitudes can be subdivided into two distinct subsets. The score achieved by the Polythene Finishing plant can be considered to be the outlier as it lies further from the overall plant score mean of 66.95 than do the scores at the other extreme of the range achieved by the Terylene Polymer and Olefines V plants. That the Polythene Finishing plant should exhibit an unenthusiastic attitude towards the enforced usage of hearing protection is not unexpected in view of the extremely low initial usage of hearing protection on this plant, the lowest of all the experimental plants. Any edict enforcing industrial discipline in the usage of ear defenders would require a large proportion of the Polythene Finishing plant employees to change their safety habits.

"ACCEPT" is the third scale on which a between plants pre-treatment attitude difference is evident, as shown by the two subsets of attitudes in table 10.9. Using the same approach as discussed above, the outlier causing the attitude differential is the Power Station. As this scale measures the attitude towards the comfort of hearing protection, it is evident that the high usage of hearing protection on the plant at the pre-treatment stage has been achieved despite the opinion in the Power Station that ear protectors are uncomfortable. It should be remembered that the Power Station possessed the greatest percentage of employees using hearing protection at the pre-treatment stage, and the attitude measured therefore results from questionnaire returns from a larger number of employees making regular use of hearing protection than is the case for other plants in the study.

10.3.3 Conclusions

This study showed that a good degree of homogeneity of attitude existed across the eight plants involved in the study, prior to commencement of the treatments. This homogeneity would probably have been slightly improved had all the individuals who were sent a questionnaire, returned them.

Between plant attitude differences could only be detected in three scales. One of these, NONUSE was shown to be a correlate of the initial measurements made of hearing protector useage, an encouraging finding. The between plant differences on the remaining two scales were not large, resulted from one plant on each scale, and could be explained in terms of the existing level of hearing protector usage.

10.4 Attitude change over the experimental period

Having evaluated the major sources of potential bias in the attitude survey study, it is now possible to investigate the change in attitude observed in the experimental plants after the treatments had been completed.

10.4.1 Method

Sections 10.1 and 10.2 showed that the questionnaires received from the 954 employees who had completed both the pre-treatment and post-treatment attitude questionnaires could be used to assess the success of the treatments. Acceptance of this approach permitted paired comparisons to be made between the pre-treatment and post-treatment attitude scale scores for each of the 954 employees individually, giving change of attitude scale scores.

Such paired comparisons permit tests to be performed which are statistically more discriminating as they prevent large differences in attitude between employees from obscuring small changes of attitude occurring within each employee. The disadvantage of a paired comparison test is that it halves the number of degrees of freedom available for the statistical comparisons. However, this problem was not of importance in the present analysis as the 19,080 available data points permitted a halving of the maximum possible number of degrees of freedom without any significant loss in discriminatory power.

The paired comparison technique had the additional benefit of making the distribution of the data highly normal. It has been shown previously in this thesis that the distribution of the data for the individual items within the questionnaires was not unacceptably skewed, but the process of generating the attitude scale scores from the individual data points improved the normality greatly, and the generation of change of attitude scale scores completed the process.

10.4.2 Results

The ICL 2970 computer was programed to extract and match the 1,908 pre-treatment and post-treatment questionnaires completed by the 954 employees who had responded to both the questionnaires. The program scored each item belonging to a scale, subtracted the post-treatment score from the pre-treatment score and reformed each of the 10 attitude scales to produce an attitude change scale score. A further program was written to analyse the attitude change by plant. The results of this process are displayed in table 10.10.

A two way analysis of variance with replication was performed on the data, which once again was too large to complete using the statistical packages available on the ICl 2970. Accordingly 10 one way analyses of variance were performed, and the results recombined and recalculated manually to provide the final two way analysis of variance, which is shown in table 10.11.

A plant x scale interaction exists at the $p < 0.01$ level, stronger than that detected in the pre-treatment attitude data, suggesting that a strong differential in attitude now exists between some plants on some scales. The pattern of this interaction has not obscured a difference between plants, significant at the $p < 0.01$ level, and the expected between scales difference, significant at the same level.

The change of attitude in each of the plants is displayed graphically in figure 10.2. The cross-hatched histogram segments show those attitude changes which reached statistical significance at the $p = 0.001$ level using the "t" test for paired data. The level of statistical significance was chosen as that providing adequate protection for a multiple comparison set of 8, as discussed in chapter 7. The overall level of significance for all 8 comparisons is $p = 0.008$, which is the closest obtainable overall level, using standard tables, to the $p = 0.01$ level of significance used in the related analysis of variance.

Figure 10.2 indicates that ENF is the only scale on which a statistically significant change of attitude was observed to have occurred amongst

Table 10.10 Showing change of attitude over the experimental period by scale and plant. The upper figure in each box shows the mean score change, whilst the lower figure shows the variance.

	NIHL	ENF	NONUSE	ENVIR	ACCEPT	CONTROL	PROG	ISO	COMPET	BEHAV
Terylene Polymer n = 128	0.8984	-4.4141	10.6328	0.1797	3.3516	6.0156	9.7656	10.2187	-0.7031	5.1797
	99.5245	110.479	369.5083	179.5653	278.0689	677.6910	255.7856	251.5713	496.3493	222.4781
Olefines V n = 92	0.6413	-5.2174	13.0543	0.9239	-4.1196	1.9565	8.1739	9.3913	1.8478	5.1630
	103.3739	104.8965	212.1159	141.9148	477.5536	613.7114	263.6161	296.1049	237.2062	287.6076
Central Workshops n = 99	0.4141	-10.2020	3.505	-1.6163	-2.0707	-1.2121	7.1111	1.3737	-0.9091	-7.6465
	213.1629	133.1208	515.9666	81.6456	347.0433	445.4505	188.9140	190.4786	381.8155	324.9006
P.F. Plant n = 161	1.354	-7.2857	0.2857	1.6584	0.8944	3.8509	8.5652	-0.1180	7.2671	-1.4224
	170.3547	187.69	579.1049	155.3986	433.7889	816.3134	172.9461	176.8022	313.7362	349.9181
Propathene Finishing n = 128	1.6719	-3.2812	7.875	0.0859	-2.2812	3.0469	8.6562	-5.375	-3.9062	4.0234
	166.8178	115.9196	448.0291	176.8181	473.6020	328.4358	234.5247	417.5074	496.4295	314.5869
Nylon Polymer n = 126	0.1508	-4.8968	5.5524	0.5635	1.3175	-7.3810	17.1270	3.7222	2.6984	2.5079
	131.6962	157.0184	337.4495	177.4783	448.7618	302.8834	158.4929	405.1444	381.4599	233.9767
Polythene Finishing n = 72	-1.0139	-13.3611	-3.9722	4.0278	-0.8056	3.7500	-1.0972	1.9167	4.0278	4.6528
	210.5459	137.3302	266.5317	202.5042	253.2554	612.4981	212.3140	314.7785	322.982	243.8906
Power Station n = 148	-1.0878	-10.9662	-1.7095	-0.4932	1.7297	2.8378	-0.8716	-2.5338	4.1892	0.9122
	133.9297	177.1481	248.980	132.7680	219.8844	600.0442	228.3544	489.2015	296.6145	180.9509

Table 10.11 Two way analysis of variance with replication of data giving the change of attitude on the experimental plants.

	d.f.	Mean square	vr
Plants	7	3954.49	13.49*
Scales	9	12538.32	42.79*
Plants, Scales	63	1710.87	5.84*
Residual	9460	293.01	
Total	9539		

* Significant at $p < 0.01$

employees in the two control plants. Therefore it can be concluded that in the case of the remaining nine scales, any statistically significant attitude changes measured can be ascribed to the effect of the plant treatments.

10.4.2.1 NIHL Measuring the attitude towards belief in noise induced hearing loss as a serious occupational hazard

It is apparent from figure 10.2.1 that none of the experimental treatments caused a statistically significant change in this attitude. The level of seriousness with which employees had originally viewed noise induced hearing loss was unchanged. Table 10.5 shows that the mean attitude score held by the population prior to treatment was 77.52 with all plants closely grouped around the mean. NIHL exhibited the highest mean score of the ten scales, which represented a point on the attitude continuum only slightly less positive than "Agree". It is possible that had the attitude level prior to commencing the treatment been closer to the "Neither Agree nor Disagree" value of 60 as would have been the case in a less well informed population, then the treatments could well have had an effect.

However, the results suggest that audiometry as it was conducted during the research programme, did not contain a sufficiently strong educational element to change a relatively positive attitude towards noise induced hearing loss as a disability into a very positive attitude that this was the case. It is not unreasonable to assume that the audiometry would have possessed a greatly increased power to achieve this attitude change had it been possible to show each individual his audiogram, and to counsel him upon the results. This could not be done because of Wilton site policy in force at the time, as explained in chapter 9.

It is probable that unless the employee population as a whole can see strong follow-up action being taken after an audiometric survey, the effect of the audiometry on this attitude dimension could even eventually become negative overall. Those employees whose hearing was subjectively normal could believe this to have been the case for the majority of employees tested, and would conclude that noise induced hearing loss was not a prevalent industrial disease. Those who suspected that they might have a noise induced hearing loss would feel that this could not have been the

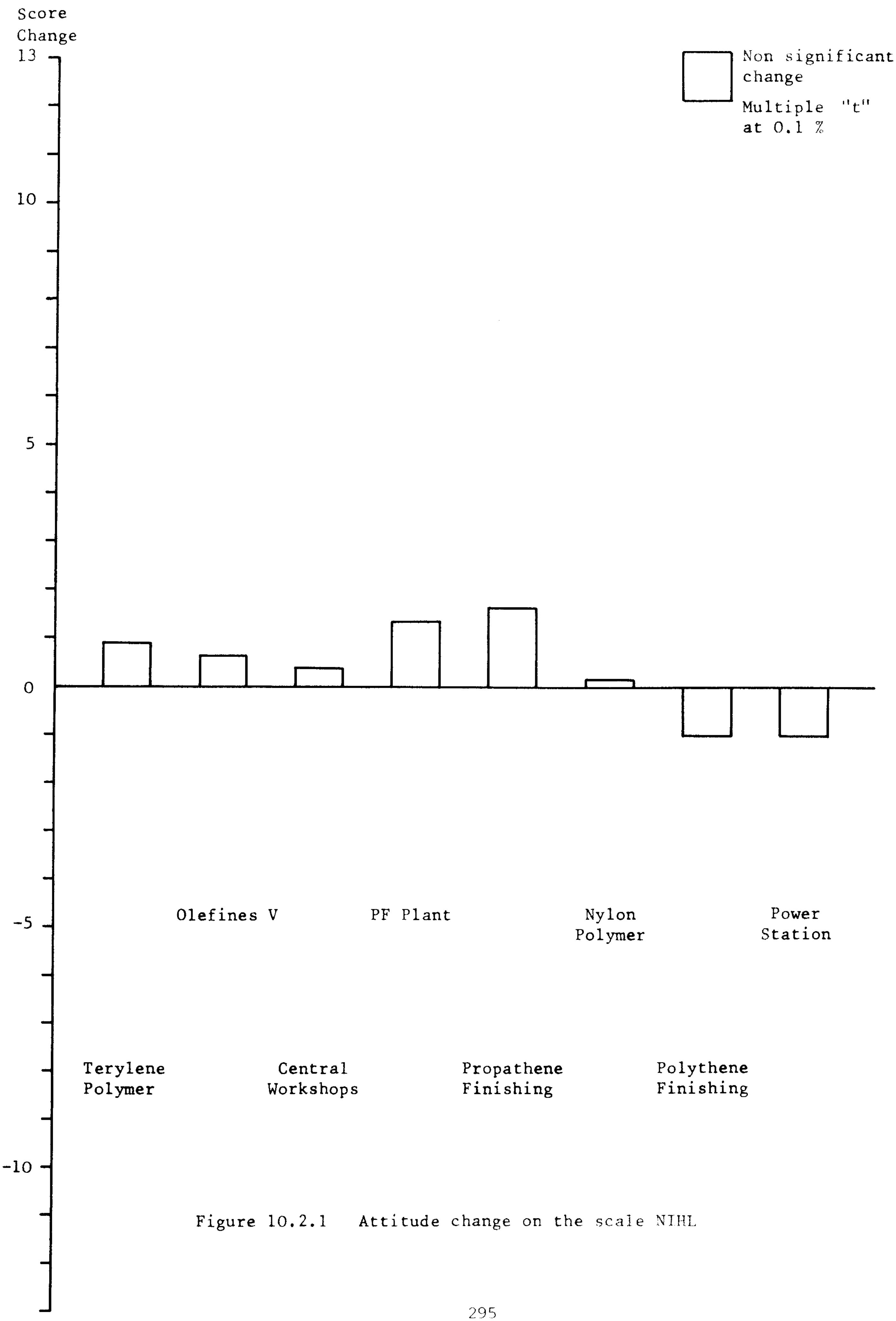


Figure 10.2.1 Attitude change on the scale NIHL

case, when the audiometric test was not followed by further diagnostic testing or a counselling session with the site doctor.

Similarly the programme of education undertaken as a treatment did not cause a long term change in attitude towards the recognition of noise induced hearing loss as a serious occupational disease. The film produced for the research programme was more factual in content than emotive, and to a certain extent the posters used were of a similar nature. It is possible that a more emotive film is needed to raise awareness along this attitude dimension, once the attitude towards noise induced hearing loss has reached the level noted during the pre-treatment attitude survey. The ideal sequence, therefore might be a factual film shown initially, followed some months later by one with a high emotive content.

The combination of audiometry and education was no more effective in changing the pre-existing attitude towards noise induced hearing loss than either of the two components used singly.

10.4.2.2 ENF Measuring the attitude towards the use of industrial discipline to enforce the usage of hearing protection

Substantial attitude change was recorded in all plants over the experimental period, as shown in figure 10.2.2. ENF was the only scale on which the attitudes held by the employees on the control plants altered in a statistically significant manner. Therefore it cannot be claimed that the experimental treatments were the cause of the attitude change noted in the remaining six plants.

It is of great interest to note that a significant negative attitude change was measured in each plant. All plants were less amenable at the end of the experimental period to the concept of management-enforced usage of hearing protection than they were at the beginning of the study. The three plants shown to be the least amenable at the pre-treatment stage, the Power Station, the Polythene Finishing Plant and the Central Workshops also showed the greatest negative change of attitude over the experimental period, and were shown by a Newman-Keuls test at the 1% level to form a distinct sub-set.

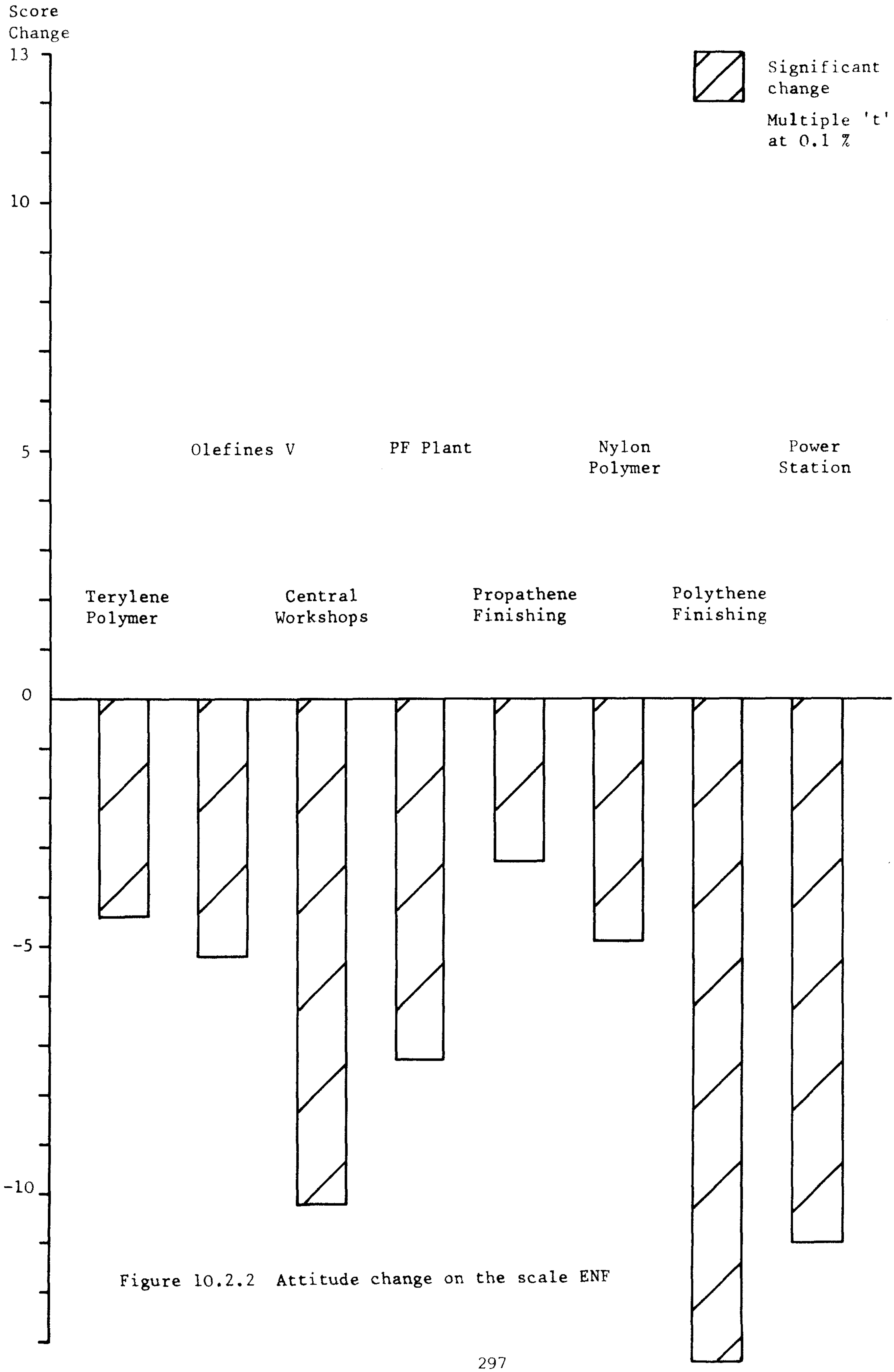


Figure 10.2.2 Attitude change on the scale ENF

That this should be so suggests either that the agency causing the negative attitude change in each of the plants was an extension of that which caused the above three plants to be the least amenable initially, or that a second agency caused the change with its action being most enhanced on those plants holding the most negative attitudes. If correct, this latter theory of attitude enhancement would be of value to the hearing conservationist, for it implies that the most successful educational efforts would be those which reinforce partly held ideas within the target population. Niehoff (1966) and Foster (1962) conducting social change studies form a similar conclusion, suggesting that it is better to supplement rather than supplant behaviour. This theory would also require a certain level of effectiveness in the stimulus to trigger an attitude change, in view of the previously described inability of the treatments to increase the attitude score on the scale NIHL, despite the fact that the population at the pre-treatment stage were already scoring well on that scale.

It is likely that the agency which caused all eight plants to drop back approximately 7 points on average, to a scale score which represented the "Neither Agree nor Disagree" region on the attitude continuum, was a growing feeling of resentment against any form of managerial discipline at that time. Heavy redundancies were occuring on the Wilton site at the time that the field work was being completed, and whole plants were closed during the research programme, with the associated industrial disquiet.

It is worthy of note that the plants showing the smallest negative change over the experimental period were those in which audiometry formed part of the treatment. However, it should also be pointed out that these plants were amongst the most amenable on the scale at the pre-treatment stage. They include Olefines V, in which it was suggested in chapter 8 that the non-response may have caused a slightly optimistic measurement of attitude.

10.4.2.3 NONUSE Measuring attitude towards the frequency of use of hearing protection

Consideration of the items contained within the scale NONUSE shows that the percentage of the time that the hearing protectors are used is related to whether or not employees simply forget to take the hearing protectors onto the job with them, and the fact that employees make their own decisions as to whether or not the noise is high enough to warrant the use of hearing protection. Both problems are amenable to solution by the hearing conservationist.

Differentials existed between plants in attitudes held at the pre-treatment stage on this scale, as discussed in section 10.3 and were correlated with the percentage hearing protector usage measured on the plants.

Figure 10.2.3 shows that over the experimental period no statistically significant change on this scale occurred on the control plants, and that statistically significant changes of attitude in the positive direction did occur on four other plants. Significantly these were those plants in which audiometry formed part or all of the treatment. Employees working on the two plants receiving education alone as a treatment showed no significant change in attitude over the experimental period.

A Newman-Keuls test performed at the 1% level shows that the Nylon Polymer, Propathane Finishing, Terylene Polymer and Olefines plants formed a subset of plants exhibiting similar results, whilst the remaining plants formed a second subset.

The greatest gains were observed on the Terylene Polymer and Olefines V plants which received audiometry alone as a treatment. The maximum gain was measured on the Olefines V plant which had exhibited the most positive pre-treatment attitude scale score, as shown in the previous chapter. Again this could be an example of the facilitation mechanism discussed in section 10.4.2.2. It may be easier for a given stimulus to create a greater change in attitude along that continuum if operating upon a population already well disposed towards the aims of the hearing conservation programme.

Plants receiving both education and audiometry as a treatment showed a statistically significant change of attitude which was not apparent in the two plants receiving education alone. As a statistically significant attitude change was also observed in those two plants receiving audiometry alone as a treatment, it is reasonable to assume that in those plants receiving both audiometry and education, it was the audiometric component

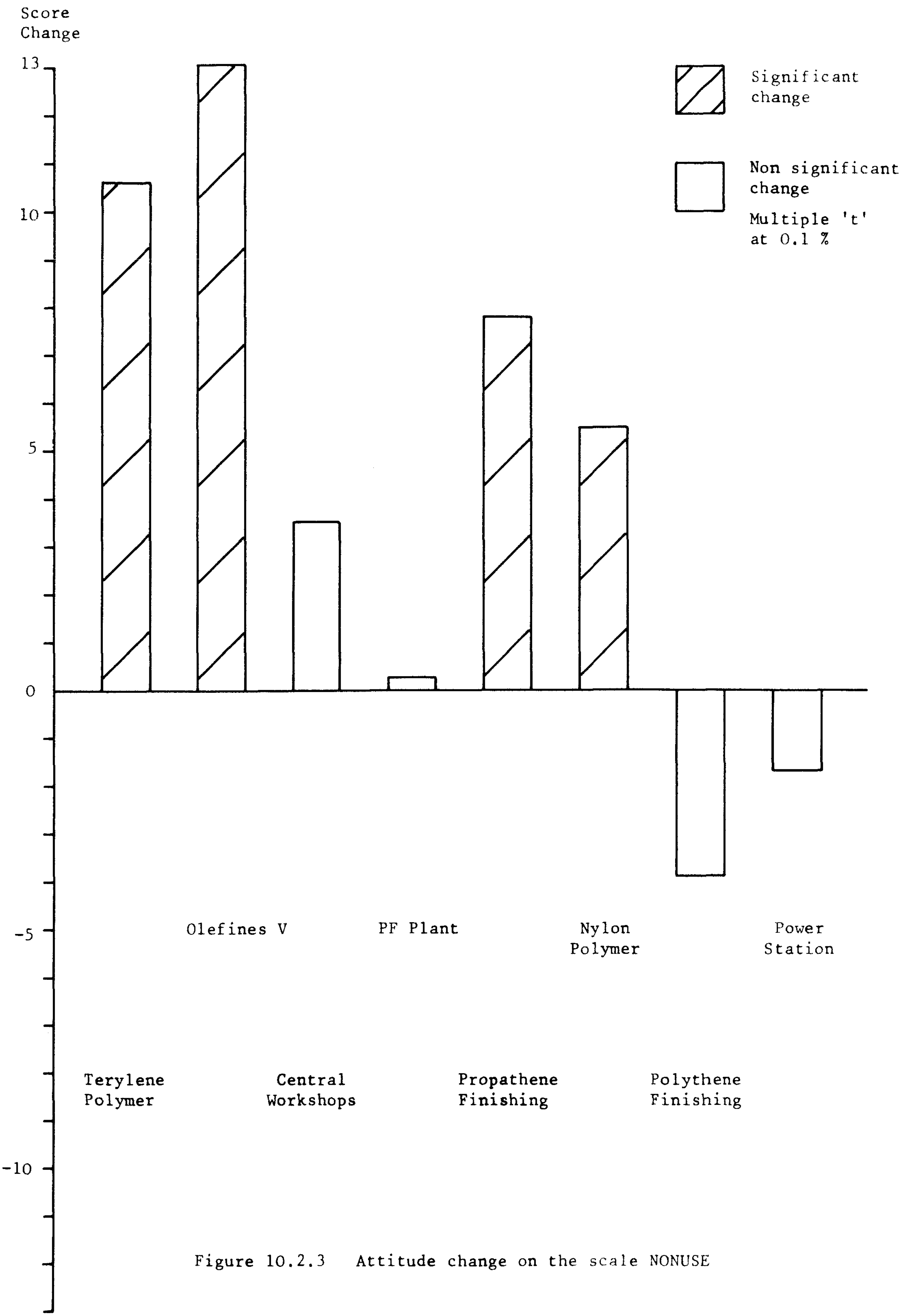


Figure 10.2.3 Attitude change on the scale NONUSE

which caused the attitude change. However, it is more difficult to explain why the combination of audiometry and education should be less effective in achieving a change of attitude than audiometry on its own.

One possibility is that the power of industrial audiometry as an educational tool used to change attitudes can be reduced along certain attitude continua if undertaken with other educational activities. It may be suggested that if audiometry is undertaken alone, the impression might be given that an industrial pollutant, noise, is being "released into the atmosphere", and that serious scientific tests were being undertaken to ascertain which individuals had been affected. However, if audiometry is undertaken simultaneously with other educational activities, it is possible that it might be relegated in the mind of an employee to the status of another, routine, facet of a health and safety programme. The average industrial employee is subjected to many of these programmes on various topics, and thus the overall impact of a combined audiometry and education programme could be less than that of the audiometry on its own.

A further possiblity is that due to the difficulty in ascribing metric dimensions to intervals between points on a Likert attitude scale as described in chapter 5, less weight should be placed upon the attitude change differential between those plants in which a statistically significant change occurred, and more weight should be placed upon the fact that an attitude change occurred at all.

As a means of increasing the confidence with which the results of the attitude survey were viewed, it was decided to test whether or not a positive correlation existed between the ranking of the plants by maximum change in hearing protector usage over the experimental period, and the plant ranking by change in attitude score on the present scale over the same period. It will be remembered that such a correlation was found in chapter 8 to exist between the ranking of the plants by initial hearing protector usage and the ranking by initial score on the scale NONUSE.

Accordingly the relevant data were drawn from table 10.10 and table 9.2. The Spearman Rank Correlation Coefficient equalled 148, indicating that a correlation existed at the $p < 0.04$ level. Thus, and importantly, it has been shown once again that scores on the scale NONUSE correlate with behavioural data. Change in attitude scale scores correlated with change in hearing protector usage rates.

This finding is encouraging, but not unexpected, as one of the three items comprising this scale tended to be factual in content, and relates to the percentage of time that employees claim to use their protectors. However, it does give an added measure of confidence to the results of the observational and attitude surveys.

The mean pre-treatment score of the four plants which showed a positive change of attitude was 71.35, approximately halfway between the "Neither Agree nor Disagree" and the "Agree" points on the scale. After the treatments had been completed this score had risen to 80.34, slightly above the "Agree" point on the scale.

10.4.2.4 ENVIR Measuring attitude towards the effect of the environment upon the usage of hearing protection

Figure 10.2.4 shows that no statistically significant change of attitude occurred in the eight plants. Both the mean pre and post-treatment attitude scale scores were approximately 74, between a score of 60 at the "Neither Agree nor Disagree" point and 80 at the "Agree" level. Consideration of the scale items shows that on analysis three similar questions clustered together, asking respectively whether it was too cold, too dirty, or too wet to use hearing protectors comfortably. Interestingly the logical fourth addition to this trio: "It is too hot where I work to use my hearing protection comfortably" clustered into the scale "ACCEPT" measuring the user-perceived comfort of hearing protection. Probably the question was interpreted by the employee as a request for an assessment of the heat generated under the earmuffs during use.

By way of contrast, the three similar items in the scale "ENVIR" concerning environmental dirt, wetness and cold were related by the employee to initial discomfort or difficulty caused by wearing the ear protector when it had been soaked by steam or rain prior to use, or the seals of earmuffs had become stiffened by the cold, which may also have caused a loss of the manual dexterity needed to insert earplugs. A dirty environment could cause a reluctance to insert soiled earplugs into the

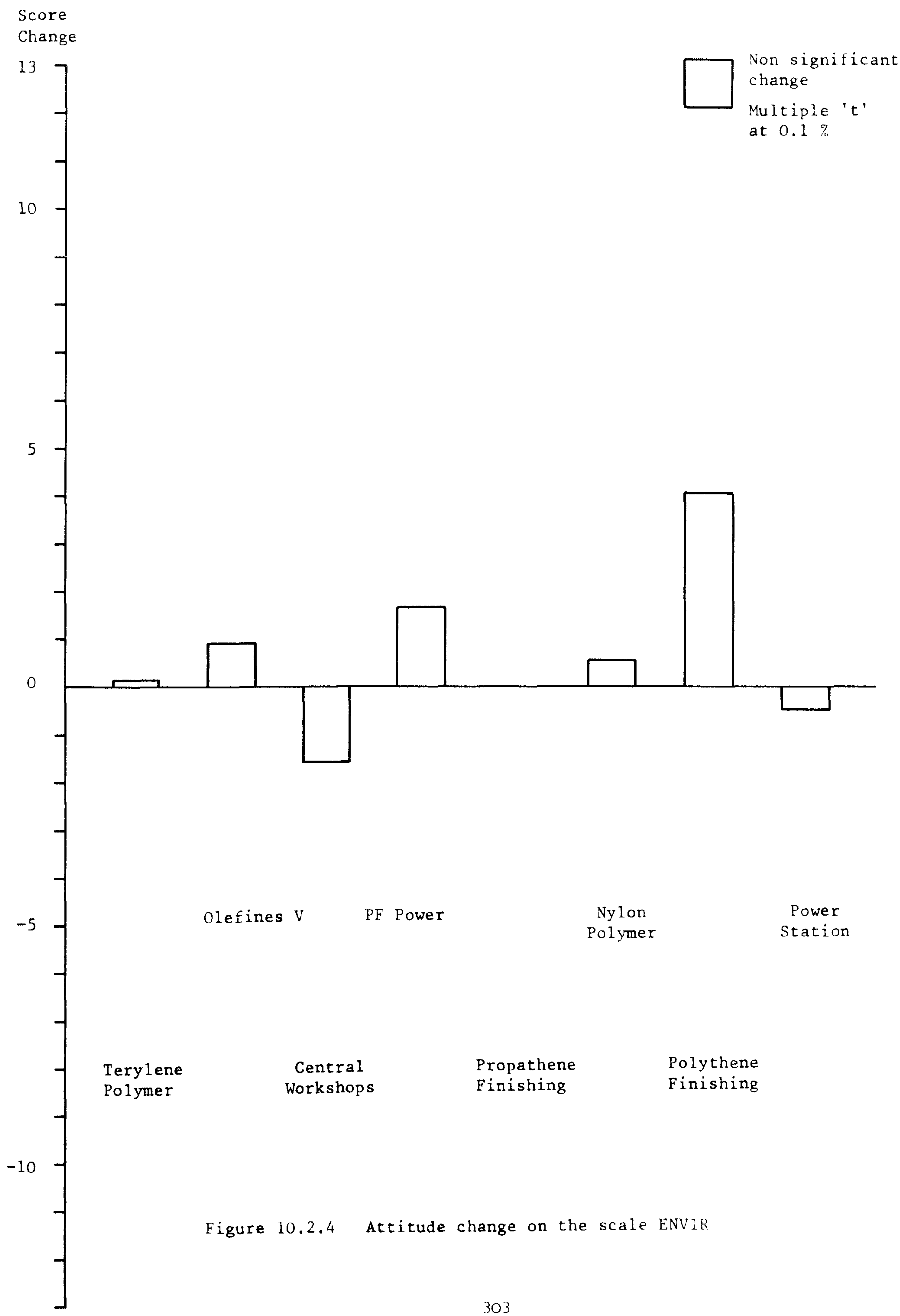


Figure 10.2.4 Attitude change on the scale ENVIR

ear, or place upon the head an earmuff with industrial pollutant on the seal or headband.

It was hoped that some component of the treatments would show itself to be efficacious in reducing the reluctance of employees to use ear protectors because of unavoidable industrial hygiene problems. However, this proved not to be the case, as was shown by the lack of attitude movement on this scale.

Future programmes of education might therefore benefit from sections describing the use, care and maintenance of hearing protection with special emphasis being placed upon methods of keeping the defenders clean and protected from deleterious environments. In this way attitudes may be changed.

With hindsight it is thought that the film used in the present study would have benefited from such a section, although this would have necessitated some other portion of the film being shortened, to keep the film of manageable length.

10.4.2.5 ACCEPT Measuring the attitude towards the comfort of hearing protection

The results of the pilot Hearing Conservation study described in chapter 3 have already emphasised the importance of protector comfort as a factor influencing the success of hearing conservation programmes in industry. It is accepted that many employees find hearing protectors uncomfortable to use, and this was demonstrated again by the pre-treatment data shown in table 10.5, when a mean score of 58.3 was measured over all plants, representing the negative side of the "Neither Agree nor Disagree" point.

It was intended that the plant treatments should be effective in increasing the awareness of the importance of using hearing protection to such a point that any small physical or psychological discomfort experienced whilst wearing hearing protection would be overcome by apprehension of the consequences of nonuse.

However, this attitude movement did not occur in any plant, as shown by figure 10.2.5 either because the hypothetical mechanism described above does not operate in that manner, or because the treatments were not strong enough to cause the required change.

The latter explanation is more likely to be correct. The point was made in chapter 4 that comfort, and thus to an extent acceptablity, can be defined in terms of the impact which the environment has upon the individual, modified by the individual's own view of the environment. In view of the results obtained on the attitude scale ACCEPT over the experimental period, it is evident that the education and the audiometry used in the present study were both insufficiently powerful. They did not cause employees to modify their views of their environment such that they were less inclined to rate the impact of their environment, in this case hearing protector usage, as being uncomfortable.

Methods for improving the effectiveness of monitoring audiometry in this respect have already been discussed, and will not be repeated here. Improvements in the educational material used in the study are also necessary in view of the results. In retrospect it is now felt that educational films or other aids should concentrate less upon the mechanisms causing the noise induced hearing loss, and similar topics, and more upon the debilitating effects of noise induced hearing loss. Films should be less restrained, and should contain an element of "propaganda". The hearing conservationist should not be adverse to using current advertising techniques, for the employee is only likely to increase his acceptance of the unavoidable problems experienced when using hearing protection if he is convinced that the consequences of non-acceptance are dire.

Martin (1984) points out that the perceived comfort of hearing protectors is likely to increase as employees become more accustomed to using them over a period of time. It is therefore important that the hearing conservationist should expose employees to educational material or processes which are strong enough to cause them to adopt the rigorous usage of hearing protection for a period long enough to become used to the different sensations experienced when using the protectors. Once beyond this barrier, which may take as longs as a few weeks, familiarity with the problems of usage may increase acceptance, even though the employee may

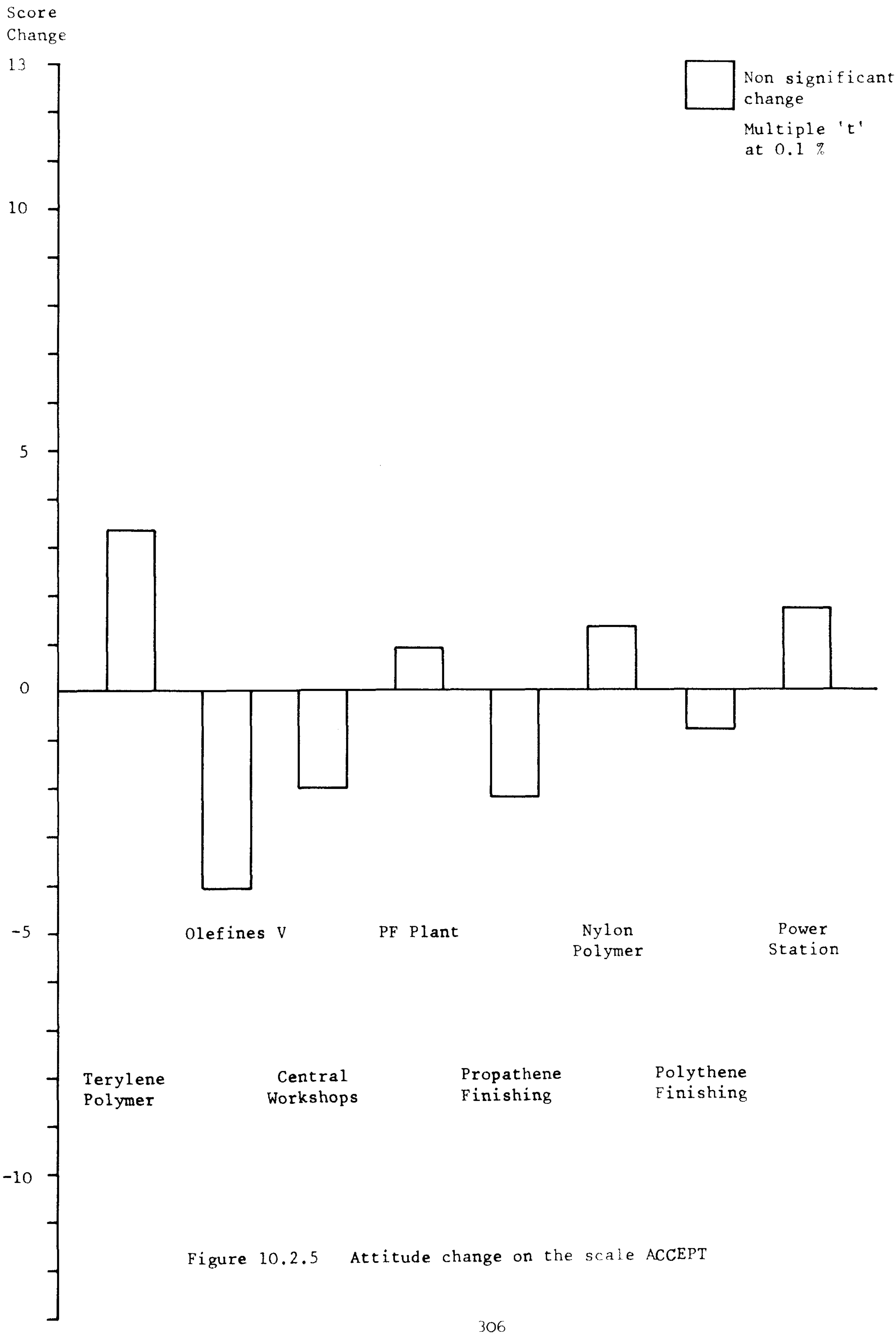


Figure 10.2.5 Attitude change on the scale ACCEPT

still perceive the discomfort or other usage difficulties.

10.4.2.6 CONTROL Measuring attitude towards the credibility of Southampton University as an independent and neutral research body

One of the objectives of the early ground work of the research project was to convince employees through their Trade Unions of the impartiality of the author as a representative of Southampton University. In this manner it was felt that the level of cooperation with the research work would be increased and the restraint with which employees supplied information would be lessened.

The scale CONTROL provided a useful indicator of the success of this exercise, and the extent of restraint still felt by employees. Additionally it gave some measure of the degree of collusion thought by employees to exist between the University and Management.

The mean attitude (n=954) held by the population at the pre-treatment stage reached 53.9, only slightly closer to the "Neither Agree nor Disagree" point than to the "Disagree" score. It is likely that employees, therefore, were still slightly wary of the objectives of the research work at the pre-treatment stage, and were not very convinced that the research was an activity independent of management.

Figure 10.2.6 shows that in seven of the eight plants including the control plants, this attitude did not change significantly during the treatment period. However, the Nylon Polymer plant showed a negative change of attitude which did reach statistical significance. Why this change should occur on one plant but not others is difficult to explain in terms of the consequences of the experimental treatments. It can only really be ascribed to local management who, in some manner, became more closely involved with the programme than was perceived to be the case in the remaining plants. Reference to this possible increased level of managerial input is made again in chapter 11, where it is noted that the level of attendance for a second audiometric test was excellent but atypical when compared to that in other plants in that the percentage attending for a second audiometric test rose when compared to that percentage attending for

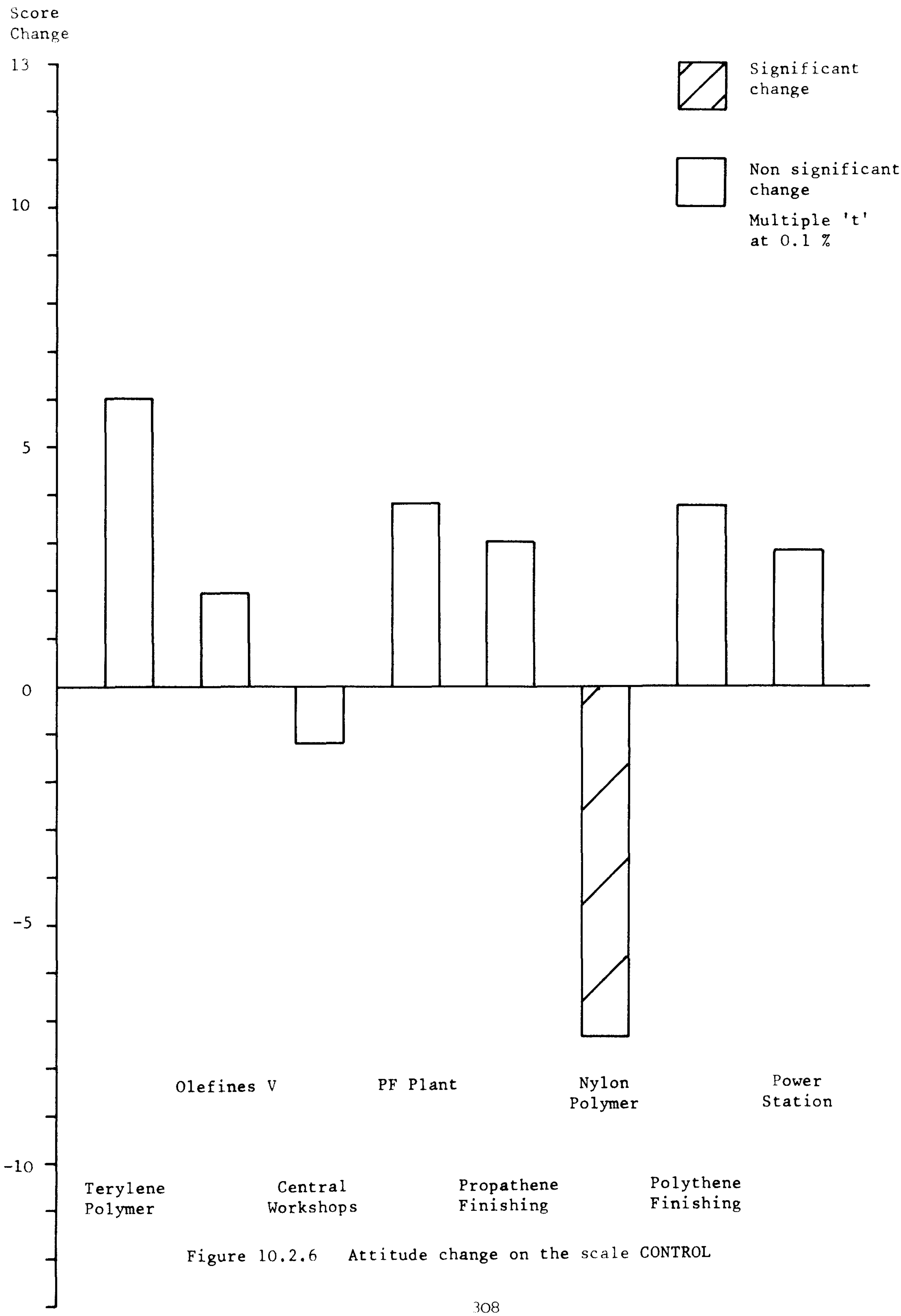


Figure 10.2.6 Attitude change on the scale CONTROL

an initial test.

In the case of the remaining plants it would appear that although in the opinion of employees the University was no more distanced from the ICI management structure at the end of the study than was the case at the beginning of the study, at least it was not perceptually closer, as was the case for Nylon Polymer. It does mean, however, that employees were not certain of the impartiality of the University throughout the study period. That this might be otherwise was probably a little optimistic, despite the work done to create this impression in committees by the author at the beginning of the study. As an example of the problems, the audiometry was conducted in the Wilton site medical centre, attendance being sanctioned by ICI management, which was also active in the administration of which sections of the workforce were to see the film, and at which times. Countermeasures were taken throughout the study by the author. For example, the educational film featured the University, University crests were used whenever contacting the workforce by internal post, and confidentiality of the data was stressed in these same communications.

It is felt likely that these statements concerning confidentiality should have reassured the workforce, even if the impartiality of the University was in doubt.

In all probability the only way to resolve these doubts concerning impartiality would have been for the University to remove from ICI hands every detail of the arrangements for the hearing conservation programmes on the eight plants and involving 1,716 men, clearly an impracticable proposition.

10.4.2.7 PROG Measuring attitude towards the adequacy of the hearing conservation programme

The mean attitude score over all plants on this scale prior to treatment was 60.94 (n=954) corresponding to the "Neither Agree nor Disagree" point on the scale. Excluding the control plants on which no treatments were undertaken, the mean score was 61.15 (n=734) which rose after completion of the treatments to 71.15. This score is half-way between the "Neither Agree nor Disagree" point and the "Agree" point on the scale.

Inspection of figure 10.2.7 indicates that all treated plants showed a statistically significant and positive change of attitude over the treatment period. It is interesting that of all the plants Nylon Polymer showed the greatest change of attitude. This was the plant in which it was suggested after consideration of the scale "CONTROL" in section 10.4.6 that management had become more involved in the research study than had been the case in other plants. This seemed to have had a beneficial effect, in that employees in the Nylon Polymer plant appeared from measurements on the scale PROG to be more satisfied with the content of the hearing conservation programme than the remaining 5 treated plants.

A Newman-Keuls test at the 1% level showed the plants to be divided into three subsets in terms of both attitude change, and the final absolute values of plant attitude score. The control plants comprised one group, the remaining plants with the exception of Nylon Polymer constituted the second group, whilst the third group consisted of Nylon Polymer alone.

The scale measured a positive change of attitude towards the hearing conservation programmes that were undertaken in each of the treated plants, irrespective of the content of those programmes. One explanation is that employees felt pleased that some action was being taken to preserve their wellbeing, irrespective of the type of action, an effect discussed fully in the final chapter of this thesis.

If employees feel that the hearing conservation programmes are being organised well, such an attitude should engender a spirit of co-operation with the aims of the programme, thus encouraging hearing protector usage. This spirit of co-operation may also extend into other safety programmes, thus giving an extra benefit to management of running a hearing conservation programme.

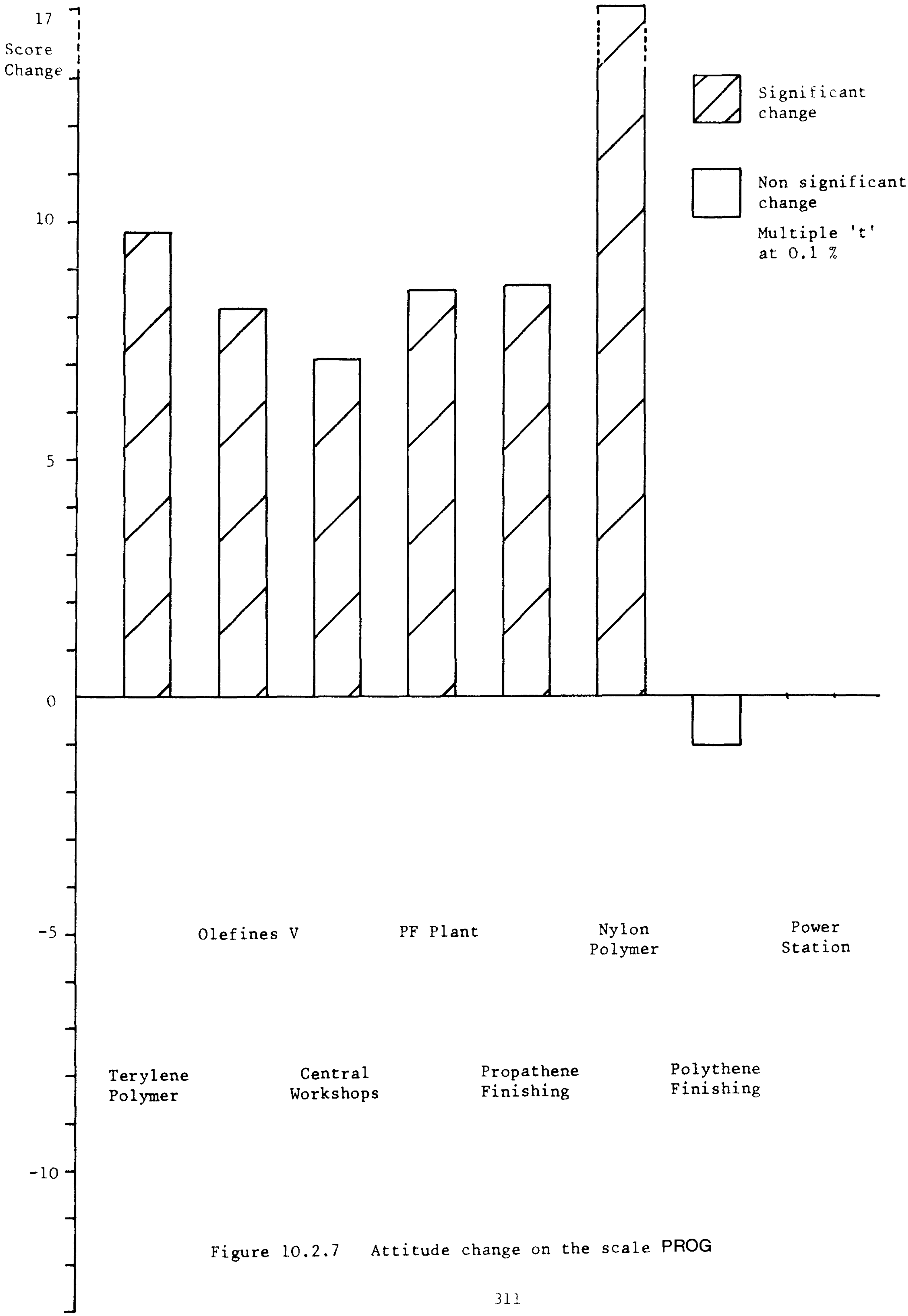


Figure 10.2.7 Attitude change on the scale PROG

10.4.2.8 ISO Measuring the attitude towards isolation caused by the use of hearing protectors

Figure 10.2.8 shows that employees on the control plants did not exhibit a statistically significant change of attitude on this scale over the experimental period. Therefore the statistically significant and positive change of attitude occurring on the Terylene Polymer and Olefines V plants can be ascribed to the effects of the audiometry which comprised the treatment on these plants.

The average attitude score on the Terylene Polymer and Olefines V plants was 60.94 (n=220) prior to treatment, close to the "Neither Agree nor Disagree" scale point. After treatment this scale score rose to 70.81, numerically half-way between the "Neither Agree nor Disagree" and "Agree" points. None of the remaining four plants showed a statistically significant change of attitude over the experimental period. Thus it can be reasonably concluded that the education alone was not capable of changing the attitudes of employees towards acoustic and psychological problems caused by the use of hearing protectors. However, it is more difficult to see why the addition of education to the audiometry should prevent the same positive attitude change as discussed above from occurring on the Propathene Finishing, and Nylon Polymer plants.

The reason for this could already have been indicated in section 10.4.2.3 when the scale "NONUSE" was discussed. It was suggested that the unique effect of industrial audiometry could be partially negated if seen to be undertaken in close conjunction with other educational activities. In this situation the industrial audiometry might not be given any more import than accorded to the posters or the film, which themselves were shown to be inadequate in changing attitudes on the PF plant and in the Central Workshops on this attitude scale.

This concept is further substantiated by data presented in chapter 11, section 11.5 where it is shown that the percentage attendance for a second audiometric test fell more severely on the Terylene Polymer plant than in other plants receiving audiometry as a treatment as a consequences, it was thought, of the much higher rate of employee tests per day on this plant compared to that on the others. This higher test rate gave the programme a

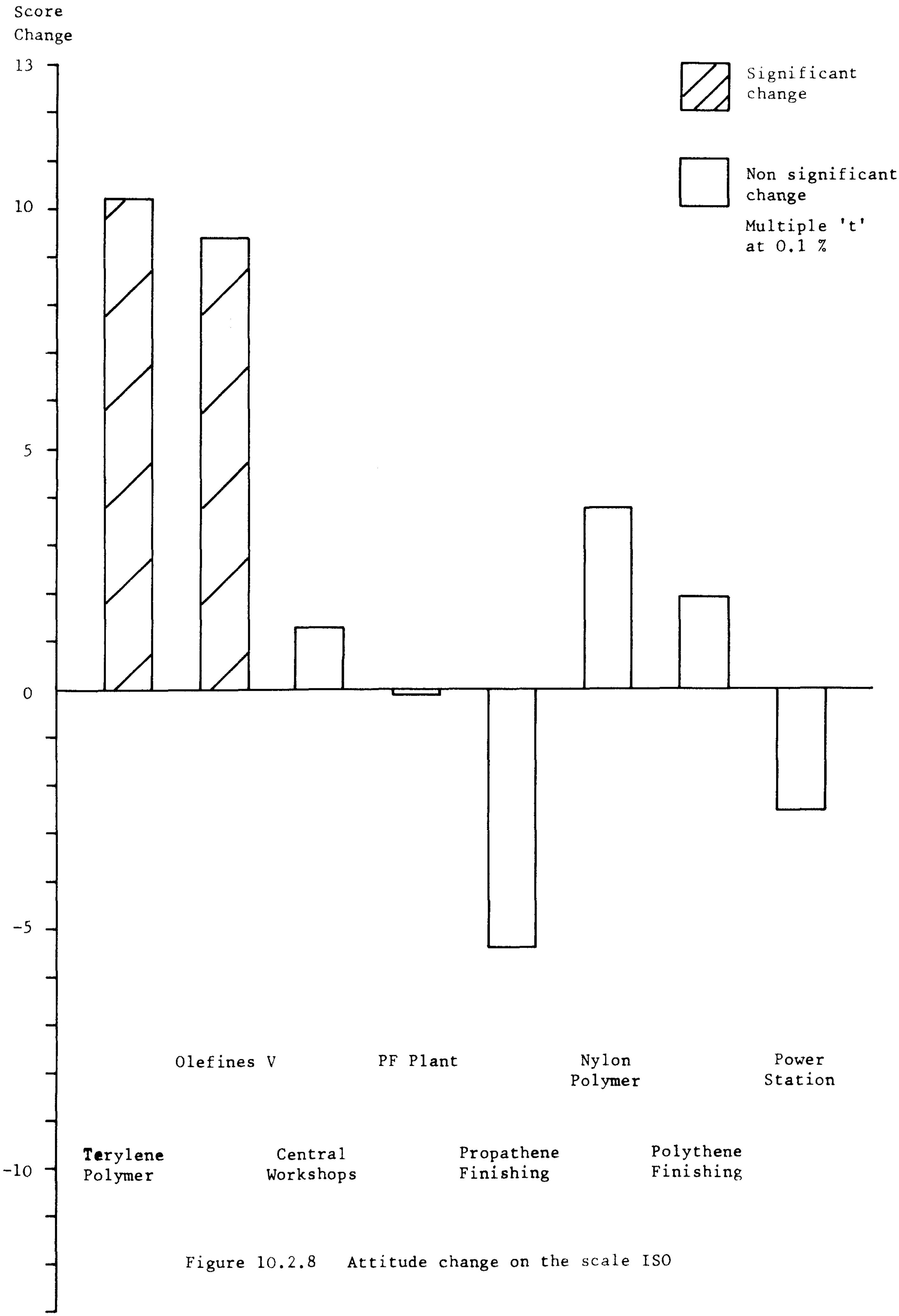


Figure 10.2.8 Attitude change on the scale ISO

more routine and less interesting profile in the minds of employees, reducing somewhat its effect.

It is apparent from figure 10.2.8 that audiometry alone was successful in changing the attitude of employees such that they were more willing at the end of the treatment period to accept the reported psychological difficulties and problems experienced with the perception of sounds when wearing hearing protection. It cannot be argued that employees on these two plants had simply become more accustomed to the effects of using hearing protectors as a consequence of the increased usage noted in chapter 9, for if this was the case an attitude change should also have occurred in those plants receiving education and audiometry as a treatment, which also benefited from increased usage.

10.4.2.9 COMPET Measuring attitude towards the handicap in a normal working life caused by hearing loss

Figure 10.2.9 shows that no statistically significant change of attitude was observed on this scale on the control plants. Therefore the statistically significant change which was measured in the PF plant can reasonably be ascribed to the effect of the programme of education.

The pre-treatment PF plant score on the scale COMPET was 69.82, approximately half-way between the "Neither Agree nor Disagree" and the "Agree" scores. After the treatment had been completed, this score had risen to 77.08, close to the "Agree" level.

The film shown emphasised the work and social disability experienced by individuals suffering from a noise induced hearing loss, and the change in attitude noted on the PF plant along this dimension could be ascribed to the influence of the film.

It is more difficult to explain why a positive reaction was obtained in the PF plant but not in the Central Workshops in which employees also saw the film as part of the programme of education, or similarly in the Nylon Polymer or Propathene Finishing plants. The probable reason is that the film was shown differently in the Central Workshops, Nylon Polymer and Propathene Finishing plants.

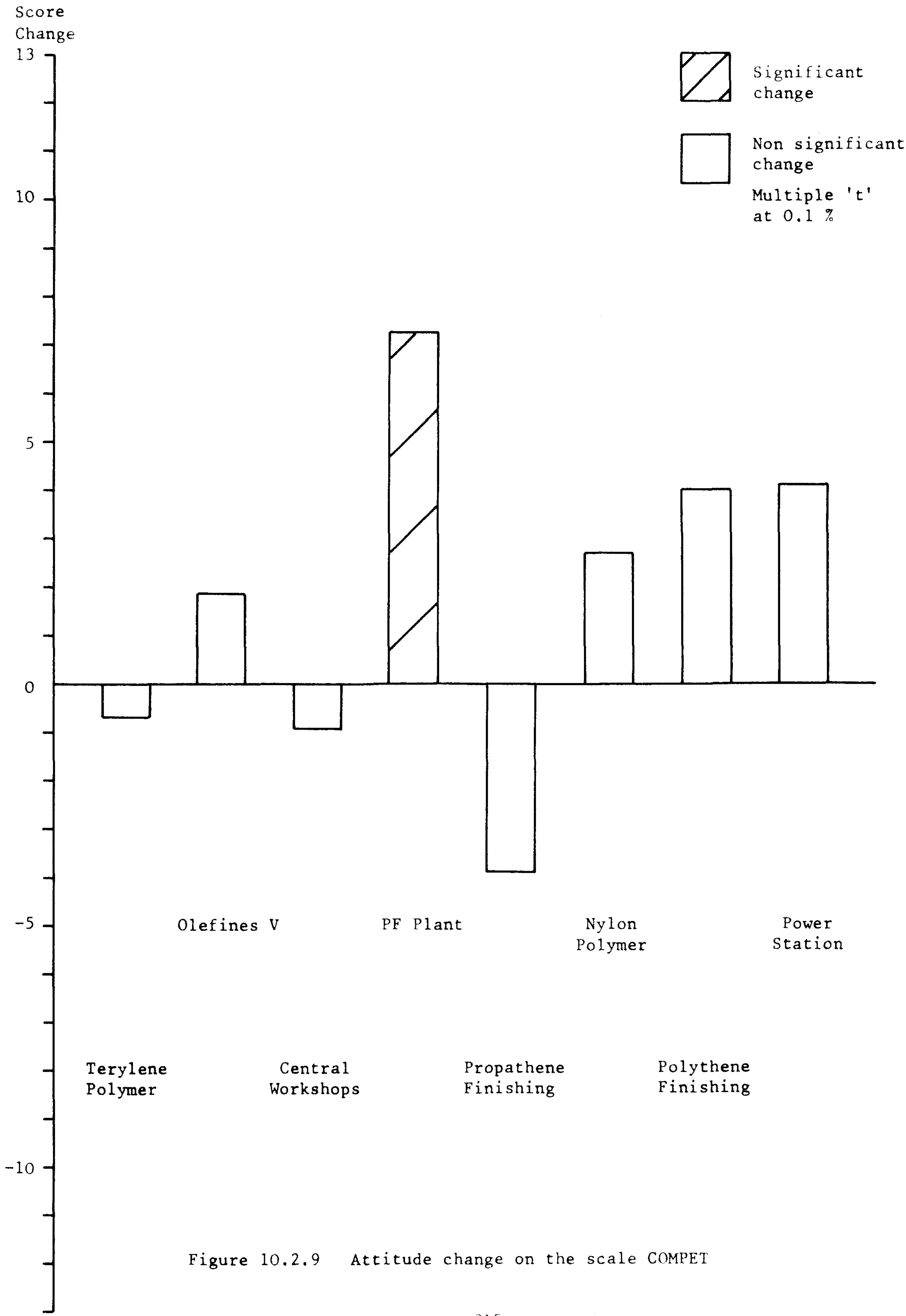


Figure 10.2.9 Attitude change on the scale COMPET

All employees in the Central Workshops saw the film over the same period of time, but shifts A and D of the PF plant watched the film approximately 17 weeks before their colleagues in shifts B and C. These latter shifts would have known that the film was being seen by groups of employees on the other two shifts from comments passed between employees at shift changeover time. This may have led to speculation as to why only half the plant had seen the film, renewed discussion, and added interest when shifts A and D were finally shown the film. Furthermore, the film was seen by shifts B and C much closer to the end of the treatment period and hence closer in time to the post-treatment attitude questionnaires than was the case in the Central Workshops. If attitudes follow the same cyclic pattern of growth and decay noted in the behavioural patterns of hearing protector usage, described in chapter 9, it can be assumed that opinion in shifts B and C would be more closely aligned towards the objectives of the film at the time that the post-treatment attitude questionnaires were completed than would be the case in shifts A and D. Hence, overall the PF plant could be expected to attain a higher post-treatment score on an attitude scale such as COMPET than achieved by other plants on which education had comprised the treatment.

The concept of attitude change decay described above is interesting, and the results and conclusions presented can be used to suggest that it occurs, but not to prove the case. However, whether this decay occurs or not, the changes measured by the post-treatment attitude questionnaires were either long term changes, or changes which were capable of decay but which did not do so because they were constantly "refreshed" by new stimuli arising from some aspect of the treatment.

Audiometry as undertaken in this study appears to be ineffective in the long term in causing individuals to change their attitudes towards accepting that noise induced hearing loss will cause both work and social disability. However, it should be remembered that it was not possible to tell the employees the results of the audiometric tests as a consequence of the agreement under which the research programme was commenced. Although an audiometric test could have caused the individual examined to consider afresh whether or not a hearing loss represented a social or work disability, lack of feedback of the audiometric results is likely to have resulted in the employee reverting to his original opinions fairly quickly along this particular dimension as for him there would have apparently been no change in his hearing acuity.

10.4.2.10 BEHAV Measuring the attitude towards the effect of noise on behaviour

Figure 10.2.10 shows that no statistically significant change of attitude occured in the control plants over the treatment period. Therefore the statistically significant changes noted in the Terylene Polymer and Olefines V plants and the Central Workshops can be ascribed to the effect of the treatments.

Both plants receiving audiometry alone as a treatment exhibited a positive change of attitude. The mean score rose from 70.05 (n=220) a point approximately half way between the "Neither Agree nor Disagree" and the "Agree" points on the scale, to 75.23, a level half as far again towards the "Agree" point on the scale, awarding the scale metric properties.

The industrial audiometry has once more caused a positive change in attitude towards the aims of the hearing conservation programme, and has apparently caused the employees to consider more deeply the debilitating effect of noise in the workplace. This effect does not appear to have occurred in those plants receiving both audiometry and education as a treatment. The same argument can be advanced as that presented during discussion in sections 10.4.2.3 and 10.4.2.8, where it was suggested that the addition of education to a programme of audiometry partially negates the attitude changing potential exhibited by industrial audiometry alone. Along this scale the attitude changing property of audiometry undertaken on its own probably results from the ability to cause employees to consider afresh noise as a pollutant in their working environment, and the stresses which it causes on them. The implication of conducting audiometry on its own is that the effects of noise on man are serious and that certain employees may already be exhibiting a disability. However, when undertaken in conjunction with various other educational exercises, the ambience surrounding the audiometry is downgraded to that of another routine, and probably unimportant, component of a large safety programme.

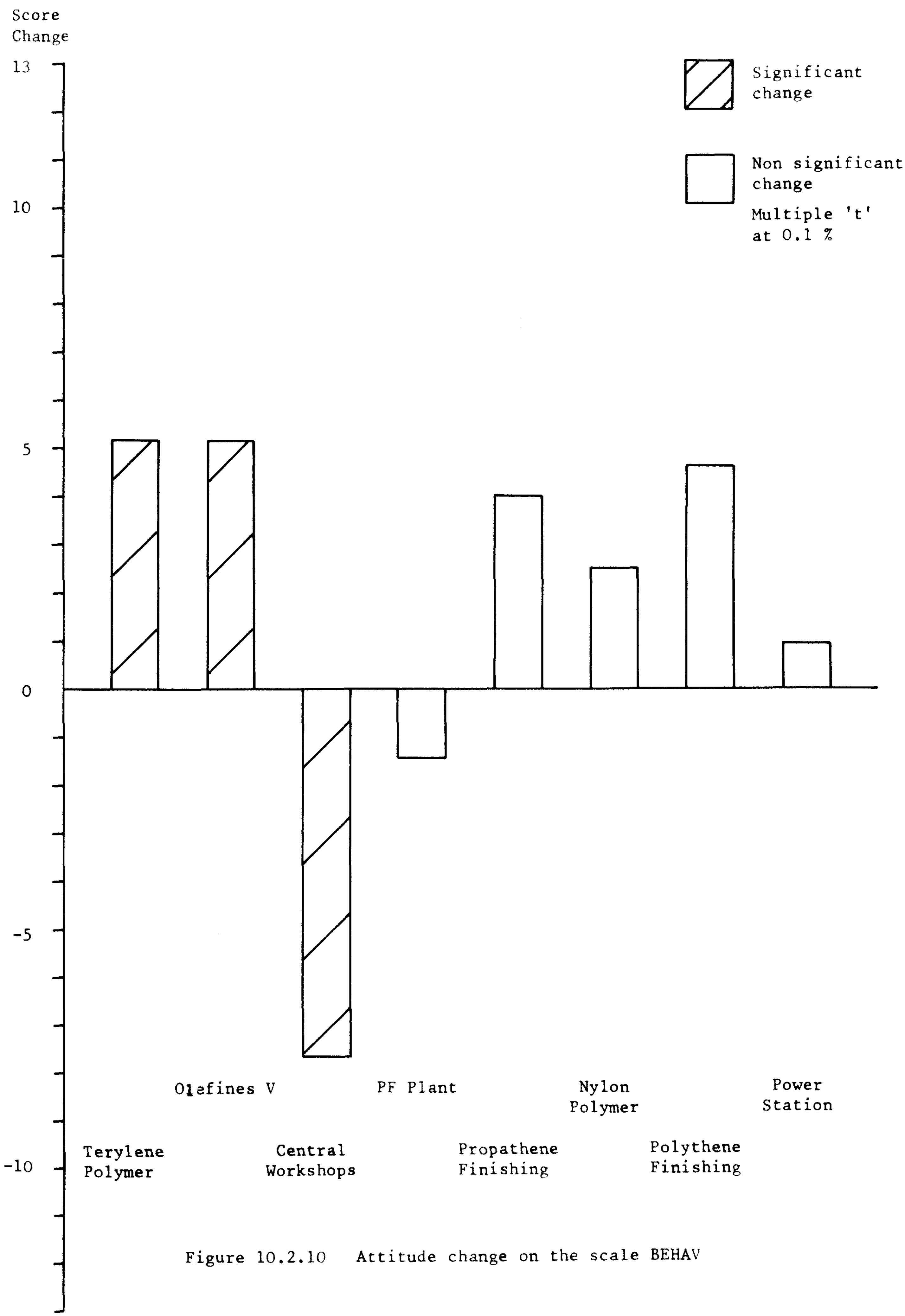


Figure 10.2.10 Attitude change on the scale BEHAV

Figure 10.2.10 also shows that the Central Workshops, which received education alone as a treatment, experienced a statistically significant but negative, change of attitude over the experimental period. This trend was not replicated in the PF plant which was the second plant in this group. It appears that the programme of education convinced employees within the Central Workshops that the problems of working in industrial noise were less difficult to overcome than they had first assumed.

A possible explanation is that the film was shown late in the treatment period in the Central Workshops and caused a sharp and significant rise in the number of individuals using hearing protection, which immediately prior to the showing of the film had fallen back to the very low pre-treatment level of usage. Thus a major rise in usage occurred only a relatively short time before the post-treatment attitude questionnaires were despatched, a situation which did not pertain on the other plants. Hence when the post-treatment questionnaires were being completed a large number of PF plant employees were experiencing for the first time, or re-experiencing, the benefits of using hearing protection. It is possible that a high proportion of these employees were feeling at that time a general decrease in the level of irritation caused by having to work in noisy surroundings, due to the effectiveness of the hearing protectors. This would cause the attitude change shown in figure 10.2.10.

Acceptance of the existance of the mechanism described above does raise once again the concept of attitude decay, discussed briefly in the previous section. In the situation described in the present section such decay would occur as employees continuing to use hearing protection lost their initial enthusiasm for the benefits, and realised that industrial noise still provided a difficult environment in which to work.

10.5 Conclusions

The attitude scales specially developed for use in this study showed differential changes in attitude to have occurred in the plants in response to the treatments.

No attitude movement was detected in the control plants in nine of the ten scales, indicating that in the case of these nine scales at least, the treatments had been responsible for any attitude changes measured in the other plants. The tenth scale was ENF, and all eight plants included in the main study showed a negative change of attitude along this dimension.This change was ascribed to influences external to the study and probably related to the effect of a site policy enforcing major redundancies at that time.

More positive long term changes in attitude were recorded on plants in which audiometry was the experimental treatment than in plants receiving either education or a mix of education and audiometry as a treatment.

A more minor conclusion drawn from this major observation is that attitudes towards hearing conservation matters appeared to change in response to the content of the stimuli, and not simply in response to the occurrence of the stimuli, a point which is pursued later in this section.

In a high proportion of the attitude dimensions along which the audiometric treatment caused a positive attitude change, the same positive change of attitude was not seen when education was added to form the audiometry plus education treatment. As a corollary, very little positive attitude change was seen in response to the audiometry plus education treatment.

An explanation for this phenomenon has already been given within the body of the results but the finding deserves immediate comparison with that described in chapter 9, where it was shown that positive behavioural change, or increase in hearing protector usage, occurred the most smoothly in those plants receiving both audiometry and education as a treatment.

A conclusion which can be drawn from the above observations is that attitude change is not automatically followed by long term behavioural change.

This problem is taken up again in section 12.2, where a solution is developed, and suggestions are made which should improve the efficiency of industrial audiometry to cause behavioural change through long term changes in attitude. It is reasonable to project that long term behavioural change can only occur through attitude change. If significant attitude change is not achieved, as was the case in those plants receiving both audiometry and education as a treatment, then the positive behavioural change noted to occur can only cease when the mechanisms causing the behavioural change cease.

It is likely that the main mechanism causing the behavioural change was a derivative of the Hawthorne effect noted in the classical experiments in the Hawthorne Works of the Western Electric Company between 1924 and 1927 (Ghiselli 1948). Changes were introduced into the work pattern of employees within the Company, and output increased after almost every change, even those which logically would have been expected, a priori, to reduce output.

The conclusion was drawn that production had increased because the attitude of employee's towards their role in the company had changed. By involving employees in the problem of increasing low production volume, the research workers had stopped employees from feeling that they were minor components in a very large industrial machine. A change in the general attitude held by employees towards their status within the company had led to a behavioural change in terms of the number of electrical components produced. Possibly this attitude dimension could be labelled "self-esteem" which, being of a general nature, was not the type of attitude measured during the present study as this was directed at developing scales to measure dimensions of attitude towards hearing conservation.

It is therefore possible that the employees receiving audiometry and education as a treatment experienced a general atttitude change along the "self-esteem" dimension, as they were exposed to more frequent and varied stimuli than those employees in plants receiving either audiometry or education as a treatment.

The various stimuli would each generate the peaked type of response seen in the behavioural pattern resulting from exposure to industrial audiometry and the shorter term changes caused by education, but the summation of these successive peaks would be a smoother growth of protector usage. However, as little significant attitude change along hearing conservation dimensions was achieved by exposure to the audiometry plus education treatment the increase in hearing protector usage can only be expected to decline when the events in the programme became sufficiently common to lose their status as stimuli.

Although frequent stimuli appear to cause behavioural change whilst they retain their novelty value, the same cannot be claimed for the formation of attitudes. Data presented in this chapter suggest that the more frequent the programme stimuli, the less effective the programme becomes in producing long term attitude change. As has been noted earlier, employees on those plants exposed to audiometry and education as a treatment were less likely to show a positive change of attitude than their colleagues in plants receiving only audiometry as a treatment. The positive change of attitude engendered in employees on the scale ISO by the industrial audiometry but not the audiometry plus education, or the education alone is an example of this effect.

The explanation for this could be similar to that already applied in chapter 9, where it was concluded that performing audiometry in a routine manner caused it to lose its effectivenss in increaseing hearing protector usage. It was suggested that the increase of hearing protector usage on the Terylene Polymer plant had not reached its expected high level because the various phases in the testing programme had been compressed in time, without any feedback of the results, when compared to the audiometric programme run on other plants in the study. Both factors had contributed towards the audiometry losing its effectiveness in terms of increasing protector usage by making audiometry seem to be a routine safety exercise.

There is, however, a secondary explanation of why audiometry plus education as a treatment is demonstrably inferior to audiometry alone as a treatment by which to change attitudes, and yet is still capable of causing approximately equivalent behavioural changes in terms of increased hearing protector usage. The reason may be that it is only necessary to alter one key attitude to cause a behavioural change.

The "key" attitude in question would have to be that measured by the scale NONUSE, as it was only on this scale that a positive change of attitude was observed on both those plants receiving audiometry as a treatment, and those receiving audiometry plus education as a treatment, but not on the plants receiving education as a treatment. Examination of the items comprising the scale NONUSE shows one to have been an assessment of the percentage time that hearing protectors were worn. The remaining two related to the ease with which an employee tended to forget to take hearing protectors on the job with him, and the judgement which he made of the noise level before deciding whether to use his hearing protection.

It is possible that these latter two points form key elements in the amount of hearing protection used on a plant.

Furthermore, it has already been noted that a positive attitude change was induced on the scale NONUSE in all those plants in which audiometry formed either all or part of the treatment, whereas a similar statement is not true for education as a treatment or part treatment. As the magnitude of the positive attitude changes described earlier in this paragraph were shown to correlate with the magnitude of the changes observed in protector usage in section 10.4.2.3, it would appear once more that the audiometric component of the treatments was that most responsible for raising the level of hearing protector usage.

Education was the least successful of all the treatments in causing long term changes in attitude, although it is possible that the education programme did cause short term changes in attitude which decayed before the post-treatment attitude questionnaires were completed. The evidence that this might have occurred is shown by a change of attitude detected in employees of the Central Workshops who all saw the film closer in time to the completion of the post-treatment questionnaires than was the case for any other plant. This particular change of attitude could not be detected in employees from other plants who had seen the film earlier in the programme. Leventhall (1965(a)) discussed similar decay in attitude occurring after a fear-inducing stimulus had ceased, in a study investigating the persistance of the influence of threat stimuli.

This suggestion of attitude decay has its counterpart in the behavioural decay discussed in chapter 9. It was noted in the Central Workshops and PF plant that the increase in hearing protector usage caused by components of the education programme decayed back towards pre-stimulus levels after 2-3 months.

The same type of behavioural decay, although at a much slower rate, was observed to a lesser extent in those plants in which audiometry alone was the treatment. Gains in protector usage reduced slowly after the initial increase for reasons which will be fully discussed in section 12.2.

However, audiometry was unique amongst the treatments in that it caused both behavioural change in hearing protector usage, and was responsible for the most frequent positive long term changes in attitude. The ability of industrial audiometry to engender long term attitude changes cannot be underestimated, as these changes must occur if long term behavioural changes are to be voluntarily sustained.

All treatments proved ineffective in causing employees to change their attitudes in a positive manner towards the seriousness of industrial deafness as an occupational disease, or to be less discouraged by comfort problems or environmental difficulties experienced whilst using hearing protection.

Increasing the fear-inducing potential of industrial audiometry by informing employees in more detail about their results could solve this problem, as might increasing the fear inducing content of any programme of education.

All treated plants showed a strongly negative change of attitude towards the concept that hearing protector usage should be enforced. As a similar attitude change was measured in the control plants it was concluded that the cause of this change was external to the study, and probably a consequence of the unrest felt at that time by employees as a consequence of large scale redundancies occuring on the site.

Even at the end of the study, after all treatments had been completed, employees on each plant still felt that the research study was a management activity. The attitude scale scores, however, did indicate that all plants were satisfied with the treatments which they had received.

Audiometry used on its own appeared to be an excellent tool for lowering the resistance offered by employees to the use of hearing protectors on the grounds of unacceptable psychological isolation. Additionally audiometry also caused employees to reassess in a manner beneficial to the hearing conservationist their attitudes towards their noisy working environment.

However, audiometry would not appear to be a good tool for convincing employees that their competence at work will reduce if they sustain a noise induced hearing loss. Short term gains can be made in this respect by a suitable programme of education although the experimental results suggest that this programme would require regular repetition if any lasting attitude change is to be achieved.

CHAPTER 11

AUDIOMETRIC MEASUREMENTS

11.1 Introduction

Chapters 9 and 10 showed that industrial audiometry offers a valuable method of changing attitudes and increasing hearing protector usage. It should therefore occupy an important position within a hearing conservation programme. If used in such a programme, however, several decisions must be taken as to how the audiometry is to be conducted if it is to be successful. This chapter addresses the more important of these questions which are shown below.

1. Should the attendance for the audiometric tests be mandatory or voluntary?

2. If the attendance is voluntary, will employees who fear that they have a hearing loss not attend, and thereby reduce the value of the industrial audiometry? These fears could arise either from concern related to job security or a reluctance to face the truth.

3. Logistic reasons normally dictate that much audiometric testing must be conducted during a shift, after the employee has been working in his normal environment, in contrast to testing prior to noise exposure at the beginning of a shift. Can within shift testing be organised so as to ensure accurate measurements?

4. What sort of analysis procedure should be used on the audiometric results, and what criteria should be set for initiating action after an audiometric test?

Furthermore, it was felt important to check on the incidence of noise induced hearing loss in the Wilton population, because if this was not prevalent within the workforce due to insufficient noise exposure, account would have to be taken of this fact when interpreting the results of the attitude questionnaire and the behavioural measurements.

Finally the audiometric data obtained during the study were used to investigate a growing theme in the literature that susceptibility to noise induced hearing loss is related to eye colour. The literature is discussed in section 11.9.2.

11.2 The Audiometric Measurement Method

Section 2.2.1 described the audiometric facilities on the site, and section 2.2.2 detailed the project group set up to conduct the audiometric testing. Section 9.1.2 described the rate at which the audiometric testing was undertaken throughout the study, and sections 9.2.4 and 9.2.5 described the timing of the first and second audiometric tests completed on employees. Appendix 11.1 describes the audiometric chamber, and gives the results of measurements made to ensure that the ambient noise levels were within the Health and Safety Executive prescribed limits (Health and Safety Executive 1978). Also contained within Appendix 11.1 are the details of the regular calibration of the clinical audiometer used (Peters, type AP6) and the spare audiometer (Amplivox 82).

Appendix 11.2 describes the wax removal procedure, daily calibration, patient instructions and technique of manual audiometry used in the survey. Utilised at the Institute of Sound and Vibration Research and recommended by the British Society of Audiology (BSA 1981) the technique is an adaptation of the Hughson and Westlake (1944) method and has been shown by Bassom (1975) to yield acceptable results. Appendix 11.3 shows the medical questionnaire used, and the audiogram chart which was designed to simplify computerisation of the results.

11.3 The Population Tested

Each process operator, or fitter, on the plants scheduled for audiometry received an appointment for a hearing test at the Medical Centre (Audiometric phase 1.1). If he did not keep this appointment, a second appointment time was arranged (Audiometric phase 1.2). Under this scheme, 563 employees were tested, and constituted population 'F'. Between 9 months and 18 months after the first audiometric test, an employee in population 'F' was sent an appointment for a second hearing test

(Audiometric phase 2.1). An employee who did not keep this appointment was sent a second appointment time (Audiometric phase 2.2). In this manner 263 employees were tested for the second time, and comprised audiometric population 'S'. After this population had been tested, a new appointment was sent to those employees who had refused to attend either audiometric phases 1.1 or 1.2. This third request for attendance was designated phase 3, and attracted 46 employees who formed population 'R'.

Audiometric population 'P' consisted of 79 employees tested during the Pilot Hearing Conservation study described in chapter 3. In total, therefore, 951 audiometric tests were performed during the research programme. In accordance with Company policy, attendance for a test was voluntary. Finally, as audiograms from 'S' are also represented in (P+F+R) only the latter are used in the analyses.

11.4 A Study of the Hearing Loss Attributable to the Effects of Noise in the Audiometric Population

11.4.1 The objective of the study

The attitudinal studies described in chapters 8 and 10 and the conclusions drawn from them, assume that the exposure to the noise levels recorded in chapter 2, either in ICI or a previous place of employment had given rise to noise induced hearing loss in the employee population, and that the population was familiar with the effect of deafness caused by noise at work.

The purpose of the study described within this section is to evaluate the justification for this assumption.

11.4.2 Method

The available manpower in the Medical Centre, the logistics of the exercise, and the alteration it would have caused to the experimental plan prohibited the further extensive diagnostic investigation necessary to conclusively define the etiology of the hearing loss of a particular individual in the study.

An as alternative it was decided to study the hearing loss of the employee population as a whole, as a method of detecting the known characteristics of noise induced hearing loss. This approach had two further advantages when compared to the method of individual diagnosis. Firstly the corrections for the effect of presbyacusis used later in this section are designed to be applied to populations rather than individuals, as individual variation in susceptibility to presbyacusis is high. (Hinchcliffe (1958, 1959, 1958), Schuknekht (1964), Rosen (1962), Sataloff (1957), Robinson (1979)) Secondly, individual variability in susceptibility to noise induced hearing loss is also high (Burns (1970(a)), Kell (1975), Chung (1982)) and therefore developing characteristics of noise induced hearing loss can best be examined by considering population losses. The technique also serves to average out disturbances in the data caused by the recognised inaccuracies in audiometric measurements, discussed in section 1.2.4.1, and thus facilitates the elucidation of developing hearing loss trends within the population.

The characteristics of a developing noise-induced hearing loss are described by Burns (1973), (1970), who together with his co-workers, undertook a large study of industrial hearing loss in the UK. Burns gives the following description of the hearing loss process. "The almost invariable first sign in the average industrial situation is a deterioration of hearing in the higher frequency range, probably maximal at the 4000 Hz audiometric frequency, but also affecting 3000 Hz and 6000 Hz."

Classically, as discussed above, the site of maximum hearing loss is considered to be 4000 Hz, but the possibility of the "dip" in the audiogram occurring at 3 to 6 kHz is not discounted. Indeed, data presented by Kenney (1975) and Sataloff (1969) clearly show population noise-induced hearing losses reaching a maximum value at 6 kHz. Robinson (1984), reanalysing a subsection of the Burns (1970) data shows that in a sample of 63 subjects with presumed occupational hearing loss, the dip occurred between 2.5 kHz and 3.49 kHz in 22% of the cases, between 3.5 kHz and 4.99 kHz in 62% of the cases, and above 5 kHz in 14% of the cases. The remaining 2% of the cases had dips of no assignable value. Data presented by Taylor (1975) would indicate that the overall frequency range in which hearing acuity is damaged by noise extends upwards from 2kHz.

Burns (1973) states that the deterioration of hearing "proceeds most rapidly at first, and then later, after perhaps ten years or so, settles down to a low rate". Dieroff (1975) also agrees that the course of impairment slows down in the long term, but suggests that 15 years is the breakpoint. However, data presented in Burns (1970(a)) indicates that this initial, rapid, rate of damage to the hearing acuity is itself variable, being a function of the level of noise causing the loss. Exposure levels of 85 dB(A) L_{Aeq} do not produce a hearing loss exhibiting the rapid deterioration characteristics described earlier but rather a linear steady decrease of hearing ability increasing with exposure time. This trend applies up to noise exposure levels of 95-100 dB(A). At higher levels the characteristic of rapid deterioration becomes pronounced. Exposure to L_{Aeq} levels of 115 dB(A) would produce a rapid onset of noise induced hearing loss increasing over approximately the first decade. This would then be followed by a period of relatively slow deterioration of auditory ability.

The dosemeter measurements made on the site were presented in chapter 2 and indicate that the majority of employees participating in the research study would be exposed to equivalent continuous noise levels of 96dB(A) and below. This figure represents the 75^{th} centile of the L_{Aeq} measurements obtained. As a consequence of the relatively low exposure levels experienced by individuals within the study, and the fact that consideration of the questionnaires completed at the time of the audiometric tests indicates that in general employees had held similar jobs in other industries prior to employement by ICI, it is reasonable to expect that the correlation of population hearing loss with time of exposure to noise would follow a linear trend, rather than one better described by a polynomial expression. It is not unreasonable to take age as an index of the length of time for which the population has been exposed to noise, as it is apparent from the questionnaires that in general employees had been exposed to hazardous levels of industrial noise throughout a substantial proportion of their working lives.

Using the definition given earlier of the important characteristics of a noise-induced hearing loss, and the description of the noise exposure of the Wilton employees, a list of criteria have been produced below, which if satisfied by the Wilton population, would indicate the presence of a sizable component of noise induced hearing loss within the population.

(1) Individuals within the population should possess a history of noise exposure such that this exposure could have resulted in damage to the hearing.

(2) Hearing loss resulting from agencies other than noise should have been excluded.

(3) The mean measured population hearing losses should exhibit a characteristic "notch" or depression in the 3-6 kHz frequency region, with some evidence of damage starting to become apparent at 1 or 2 kHz.

(4) The component of the hearing loss of the population which is not ascribable to age, should increase with age at those frequencies at which the human ear is most susceptible to noise induced hearing damage.

(5) A strong linear component should exist in the relationship between the duration of noise exposure, represented in this case by age, and measured hearing loss at frequencies susceptible to noise damage, if the population has been exposed to working lifetime L_{Aeq} of 96dB(A) or below. If the noise exposure levels exceeded the 96dB(A) L_{Aeq} over the working lifetime, the relationship between loss of hearing acuity and exposure time should follow a polynomial trend, probably of second order.

Having developed these criteria, analyses were then performed on the audiometric data to ascertain whether or not noise induced hearing loss could be said to exist on the Wilton Site.

The medical questionnaires associated with the audiograms obtained from the 687 employees in populations (P), (F), and (R) were examined. Employees were rejected from the sample if they had reported a previously diagnosed non-noise-induced hearing loss, a history of discharge from the ears, abscesses, a severe blow to the head resulting in a fracture, Meniere's disorder, otosclerosis, vertigo, a perforated eardrum, a history of usage of ototoxic drugs, or any other disorder which made it likely that the hearing loss exhibited was the result of an agency unrelated to noise. Employees were rejected on these grounds were labelled "pathological" and use was made of their data in a study described in section 11.10.

The 580 remaining employees were divided into 12 five-year age groups. A computer program was written to correct the audiograms for the effects of age using a formula given by Shipton (1979) and reproduced below.

$$H_{cf} = a(N-20)^2 \qquad (11.1)$$

N = age in years

a = function of frequency given in Appendix 11, table A11.3

H_{cf} = Median age correction factor at frequency f for males.

Note: $H_{cf} = 0$ for $N \leq 20$.

The formula was chosen after consideration of the literature describing presbyacusis data as summarised by Robinson (1979). Robinson does offer a slight alteration to equation 11.1, but as this alteration was effected to bring the formula into line with other European data bases, it has not been adopted. The form of equation 11.1 is that used in Burns (1970(a)).

The computer programme also corrected each audiogram in accordance with the current calibration factors applicable to the audiometer used, as given in Appendix 11.1.

11.4.3 Results and discussion

(a) Criterion (1)

Criterion 1 of section 11.4.2 was fulfilled by each of the employees within the study, as each was working in a plant in which a noise hazard had been shown to exist. Furthermore in approximately 97% of the test population additional noise exposure had been received by the individuals during the course of employment with companies other than ICI, previous noisy occupations within ICI, or recreational activities.

(b) Criterion (2)

Criterion 2 was met by use of the screening technique, described earlier in section 11.4.2 which removed from the study those individuals who could have been suffering from a non-noise induced hearing loss.

(c) Criterion (3)

The mean age corrected hearing loss at each frequency exhibited by the 580 employees remaining in the screened sample was calculated for each ear separately, in each of twelve five year age groups. A comparison of the data for the right and left ears showed no statistically significant difference at the 5% level, using a multiple protected 't' test. The data for the left ear are displayed in figure 11.1. Criterion 3 is met in that a clearly developing 'notch' can be seen in the mean audiograms in the frequency range previously defined as being the most susceptible to noise induced hearing loss.

(d) Criterion (4)

Inspection of figure 11.1 shows that the audiometric notch becomes more pronounced with increasing average group age. This visual trend was confirmed statistically by a one way analysis of variance. The results of this analysis are displayed in table 11.2 and show that a statistical difference at the 1% level exists between the mean hearing losses exhibited by the age groups considered, over the frequency range 2 kHz-8 kHz. The frequency of maximum mean hearing loss is 6kHz in each age group except the oldest, in which the maximum loss occurs at 4 kHz. The presence of a 6kHz notch is not inconsistent with noise induced hearing loss, as has been stated earlier, but the most probable reason for its existence lies in data presented by Robinson (1981). This author shows, in essence, that the audiometric zero levels given in the National Standard to which the audiometers used in this study were calibrated, are in error by approximately 4dB at 6kHz, and 2.5dB at 500 Hz. The errors are such as to increase apparent hearing loss at these frequencies. If removed from the data displayed in figure 11.1, the maximum depth of the notch would move back to the more traditional 4kHz frequency.

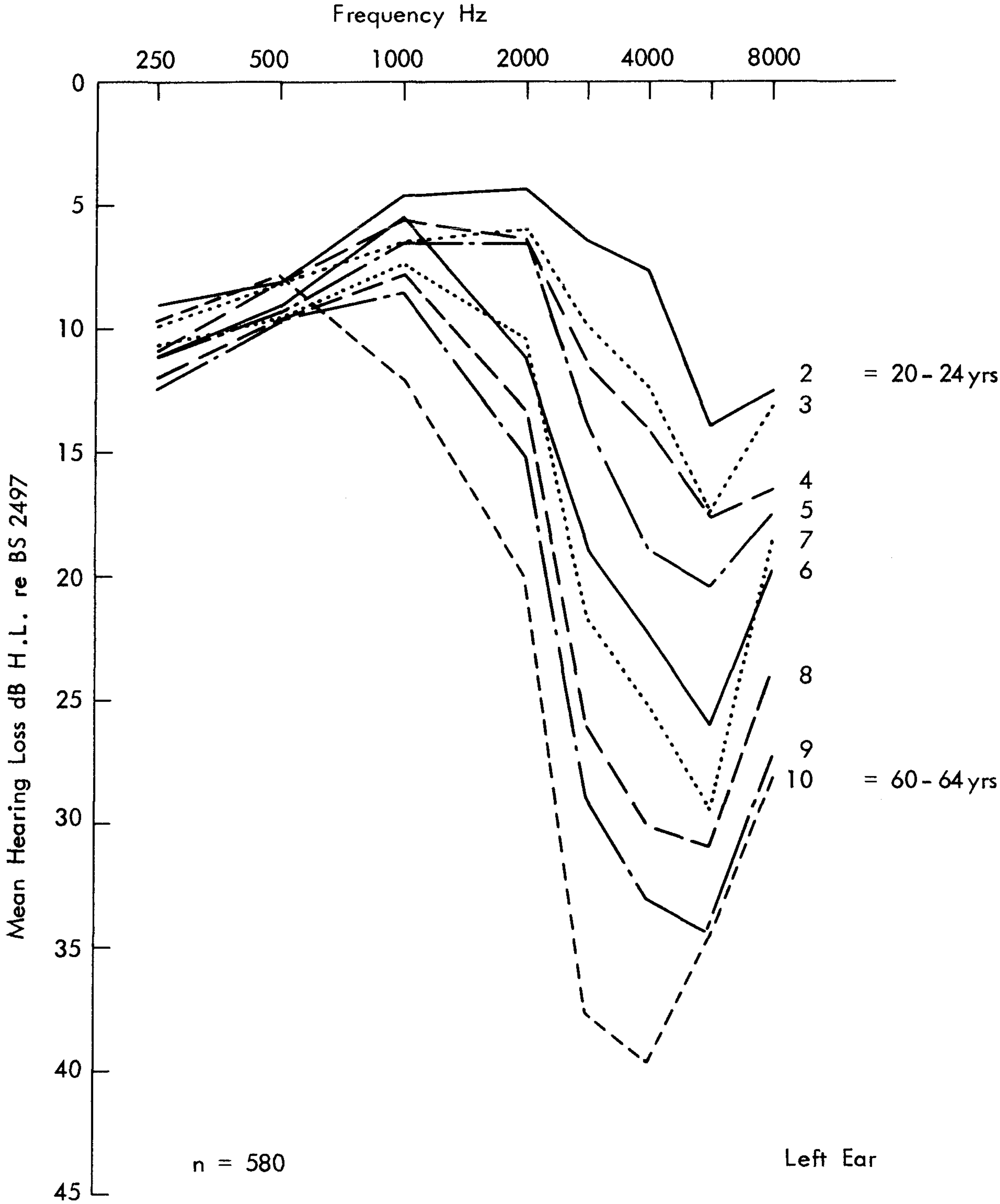


Figure 11.1 Showing the hearing acuity of population "P" + "F" + "R", after removal of employees with pathological conditions of the ear, unrelated to noise induced hearing loss, from the population.
The mean hearing loss is shown broken down by age, after age correction. The key to the age groups is shown in Table 11.1 , together with right ear data and the numbers in each age group.

Table 11.1 The hearing acuity of population P + F + R after employees have been removed from the analysis possessing pathological conditions of the ear unrelated to noise induced hearing loss. The main hearing loss is shown analysed by age, after age correction.

	Left ear								Right ear								
Frequency kHz	0.25	0.5	1	2	3	4	6	8	0.25	0.5	1	2	3	4	6	8	N
1 15-19yr																	
2 20-24yr	9.1	8.2	4.8	4.5	6.4	7.6	13.9	12.5	11.6	8.3	5.3	5.6	8.9	6.9	11.4	11.5	43
3 25-29yr	9.9	8.2	6.5	6.1	9.8	12.4	17.4	13.1	11.4	9.2	6.4	7.2	8.2	8.2	14.3	14.1	103
4 30-34yr	10.9	8.1	5.6	6.4	11.6	14.0	17.8	16.4	14.1	12.4	8.6	7.9	12.9	13.5	18.9	16.5	80
5 35-39yr	11.1	9.3	6.3	6.6	13.9	18.9	20.4	17.5	13.8	10.6	8.6	8.7	14.5	17.5	21.3	17.3	76
6 40-44yr	11.0	7.8	5.4	11.2	18.9	23.5	26.0	19.7	12.5	10.0	7.4	10.4	17.1	20.7	23.3	19.1	68
7 45-49yr	10.7	9.4	7.4	10.5	21.7	25.1	29.6	18.5	13.6	11.8	8.0	9.7	20.8	24.9	25.5	18.1	77
8 50-54yr	12.0	9.5	7.7	13.3	26.0	30.0	30.9	23.7	13.5	11.5	9.4	13.6	24.7	26.9	28.5	23.8	65
9 55-59yr	12.4	9.3	8.6	15.1	29.8	33.0	34.3	27.2	14.8	11.1	9.5	11.9	26.4	28.1	27.5	22.2	52
10 60-64yr	9.8	7.8	12.0	20.0	37.7	39.6	34.6	28.0	12.4	11.3	8.5	13.4	32.0	30.3	32.6	29.1	16

The table shows dB H.L. re B.S. 2497

Table 11.2 Showing F ratios obtained from a one way analysis of variance of mean hearing loss by age group on a screened population, in which the hearing levels were corrected for the effects of presbyacusis.

Population (P + F + R) used in the analysis

Frequency (Hz)	Left ear	Right ear
250	0.845	1.083
500	0.474	1.035
1000	1.501	1.082
2000	6.371*	2.674*
3000	18.108*	14.734*
4000	17.734*	16.779*
6000	10.435*	8.069*
8000	4.640*	3.353*
n	580	580

*F tables $1\%_{8,579} = 2.59$

(e) Criterion (5)

A regression analysis was completed to investigate the linearity of the relationship between the age corrected hearing loss and the age/noise exposure time of the test population. Data were fitted to the general statistical prediction model given in equation 11.2 and the hypothesis was tested that the coefficients of the nonlinear terms (B_2, B_3, B_{j-1}) were equal to zero. (Winer (1971).

$$Y_{ij} = B_o + B_1(X_j-\mu_x) + B_2(X_j-\mu_x)^2 + \ldots + B_{j-1}(x_j-\mu_x)^{j-1}+e_{ij} \qquad 11.2$$

where Y = dependent variable

B_o = constant

B_j = regression coefficient

X = independent variable, age/exposure time

μ_x = mean value

e_{ij} = error term.

The between age groups sums of squares were partitioned at each frequency tested, into that explained by a linear relationship between the groups, and that explained by a nonlinear relationship between the groups. Forming the appropriate 'F' ratios using the within groups mean squares as the denominator, yielded the results shown in table 11.3. Here it can be seen that a strong linear relationship exists between the age of employees, and their age corrected hearing losses at frequencies of 2kHz and above. The nonlinear component in this relationship is very weak.

Pearson's 'r' coefficient, and hence r^2, is also displayed in table 11.3 permitting an estimate to be made of the percentage variation in the data explained by a linear relationship. The statistical significance of the 'r' coefficient follows that of the linear 'F' ratios, not unexpectedly as 'r' is linked to the linear 'F' ratio. (Blalock, 1979).

Table 11.3 The 'F' ratios and significance values resulting from a test of linearity of increase of hearing loss with age. The age corrected hearing losses used in this analysis were those of population P + F + R, with the "pathological" component removed.

Left ear								Right ear								n = 580
250	500	1000	2000	3000	4000	6000	8000	250	500	1000	2000	3000	4000	6000	8000	Frequency (Hz)
3.77	1.107	7.18	46.20	141.4	140.2	80.66	34.19	3.104	2.195	5.073	18.73	114.8	130.5	61.74	23.53	$F_{1,571}$ ratio linear terms
5.25	29.32	0.76	0.0	0.0	0.0	0.0	0.0	7.86	13.9	2.47	0.0	0.0	0.0	0.0	0.0	significance level %
0.43	0.384	0.689	0.68	0.495	0.233	0.402	0.418	0.794	0.87	0.512	0.381	0.435	0.529	0.401	0.47	F_{7571} ratio non linear terms
88.6	91.2	68.15	68.93	83.83	97.74	90.13	89.13	59.26	53.02	82.6	91.36	88.06	81.27	90.17	85.64	significance level %
0.081	0.044	0.111	0.273	0.444	0.443	0.351	0.237	0.073	0.062	0.094	0.178	0.408	0.430	0.312	0.198	Pearsons 'r'

11.4.4 Conclusion

It can be stated with confidence that the acuity of the population studied has been affected by noise. The results presented met the criteria developed from consideration made earlier in this section of the characteristics of noise induced hearing loss. The population hearing loss showed the correct causation, affected frequencies, and time course of deterioration of hearing acuity. It is not unreasonable, therefore, to cite noise exposure as a major causative factor in the loss recorded in figure 11.1.

British Standard 5330 (1976) defines a loss of 30dB averaged over, 1, 2, and 3kHz as being the onset of auditory disability. Figure 11.7 developed and discussed in section 11.10.3.2, shows the percentage of the screened and unscreened populations 'P'+'F'+'R', and the pathological population, exceeding various hearing loss levels averaged over 1, 2, and 3 kHz. Equation 11.1 was used to calculate the three frequency average age correction to be added back into the data shown in figure 11.7 for the unscreened population 'P'+'F'+'R'. This reached 3dB, based on the population average age of 40 years taken from table 11.4. The same factor for the screened 'P'+'F'+'R' population was 1.7dB. Allowing for these factors, it can be seen that 16.5% of the total population tested possessed hearing losses in one or both ears exceeding the 30dB criterion described above, and that 13.25% of the screened 'P'+'F'+'R' population would suffer from the same problem.

It has been shown therefore, that one employee in six on the site would be aware of deficient hearing in one or both ears, and that at least 1 employee in 7 or 8 would know of no other reason than industrial noise to cite as the cause of the loss, unless he wished to accept premature ageing as a reason. Hearing loss is therefore a real factor in the daily lives of the employees studied. Education and other efforts to change attitudes should therefore strike a responsive chord in the population.

Furthermore, evidence is growing that the 30dB average loss figure given in BS 5330 may be an overestimate of the level at which auditory disability commences (Robinson (1986)). Kell (1971) showed that the main problems experienced by noise deafened individuals were those found in the various

Table 11.4 The mean hearing levels for the 4 audiometric populations, right and left ears. The losses are corrected for age. Upper cell values give the mean hearing loss in dB. The lower cell values give the standard deviation. The age is given in years.

	Left					Right			
Population	P	F	S	R		P	F	S	R
250 Hz	10.9	11.34	14.42	13.0		11.89	14.45	14.29	16.24
	9.43	9.41	9.40	8.34		7.98	11.76	8.97	13.34
500 Hz	9.9	9.46	9.99	9.02		9.06	12.08	10.29	15.09
	8.87	9.72	10.18	7.85		8.1	12.45	9.48	13.79
1000 Hz	8.24	7.32	6.80	8.13		6.66	9.32	5.41	10.13
	9.82	10.66	11.00	8.28		8.35	12.72	9.48	13.58
2000 Hz	8.34	10.27	9.93	10.49		8.01	10.57	9.03	11.29
	12.63	13.97	14.56	11.86		10.89	14.00	12.41	14.99
3000 Hz	13.89	18.18	19.05	20.56		13.09	17.76	17.16	20.44
	17.79	18.0	18.37	19.15		14.41	17.19	15.98	20.51
4000Hz	17.05	21.35	19.47	23.67		14.06	19.43	17.36	21.67
	17.82	19.16	18.08	19.30		16.66	18.03	16.97	20.45
6000 Hz	19.06	24.73	20.93	27.07		16.06	23.13	18.91	24.87
	18.11	19.16	17.67	18.97		16.66	18.40	15.99	21.98
8000 Hz	18.66	19.53	18.41	19.71		17.04	19.68	18.53	22.91
	19.33	19.7	18.61	19.97		16.45	20.03	20.24	22.51
Age	34.14	40.78	40.82	41.49					
	10.44	11.0	11.05	11.61					

forms of social communication. The important frequencies are those contained within the speech spectrum below 3kHz. The youngest age group included in figure 11.1 showed normal hearing in this range, but the notch in the mean audiogram at 6 kHz does indicate that their hearing had already been affected by noise. Studies by Komouic (1973), and Findaly (1976), would indicate that a high frequency hearing loss is also accompanied by damage to the discriminatory capacity of the auditory mechanism at mid frequencies within the speech band, not evidenced by a permanent threshold shift occuring at lower frequencies. Thus "before significant hearing loss is apparent at mid frequencies, listeners may begin to experience undue speech perception difficulties under conditions of competing speech and noise" (Findlay (1976)). This conclusion is strengthened by work, particularly that on animals, showing that excessive noise can cause damage to the infrastructure of the cochlea, altering neural coding, without a substantial permanent shift occuring in the auditory threshold. Clark (1978), McFadden (1982), Feth (1980).

It is apparent therefore, that the hearing losses measured in the Wilton population are of a serious nature. In fairness to ICI, however, it should be emphasised that the responsibility for these losses cannot be ascribed to the company without careful examination of the work history of each employee.

11.5 A Study of the Attendance for Audiometric Testing

11.5.1 The objective of the study

Chapters 9 and 10 recommend the use of industrial audiometry as a technique for changing both attitudes and behaviour. The purpose of the present study was to ascertain if industrial audiometry could remain a voluntary exercise or whether it should be made mandatory on a site. An additional objective was to discover whether or not the lack of audiometric records from those employees declining an audiometric test could have biased the results of the audiometric analyses described later in this chapter.

11.5.2 Method

Employee turnover caused the original population participating in the research study to decrease at a rate of approximately 13% per annum. This rate varied only slightly from plant to plant, and does not include the total closure of two plants as described in chapter 2. It will be remembered that these plants were replaced in the experimental plan.

As it was administratively impracticable to continuously update the list of employees remaining on the plants the original list was used to schedule the audiometric appointments throughout the study. This had the consequence that towards the end of the study, that is, during the period in which the second audiometric tests were conducted, individuals who had left the company were scheduled for test.

To provide an estimate of this effect, plant listings were obtained on three occasions spaced throughout the research period, which allowed leaving rates to be calculated for each plant individually. This turnover rate was applied to the number of employees attending for an inital audiometric test during phases 1.1 or 1.2 as only these employees were recalled for a second audiometric test during phase 2. In this way an estimated number was obtained of those employees who had been tested initially and were still available for a second audiometric test. The actual number of audiograms obtained during phase 2 in each plant was then expressed as a percentage of this latter, derived, population estimate to produce the plant attendance rates for audiometric phase 2. A similar technique was used to produce the plant attendance rates for audiometric phase 1.

11.5.3 Results

Figure 11.2 displays the estimated percentage of the available employee population in each plant attending the medical centre for the initial audiometric test. The percentage attendance from each plant is shown broken down by the phase during which the employees were tested.

Attendance figures for the Terylene Drawtwist plant are not shown in figure 11.2 as the plant closed soon after the audiometric testing began. Before the plant closed, 40 employees did attend for test, and these have been included in the test totals for population 'F' in other audiometric analyses completed in this chapter.

Figure 11.3 shows the estimated percentage of the available employee population attending the medical centre for a second audiometric test.

11.5.4 Conclusions

It is immediately apparent from figures 11.2 and 11.3 that acceptance of audiometric testing by the workforce is not universal. Although attendance for the inital audiometric test was excellent in the Terylene Polymer plant at 96% it is unacceptable to instigate audiometry on a voluntary basis when the possibilty exists that under this voluntary regime up to 40% of a plant population may not attend as was observed in the Olefines V plant. Nylon Polymer and Propathene Finishing both exhibited attendance rates for the inital audiometric test of approximately 80%. The problem of voluntary attendance for audiometric test can become exacerbated when employees are required to return for a second audiometric test. It was noted that up to 70% may not attend, as was seen in figure 11.3 in the case of Terylene Polymer.

It is therefore recommended that any hearing conservation programme should commence with negotiations between management and unions to ensure that attendance for an audiometric test is compulsory. Conditions of employment should be altered, if necessary, so that new entrants to a company are obliged to present themselves for audiometric examination when required.

Yet again, inspection of figures 11.2 and 11.3 would suggest that the effect of industrial audiometry in changing hearing protector usage results more from the fact that audiometry may be seen as an appropriate stimulus than the content of the test itself. Figure 11.2 shows that attendance for an inital audiometric tests was better in the Terylene Polymer plant than in Olefines V, and yet hearing protector usage increased at a better rate in Olefines V than in Terylene Polymer. Both plants receiving audiometry and education as a treatment showed good attendance rates of approximately 80% for an intial audiometric test, and as shown in chapter 9, enjoyed approximately the same increase in hearing protector usage as did Olefines

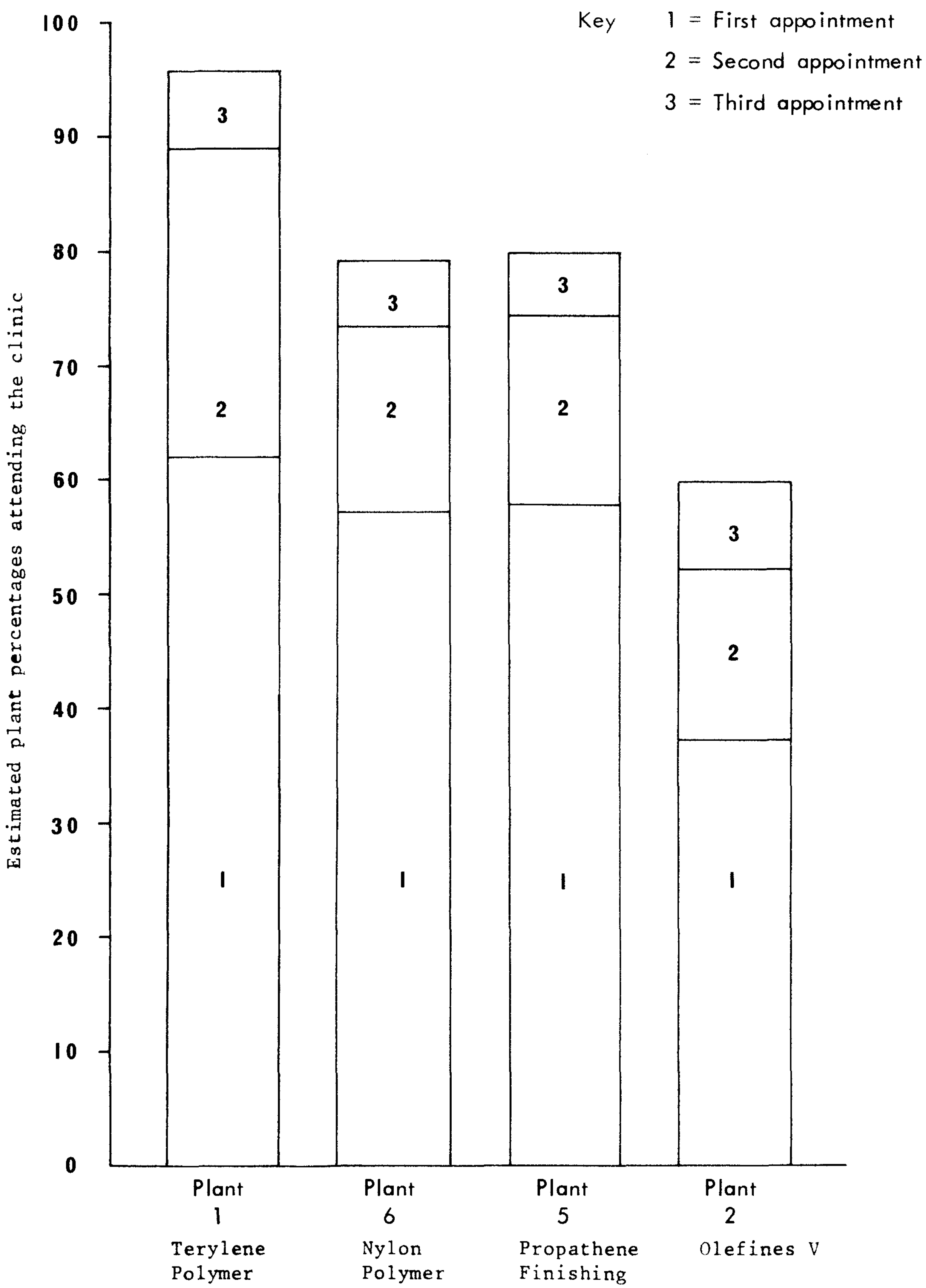


Figure 11.2 The estimated percentages of the available plant population completing a first audiometric test.

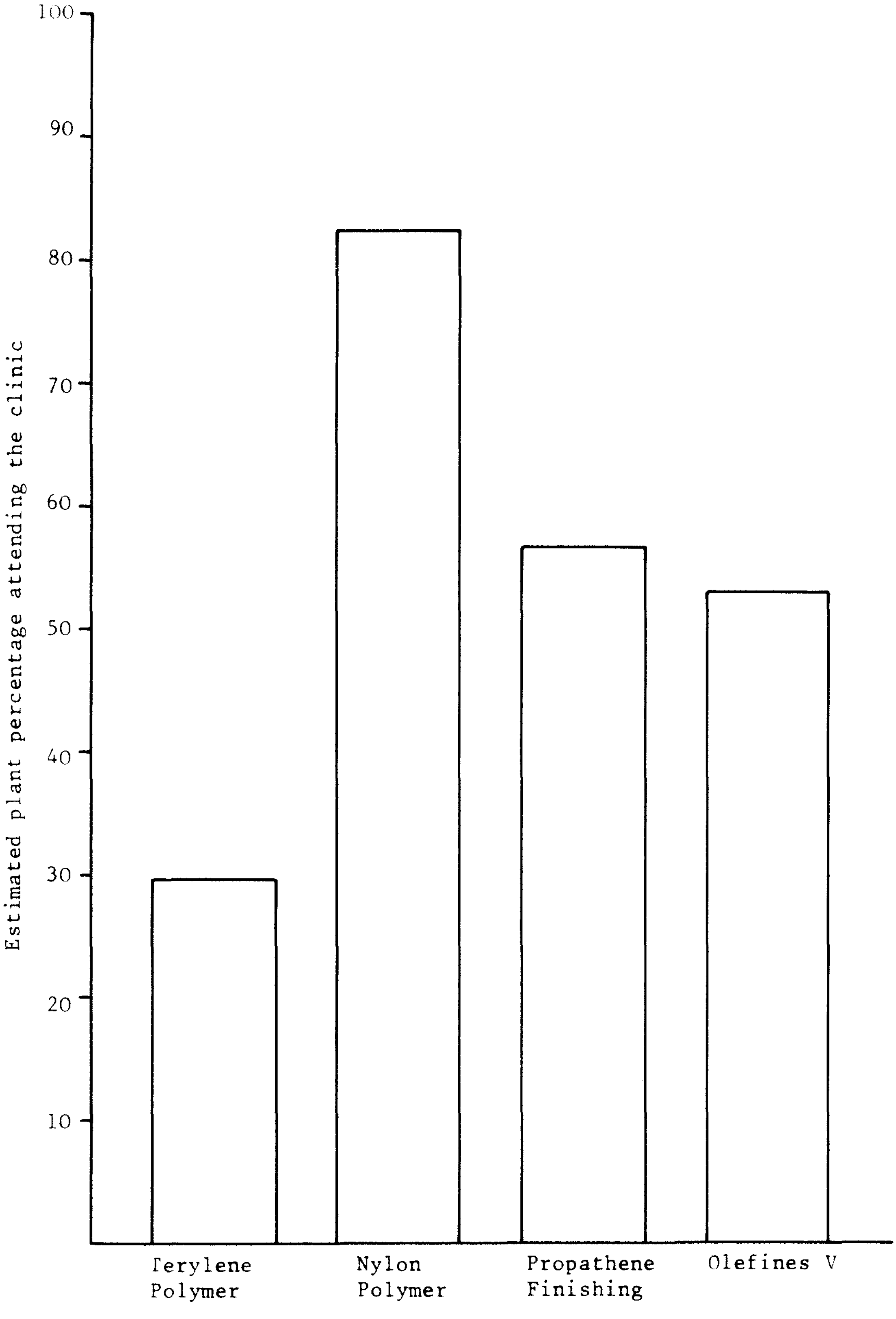


Figure 11.3 The estimated percentages of the available plant population completing a second audiometric test

V which exhibited a 60% attendance rate.

It is felt that figure 11.3 further substantiates the statement made in chapter 9 that audiometric results must be fed back to the tested population if the value of audiometry is to be maintained. This was not possible in the present study for the reasons explained in chapter 9 and attendance for a second audiometric test in the monitoring series dropped by 12% in the Olefines V plant, approximately 30% in the Propathene Finishing plant and an extraordinary 69% in the Terylene Polymer plant when compared to that population percentage attending for an intial audiometric test. Attendance did rise, however, by approximately 3% in the Nylon Polymer plant.

The large decrease observed in the Terylene Polymer plant is probably another manifestation of the point emphasised in chapter 9, where it was stated that the effectiveness of the audiometry was reduced by the higher number of audiometric appointments made per day for employees on the plant than was the case for other plants receiving audiometry as a treatment. Figure 11.3 shows that only 30% of employees in the Terylene Polymer plant felt it worthwhile to return for a second audiometric test, and it is therefore apparent that audiometry had started to lose its impact as a stimulus by that time. It should also be remembered that the interval between the initial audiometric test and the retest was, on average, shorter for employees of the Terylene Polymer plant than was the case for employees of other plants in which audiometry was conducted.

It is therefore important that every effort should be made to avoid giving the exercise the ambience of routine mass screening, by scheduling the tests at a low rate, and taking care over the manner in which the results are fed back to employees.

Interest was obviously maintained in the Nylon Polymer plant, which showed an increase in attendance for the second test. Mention has already been made in chapter 10 of the apparently increased involvement of management in the programme in that plant, as evidenced by the observed change in the attitude scale score CONTROL over the experimental period.

It would appear from the attendance rates that this maintenance of interest did not occur in the Propathene plant, which also received education as part of the total treatment. However, the Propathene plant equalled the performance of the Nylon Polymer plant in terms of increased usage of protection, even though there existed an approximate 25% difference in the attendance for a second audiometric test.

11.6 A Study of the effect of Non-attendance for an Audiometric Test upon the Overall Reliability of the Audiometric Database

11.6.1 The objective of the study

Section 11.5 detailed the attendance levels for a first audiometric test in the treated plants, and showed that the overall success rate reached approximately 80%. The study described in the present section was designed to evaluate whether the 20% of individuals who did not attend for a test possessed substantially worse hearing levels than the 80% of employees who were tested. If this proved to be the case, the consequences would be twofold. Firstly studies of population hearing levels based upon volunteer industrial populations would be biased towards the more acute hearing acuity end of the spectrum. Secondly, the argument for mandatory audiometry would be enhanced, as the implication would be that those employees with the worse hearing levels were not attending for an audiometric test under a voluntary policy.

11.6.2 Method

The approach used to estimate the hearing acuity of those employees who had not attended the Medical Centre for audiometry was to compare the hearing acuity of populations P, F, and R. It was reasoned that these three populations represented types of individuals who attended for audiometry with differing degrees of reluctance, increasing from population 'P', through 'F', to 'R'. If population hearing levels worsened through this progression, it might be reasoned that the population of employees who would not attend for a test would have exhibited still poorer hearing acuity.

Population 'P' consisted of employees drawn from four plants or areas not involved in the main study on the Wilton site. These individuals can be regarded as true volunteers, as it was made clear to them that their plants or areas were not involved in any large scale study, but rather all that was required were some individuals to attend the Medical Centre for an audiometric test, and to answer certain questions on hearing conservation. Population 'F' employees were part of a plant study in which attendance for audiometry was strongly requested and encouraged, but was not mandatory. Figure 11.2 shows that two appointments needed to be made for a sizeable proportion of population 'F' employees before they could be encouraged to attend. Population 'R' was more difficult to encourage to attend than either populations 'P' or 'F', refusing two appointments made during phase 1, and finally only agreeing to be tested at the very end of the study after receiving a third invitation during phase 3.

11.6.3 Results

The audiograms describing populations 'P', 'F', and 'R' were corrected for the effects of presbyacusis as described in section 11.4.2 by a specially written computer program which also calculated the mean and standard deviation of the hearing loss by frequency and population. Table 11.4 shows the results, together with those for population 'S'.

Inspection of table 11.4 showed that it would be acceptable to treat the left and right ears as replicate measures, a procedure used successfully by other research workers (Pell 1972, Burns 1970).

A two way analysis of variance was completed using a nested, incomplete block, fixed effects model to investigate the difference in hearing acuity between the three populations. The results are shown in table 11.5. Figure 11.4 displays the mean hearing loss for each population by frequency, whilst table 11.5 breaks this data down by ear, and also shows the mean age of each population.

Table 11.5 indicates that each of the two-way interactions are significant at the 5% level. In this statistical design the interaction of subject with population is a measure of the subject variation within a population. As an example, although the audiograms were age corrected, the differing

Table 11.5 The results of the analysis of variance completed on the data displayed in figure 11.05

Source of variation	df	ss	ms	vr
Population	2	12032.4	6016.2	46.255*
Frequency	7	291045.9	41578.0	319.671*
Population.Subject	683	1315989.0	1926.8	14.814*
Population.Frequency	14	4446.8	317.6	2.442*
Residual	10269	1335638.0	130.1	
Total	10975	2959151.0	269.6	
Grand Total	10975	2959151.0		
Grand mean	15.31			
Total number of observations	10976			

*significant at 5% level

Freq	250Hz	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz
Population								
First "F" n replicate=1124	12.90	10.77	8.32	10.42	17.97	20.39	23.93	19.60
Pilot "P" n replicate=158	11.39	9.49	7.45	8.18	13.49	15.56	17.56	17.85
Recalitr "R" n replicate=90	14.62	12.06	9.13	10.89	20.50	22.67	25.97	21.31

Mean hearing loss in dB HL

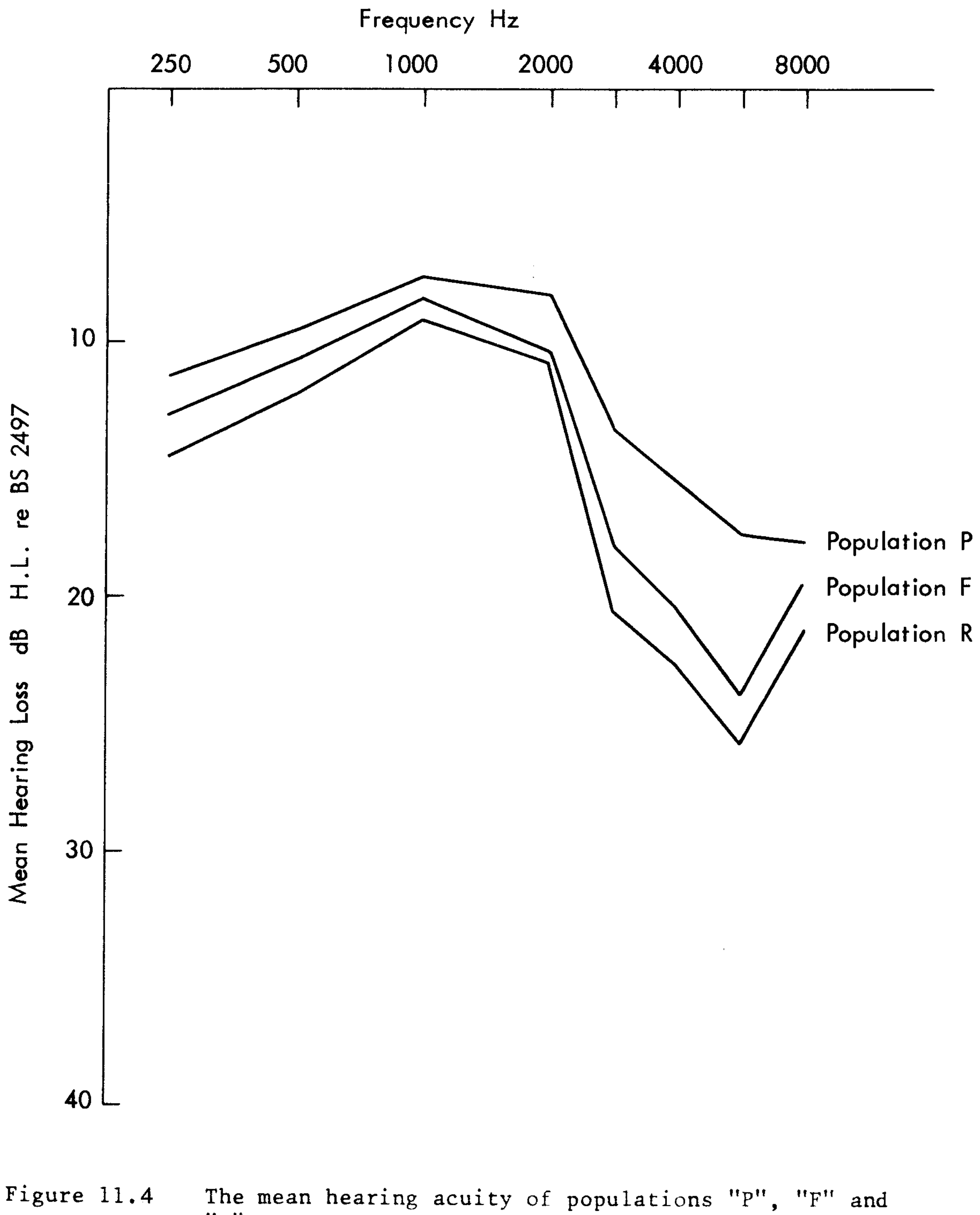


Figure 11.4 The mean hearing acuity of populations "P", "F" and "R" averaged over ears.

ages of the subjects meant that in all probability, they had been exposed to industrial noise for differing lengths of time. Thus variation in hearing loss between subjects was to be expected, and would not prevent interpretation of the main effects. That the frequency two way interaction should be significant at the 5% level, together with the frequency main effect is neither surprising, from inspection of figure 11.4, nor important. The statistical significance of the population x frequency interaction at the 5% level would indicate that any differences between population hearing acuity tends to exist at some frequencies rather than others. Exploration of the differences between population means was made on this basis, using the protected 't' test procedure described in section 7.2.2. As 24 comparisons were to be made, the statistical significance level was set at 0.2% this being the closest tabulated figure to 5/24%.

The pattern of statistically significant comparisons is shown in table 11.6 and indicates that no statistically significant difference exists between populations "F" and "R", but that a strong difference exists between population "P" and the other two populations over the frequency range 3-6 kHz. A statistical comparison of the mean age of the populations was also performed, using three protected 't' tests and indicated that the mean age of population "P" was approximately 6 years less than that of the other two, which did not differ between themselves.

11.6.4 Conclusions

The results would suggest that the hearing acuity of population "F", which was relatively easy to encourage to attend for an audiometric test, could not be distinguished statistically from that exhibited by population "R" which was reluctant to attend the clinic for a hearing test. This finding is not a function of the use of the protected 't' test at the 0.2% level, as the same result would have been achieved had it been acceptable to perform the 't' tests at the 5% level. After considering figure 11.4 it is difficult not to assume that a statistical difference must exist between populations "F" and "R", as "R" hearing levels always lie slightly below those of F. Use of the binomial theorem would suggest that there is only a 4% possiblity of this occurrence arising by chance.

Table 11.6 The results of protected 't' tests undertaken on the inter-population mean hearing levels plotted in figure 11.5 , and the difference in mean population age.

Population	250Hz	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz	Age
P	x x	x x	x x	x x	x x	x x	x x	x x	x x
F	x x	x x	x x	x x	x x	x x	x x	x x	x x
R	x x	x x	x x	x x	x x	x x	x x	x x	x x
Significance	- - -	- - -	- - -	- - -	* - *	* - *	* - *	- - -	** ** -

* significant at the 0.2% level (≃ 5%/24) Hearing acuity

** significant at the 2% level (≃ 5%/3) Age

\- nil significance

x comparison populations

However, it is important to remember that the hearing level measurements made are not truly independent at each frequency. Poor hearing at 1 kHz is likely to be linked to poor hearing at 2 kHz. Hence use of the binomial theorem, and the concept behind its application , is not valid in this case.

Having accepted the finding that populations "F" and "R" are statistically indistinguishable, but differ from population "P" it is likely that this difference is caused by the population age differential noted. Population "P" was found to be substantially younger than "F" and "R" which did not differ between themselves. Although the audiograms were age corrected, the greater mean age of "F" and "R" employees permitted more time for the growth of a noise induced hearing loss. This hypothesis is further substantiated by the fact that the statistically significant differences in hearing acuity between the two groups of populations arise in the 3-6 kHz range, which is that in which noise induced hearing loss first becomes apparent.

Thus it can be concluded that the decision of an individual to come forward for a hearing test is being made on grounds other than the subjective impression of auditory ability, which is reassuring for those research workers who have performed audiometric surveys on the basis of voluntary attendance for a hearing test. The implication for the present study is that the audiometric analyses described in this chapter have not been biased by the non attendance of a certain percentage of the total population, and that the individual's subjective impression of his hearing acuity does not necessarily motivate him one way or the other with respect to attendance for hearing acuity tests.

11.7 A Study of the Influence of Appointment Time on the Probability of Attendance for an Audiometric Test

11.7.1 The objective of the study

The work detailed in chapters 9 and 10 has indicated the value of industrial audiometry in increasing hearing protector usage. Section 11.5 of this study has indicated that attendance for a voluntary audiometric test was not as high as might have been wished on some plants participating in the main study, and work in section 11.6 suggested that the subjective impression of auditory acuity was unrelated to attendance rates. It was thought that the appointment time might be related to attendance rates. If proven, this finding might indicate a way in which attendance rates for industrial audiometry could be improved.

The attitude held by an employee is not always the sole arbiter of whether or not he will attend an industrial Medical Centre for a hearing test. If the appointment is scheduled for mid shift, it is possible that work commitments may prevent an employee from leaving his post. This situation will arise whether or not the audiometry is undertaken on a compulsory or a voluntary basis. Audiometric tests could be scheduled so as to mitigate this effect.

The study described in this section was designed to ascertain whether appointments made at the start of a shift were attended more frequently than appointments scheduled later in a shift.

11.7.2 Method

As described in chapter 2, the ICI Wilton site operates on a 4 shift system, the shift times being 14.00 hrs-22.00 hrs, 22.00 hrs-06.00 hrs and 06.00 hrs to 14.00 hrs, with the fourth shift resting. A small proportion of day workers are employed on the site, their hours of work being 08.00 hrs to 16.00 hrs.

Restriction on the number of staff available to undertake the audiometric testing, and the need to keep employees away from their plants for a minimum length of time, resulted in two one-hour periods being allocated to audiometric testing. These were 09.00 hrs-10.00 hrs and 14.00 hrs-15.00 hrs. Employees whose appointments were for times during this latter period attended for test prior to going to their plants, whilst employees attending the morning session had worked in their plants for between 1 hour and 3 hours prior to test. Employees were allocated an appointment time on a random basis, with the exception that day workers were tested during the 09.00 hours to 10.00 hours period.

11.7.3 Results

A computer programme was written to divide population "F" into the 127 employees tested at 09.00 hours and the 435 individuals tested at 14.00 hours. The 09.00 hours group consisted of 23 day workers, and 104 shift employees.

Table 11.7 shows, for each plant, the percentage of appointments which were kept at the two appointment times. It should be remembered that many employees in population "F" attended only after two appointments had been made for them.

Table 11.7 shows that appointments made for the start of the 14.00 hours shift test period were better attended than the 09.00 hour appointments in each of the five plants. Application of the binomial theorem shows that this result has only a 3% probability of occurring by chance. Considering the relative unimportance of rejecting the null hypothesis of no difference between the populations when it was in fact true, a 3% level was considered adequate at which to reject this null hypothesis, and accept the proposition that a true difference existed between the attendance percentages for the two test periods.

11.7.4 Conclusion

The most probable explanation for poorer attendance at the 09.00 hrs appointments was that the employee becomes involved in a piece of work soon after the start of his shift, and is either unable, or unwilling to leave the job partly finished in order to attend the Medical Centre. This could in part be due to the reluctance of the employee to explain to the foreman why he needs to visit the Medical Centre, or the fact that once a process is started in a chemical plant, an employee involved in the process may not be able to leave his post until a replacement is available, a replacement which the foreman may find difficult to find.

The solution to this difficulty would be to involve strongly the foremen in assisting the flow of employees from the plant to the Medical Centre. The onus should not be left on the employee to obtain permission to leave his

Table 11.7 Showing the attendance of employees for audiometry as percentage of the number of appointments made.

Plant	% of appointments made, which were attended	
	09.00 appointment	14.00 appointment
Nylon Polymer	40.59	51.14
Terylene Polymer	52.25	54.39
Propathene Finishing	38.35	52.73
Olefines V	26.96	31.28
Terylene Drawtwist	25.0	32.65
Overall Attendance	40.37	48.42

place of work, but rather the foreman should be required to send the employee from the plant to the Medical Centre at the appointed time. These comments apply whether or not attendance for an audiometric test is made compulsory, although again the results presented in this section strengthen the argument for compulsory audiometry.

11.8 A Study of the Effect of Appointment Time upon the Auditory Acuity Measured

11.8.1 The objective of the study

The best time for an audiometric test to be conducted is at the start of a shift. This ensures that the employee has had 16 occupational noise free hours prior to the measurement, minimising the risk of Temporary Threshold Shift (TTS) affecting the audiogram. Conversely, if an audiometric test is completed after a shift has started, it is possible that a wide variety of reasons could have caused the employee to have received an unacceptably high noise exposure immediately prior to the test, the effects of which could still persist at the time of measurement.

However, when the logistics of scheduling audiometric tests are considered, factors such as the availability of audiometricians, the length of time for which an employee can be spared from his plant, and the numbers which must be tested each year, usually require that audiometry be conducted during the shift. The Health and Safety Executive (1978) recommend that if this is necessary, care should be taken to ensure the useage of hearing protection in the hours worked prior to test.

The study described in this section was designed to evaluate whether or not this policy worked in practice.

11.8.2 Method

Each employee scheduled for an audiometric tests received, in addition to his appointment card, a letter stressing strongly that hearing protection was to be worn in the hours worked in noise prior to test.

The audiometric results obtained from those employees tested at 14.00 hours, that is, before reporting to the plant for work, were compared with those obtained from employees tested at 09.00 hours. These latter individuals had worked for part of their shift prior to reporting for test.

11.8.3 Results

Population "F" audiometric results were age corrected, and subdivided by a computer program into 435 individuals tested at 14.00 hours, and 127 employees tested at 09.00 hours. Of this latter population 23 had worked for an hour prior to test, and 104 had completed 3 hours of their shift.

A further computer program was written to calculate the mean and standard deviation of the age of each test group or subpopulation, and to submit the audiometric data to a two way analysis of variance using a fixed effects incomplete block nested design. The right and left ears were treated as replicate measures as explained in section 11.6.3. Table 11.8 shows the results of this analysis.

11.8.4 Conclusions

A Student's 't' test and an 'F' test showed that the mean age and distribution of age in the two subpopulations were not statistically different at the 5% level. It is not unreasonable, therefore, to assume that both groups have a similar noise history. The only two way interaction to reach statistical significance at the 5% level was that of subpopulation by subject. As has been explained in section 11.6.4, the statistical significance of this type of effect is to be expected, and does not prevent interpretation of the main effects.

The "frequency" main effect reached statistical significance at the 5% level, but again this is to be expected, as hearing loss, especially that caused by noise, is very rarely constant with frequency.

Table 11.8 however, clearly shows that the hypothesis that a difference in hearing acuity exists between the two subpopulations can be rejected at the $p < 0.05$ level. Lack of a statistically significant subpopulation by frequency interaction would indicate that this result is constant across

Table 11.8 Analysis of variance, and comparison of the hearing acuity of employees tested at 9 a.m and 2 p.m

Source of variation	df	ss	ms	vr	
Subpopulation	1	144.5	144.5	1.083	Nonsig
Freq	7	252173.5	36024.8	269.924*	
Subpopulation.Subject	560	1096569.0	1958.2	14.672	Nonsig
Subpopulation.Freq	7	116.8	16.7	0.125*	
Residual	8416	1123223.0	133.5		
Total	8991	2472226.0	275.0		
Grand Total	8991	2472226.0			
Grand mean	15.54				
Total number of observations	8992				

*significant at 5% level
**significant at 0.5% level

Freq	250Hz	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz	Age yrs	
Subpopulation									$\bar{x}$	σ
9 o'clock n replicate=254	12.37	10.40	8.41	10.04	17.89	20.25	23.91	19.15	40.15 n=127	11.35
2 o'clock n replicate=870	13.05	10.88	8.30	10.53	18.00	20.43	23.93	19.74	40.96 n=435	10.92
t_{calc} significance	--	--	--	--	--	--	--	--	-	

- non significant at 5% level
-- non significant at 0.5% level

frequency, a finding confirmed by inspection of the subpopulation means also shown in table 11.8. Therefore, considering population rather than individual hearing levels, it can be concluded that either the time elapsing between the employee leaving the plant and starting his audiometric test was sufficiently long to permit the decay of TTS caused by exposure to the levels of industrial noise described in chapter 2, or that the employees were making use of their hearing protection prior to attendance at the Medical Centre.

Either of these two conclusions justifies the acceptance of the HSE strategy outlined in section 11.8.1 and its use in the present research work. This justification has been argued, however, on the basis of population means. It is possible that a few individuals did not protect themselves sufficiently whilst working prior to test. Although the results presented have indicated that this did not happen on any scale, a few audiograms elevated by TTS would not have disturbed the population mean sufficiently to be detectable. Steps should therefore be taken to ensure that such employees are encouraged vigorously to comply with the pre-test procedure. For this reason the following guidelines are suggested if employees are to be tested in the middle of a shift.

1. Each employee scheduled for audiometry must receive a letter or at the very least, verbal instructions, stating that hearing protection must worn prior to the audiometric test, and giving the reasons for this requirement.

2. On the day of the audiometric test an employee should have a tab placed on his clock card reminding him of the need to use hearing protection prior to his audiometric test.

3. Specially coloured hearing protectors should be issued to employees scheduled for examination that day. This will enable the foreman to check that employees are following the pretest requirements.

4. If logistically possible the employee should be required to obtain a signed card from the foreman stating that the employee has used hearing protection continuously in the work period prior to audiometry.

5. When attending the clinic for a hearing test, the employee should be asked twice if he has worn hearing protection prior to attending the Medical Centre that day, once at the reception desk, and once by the audiometrician. If the answer is in the negative in either case, the employee should be given a new appointment time. Space should be provided on the audiogram record card for the audiometrician to confirm that this question was asked of the employee, and that he replied in the affirmative.

This procedure should have the effect of encouraging employees to use protection prior to an audiometric test, and validating the audiometric trace should this ever be examined in the Courts.

11.9 A Study of the Correlation Between Noise Induced Hearing Loss and Eye Colour

11.9.1 Objective of the study

Several large retrospective surveys of the hearing acuity of noise exposed employees have been completed during the last two decades. These include studies completed by Taylor (1965), Burns (1970), Paschier-Vermeer (1973), Kell (1975), and Sataloff (1969). Although some disagreement exists between these research workers as to the extent of a noise induced hearing loss which will result from a given noise exposure, they do all agree that variation in individual susceptibility to noise induced hearing loss does exist, an observation also confirmed by Schertz (1978), and Chung (1982).

Robinson (1970) states that at a given frequency, the distribution of hearing loss in a non-noise exposed group of individuals is nearly Gaussian. However, as groups of individuals with increasing noise exposure are considered, the Gaussian distribution becomes distorted in a highly systematic way.

This finding becomes significant in the light of an argument presented by Thiessen (1977) in which this author, referring to Glorig (1960), states that hearing levels in young people who have not been exposed to noise or similar hazards to the hearing, are normally distributed about the mean. He then reasons that if such a population is then exposed to hazardous noise levels, the distribution must become skewed, unless all individuals are equally susceptible to damage.

The conclusion to be drawn from the information presented in the preceding two paragraphs is that individual susceptibility to noise induced hearing loss must exist.

Robinson (1976) makes several further interesting comments upon the topic of individual susceptibility to noise induced hearing loss. This author states that "Noise exposed groups show a much greater inter-subject variability than controls whether "unpurged" or "clean" which must mean that noise susceptibility is itself variable ... for example, Burns and I found cases where the rate of deterioration corresponded to noise levels as much as 20 dB(A) below or above average". Robinson also comments that on balance, better ears are more resistant to noise, they start better and suffer less, and that intra-subject variability of susceptibility is not explicable on the basis of variable transmissibilty of the sound in the conductive pathways, although anatomical differences between individuals do exist.

Sataloff (1969) considered the question of variable susceptibility to noise induced hearing loss between the two ears of one individual. Audiograms were obtained from miners exposed to high levels of industrial noise. Employees were rejected from the sample if the hearing loss was 40 dB greater in one ear than the other at two or more frequencies, if there also existed a history suggestive of unilateral deafness due to causes not related to noise, bilateral or unilateral conductive hearing loss or sensorineural deafness having characteristics not in keeping with the diagnosis of a noised induced hearing loss. The 187 employees remaining in this sample "almost always" had hearing levels within 10 dB at every frequency tested.

A technique for estimating the susceptibility of an individual to a noise induced hearing loss prior to noise exposure, would be of value in any hearing conservation programme. Eye colour has been suggested as an indicator for the following reason.

It has been suggested that the presence of melanin within the inner ear structures, can restrict noise induced hearing damage. (Bonaccorsi (1963)) Tota (1967). The findings of these authors encouraged other workers to attempt to correlate the susceptibility of an individual to noise induced hearing loss with eye colour, as the concentration of melanin in the iris, giving an index of the concentration of melanin in the inner ear, varies according to eye hue. (Hood (1976), Tota (1967), Karlovich (1975), Carter (1980), Carline (1980)).

The concentration of melanin within the iris is at a minimum in blue eyed individuals, and increases through the colour sequence blue, grey-green. light brown and dark brown.

Bonaccorsi (1965) established that the concentration of melanin within the iris is reflected in the concentration to be found in the stria vascularis, within the cochlea. In a previous paper, Bonaccorsi (1963) indicated that melanin performs an important metabolic function of a protective nature within the cochlea, a view shared by Tota (1967). Bonaccorsi feels that melanin could either act as an enzyme within the cellular oxide reducing reaction chain, or form a store of energy itself, available for use if the normal energy releasing compounds with in the cell are deactivated by intense acoustical stimulation. Lyttkens (1979) suggests that melanin could be a semi-conductor material permitting harmless discharge of high energy electrical pulses developed by the hair cells after high level impulse noise.

Tota (1967) and Hood (1976) claim to have established a link between the amount of temporary threshold shift (TTS) exhibited by subjects after exposure to high intensity noise, and the pigmentation of the iris. These authors claim that the smaller the amount of melanin within the iris, and hence the cochlea, the greater the susceptibility of the subject to TTS. Thus blue eyed individuals exhibited the greatest amount of TTS after exposure to the stimulus. Karlovich (1975) attempted to duplicate the findings of Tota, but was unable to do so. However, Hood argues conclusively in his paper that this was due to differences in methodology between the studies, and that a correlation does exist between eye colour and temporary threshold shift.

Although the existance of a relationship between TTS and permanent threshold shift (PTS) is debateable, (Ward (1976), Burns (1973)) Hood feels sufficiently confident of the link between eye colour and PTS to recommend that the "suggestion that susceptibility to noise trauma is linked to eye colour would seem to be deserving of further consideration".

In an effort to test this hypothesis, Carter (1980), measured the hearing acuity of 257 third year apprentices and also noted the colour of their eyes. The apprentices were divided into two groups depending upon whether or not their irides contained melanin pigment. The mean hearing levels of the two groups were compared at frequencies between 0.5 kHz and 8.0 kHz, the right and left ears being analysed separately. Only at 4 kHz in the left ear was a result obtained at the 5% level of statistical significance suggesting that the presence of melanin in the body structures protected the individual, to some extent, from the damaging effects of noise. The author suggested that the lack of a significant difference betwen the hearing acuity of the two groups at 4 kHz in the right ear could have arisen because noise induced hearing loss could occur first in the left ear of a predominantly right handed population. This hypothesis must be viewed as tenuous.

Carter's study is open to criticism on several points. Firstly, the mean levels of hearing loss measured were low, the largest being 8.8 dB at 6 kHz. Secondly, no attempt was made to check that the loss exhibited by the test population was caused by noise exposure. Thirdly, the one significant result found, in one ear at one frequency, existed only between the melanin/non melanin groups described, and could not be replicated if any other comparison of hearing loss with particular eye colour was made. Furthermore Carter did not adjust the statistics used for the fact that he was making multiple comparisons, and the result reported could, therefore, be spurious. Finally the author could not estimate the noise levels in which his subjects had worked.

The study by Carter could not be claimed to prove or disprove the hypothesis. The author states "... we do not regard the present results as conclusive, but they are sufficiently encouraging to warrant a further study specifically directed at this question".

Carlin (1980) attempted such a study, but obtained results no more conclusive than those of Carter. A very weak relationship between eye colour and hearing loss was detected, but not that originally postulated. The brown eyed individuals did not appear to suffer significantly less PTS than the blue eyed employees, and it was the grey eyed group which exhibited the greatest losses. Although Carlin used 100 industrial employees, no real evidence was offered that these were suffering from a noise induced hearing loss, and the group mean audiograms presented did not show the characteristic 4 kHz notch. This factor could have confounded the results. Carlin suggests that the data presented offered "... some support for the theory of Hood" but recommends further study.

From the literature reviewed, it appeared that eye colour as an indicator of susceptibility offered a promising area of investigation. It was thought that the audiometric study described in this thesis offered an excellent opportunity to resolve the uncertainties still existing as to whether or not eye colour was a good predictor of susceptibility to noise induced hearing loss.

The objective of the study described in this section was to verify, or otherwise, the acceptance of eye colour as an index of susceptibility.

11.9.2 Method

Audiometricians, whose colour vision had been checked, recorded the eye colour of each employee tested, using colour swatches to ensure uniformity of classification. The colour categories utilised were blue, grey, hazel, green and brown.

This data was entered into the computer together with the audiogram, which was then age-corrected using the method described in section 11.4.2. The otologically screened subpopulation of populations "P", "F" and "R" described in section 11.4.2 was employed in the study, as work reported in section 11.4.3 had already shown the existence of sizeable noise induced hearing loss in this segment of the population. The industrial noise exposure of these employees has been described in chapter 2.

11.9.3 Results

Several different analyses of variance were performed on the audiometric data, to detect any correlation between eye colour and age corrected hearing loss. These are listed below.

(i) Eye colour against hearing loss

(ii) Eye colour containing the most melanin (brown) versus the rest of the eye colours by hearing loss.

(iii) Eye colour containing the least melanin versus the rest of the eye colours, by hearing loss.

(iv) Eye colour containing the most melanin, versus the eye colour containing the least, by hearing loss.

(v) Eye colour containing the most melanin versus the eye colour containing the least, by hearing loss, with the first two age groups removed.

The first two age groups were removed from the data in analysis (v) as it was decided that although differential susceptibility to noise induced hearing loss according to eye colour could exist in employees 24 years old and younger, it is possible that the results of this differential susceptibility might not be very evident after only a short time of exposure to noise.

A nested, fixed-effects, two-way analysis of variance was performed on each of the models (i) to (v). Right and left ears were treated as replicates, as in earlier analyses. The results showed a strengthening relationship progressing from (i) to (v), a progression which is mirrored by an increasing elegance of comparison, increasingly free of confounding factors. Accordingly it is the results of this final analysis which are shown in table 11.9 as they show the effect under discussion the most clearly.

Table 11.9 Analysis of variance and comparison of the hearing acuity of employees with differing eye colour.

Source of variation	df	ss	ms	vr	Significance level
Eye	1	1314.32	1314.32	15.552	***
Freq	7	96330.69	13761.52	162.840	***
Eye.Subject	222	393398.00	1772.06	20.969	***
Eye.Freq	7	974.84	139.26	1.648	nonsig
Eye.Subject.Freq	1554	269651.69	173.52	2.053	***
Residual	1792	151441.19	84.51		
Total	3853	913110.69	254.85		
Grand Total	3583	913110.69			
Grand mean	14.39				
Total number of observations	3584				

Freq	250Hz	500Hz	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz
Eye								
Brown n replicate=102	14.66	10.28	7.45	12.05	20.25	19.54	20.72	19.12
Blue n replicate=346	13.64	9.44	5.51	8.39	17.19	19.04	20.89	18.41
t_{calc} significance				**	**			

Mean hearing loss in dB HL

* significant at the 0.1% level
** significant at the 0.5% level
*** significant at the 5% level

The table shows that the main effects, the eye x subject interaction, and the three way interaction containing a subject component are all significant at the 5% level. Given the variability that exists between humans and the differences in the subjects' previous noise exposure, the significance of the interactions containing a subject component is to be expected, as discussed earlier in this chapter. Similarly the significance of the frequency main effect is of no present importance as this is simply a reflection of the audiogram shape caused by noise induced hearing loss. The major finding is the statistical significance of the eye colour main effect, indicating that a differing hearing loss exists betwen the two populations, which is a function of eye colour.

Table 11.9 shows the mean hearing loss broken down by eye colour and frequency. The difference between the 8 sets of means was investigated using a protected 't' test at the 0.5% level (approximately 5%/8) utilising as the error estimate the residual mean square from the analysis of variance, divided by the harmonic 'n', or weighted number of measurements contributing to any pair of mean values.

This procedure showed the brown eyed individuals to have significantly different hearing acuity from that of blue eyed employees at 2 kHz, and 3 kHz. However, the effect was the reverse of that reported by Hood (1976) in that the brown eyed employees are shown to have sustained a greater loss than blue eyed employees.

The mean age of the blue and brown eyed employee groups was 42.5 years and 41.6 years respectively, indistinguishable at the 5% level. Both sub-populations, as groups, can be assumed to have received similar exposure to industrial noise over their working lifetimes.

11.9.4 Conclusion

The frequencies at which a statistically significant effect was shown to exist, 2 and 3 kHz, were not those of the maximum hearing loss occasioned by noise exposure. Hearing acuity is affected at 1-3 kHz by excessive noise exposure, but later than it occurs at 4 kHz or 6 kHz (Burns (1970)). It is possible that if susceptibility to noise induced hearing loss is redefined in terms of the rate at which an individual will suffer a noise induced hearing loss, rather than in terms of its eventual extent, then the rapidity of damage at 4 kHz or 6 kHz could be such as to obscure the differential susceptibility effect in test groups such as the ones used in this study in which the mean age was approximately 42 years. Detection might only be possible at the lower frequencies affected more slowly by noise.

However, it is felt that it is more likely that eye colour is not the true index of susceptibility to noise induced hearing loss, but is merely loosely related to some other aspect of the genetic difference between humans which causes this differential susceptibility. This could explain why the results of the studies discussed earlier show some indications of a positive eye colour/hearing loss correlation but which are either weak, or conflict as did the results of the research work undertaken as part of this thesis.

Further research work should concentrate upon collecting various physiological data on each employee tested audiometrically so that a correlation analysis, or a factor analysis, can be performed. This approach should indicate that group of human parameters which correlate the most highly with noise induced hearing loss and thus delineate specific areas for further research.

11.10 A Study of Referral Criteria for use in an Audiometric Programme

11.10.1 The objective of the study

The results of work described in chapters 9 and 10 suggest that industrial audiometry can be used to increase hearing protector usage. If industrial monitoring audiometry becomes adopted as a standard component of a hearing conservation programme, a status which it does not enjoy at the present time, one problem which must be resolved is the question of the analysis of the audiograms after measurement. Central to the problem is the task of setting a hearing acuity criterion, which if exceeded by an employee requires that he either be referred for further audiometric tests or warned that his hearing is not as acute as it should be.

The objective of the work detailed in this section is to evaluate and develop a referral criterion for use in a hearing conservation programme in which industrial audiometry is included. Failure to use the correct criterion level can cause the audiometric programme to fail, and the validity of the work to be questioned, thus reducing the effectiveness of this hearing conservation tool to increase protector usage. Fixing referral or warning level criteria represents a professional dilemma for the industrial medical department. Set too high, the criteria will not fulfill their function of providing an early warning of hearing acuity deterioration in the workforce. If they are set too low, the credibility of the hearing conservation programme is reduced in the eyes of those medical or para-medical personnel charged with the follow-up work ,whether these are employed by the company or are General Practitioners or are drawn from the public health services. This can lead to employees being told that their referral was not really necessary, as their hearing losses were not particularly serious, or local NHS medical resources being stretched beyond their limits. The latter problem has more serious practical consequences as it can lead to resentment amongst employees, with a large proportion of the workforce feeling that action is not being taken swiftly enough over the hearing loss which has been reported to them. Until such time as the further medical tests or consultation was completed the employees would probably continue to blame the company for causing the noise induced hearing loss.

Industrial monitoring audiometry is a screening process usually undertaken by staff not qualified to diagnose by judging the relationship between the medical and occupational history of the employee and the measured hearing loss. The referral or warning criterion used in the audiometric programme should therefore be unequivocable and not rely on value judgements, applying optimally to the air-conduction audiogram. The criteria should also be clear enough to be applied by staff who may not be very mathematically adept. If the recommended criteria are to be widely accepted for use, they should also be validated in some manner, either through recognition by the medical profession, or substantiated by research work, preferably endorsed by a government body. The latter two requirements are necessary because any criteria adopted for use by an industrial medical officer could be eventually examined in a Civil Court.

11.10.2 Method

Four possible criteria which meet the conditions described in section 11.10.1 are shown below.

Criterion 1 A referral value set at 6 kHz, the frequency of maximum hearing loss in the Wilton population.

Criterion 2 A referral value based upon information in British Standard 5330 (1976).

Criterion 3 A referral value based upon information in International Standards Organisation R1999 (1971).

Criterion 4 Referral and warning criteria drawn from the Health and Safety Executive discussion document on audiometry in industry (Health and Safety Executive 1978).

The four criteria were evaluated using audiometric data drawn from populations "P", "F", and "R".

The four criteria outlined above would be applied in practice to otologically unscreened populations. Therefore the analyses described later in this section were also performed without first screening otologically the Wilton audiological data. However, it was decided that it was of interest to evaluate the effect that the "pathological" section of the audiometric population, as previously defined in section 11.4, had upon the mean hearing level of the general population. Accordingly, analyses performed using criteria 1, 2, and 3, were repeated with the "pathological" component of the population removed, to provide a closer estimate of the percentage of employees exceeding these criteria whose hearing might have been affected by noise alone.

All audiometric data were corrected for the effects of age in the manner discussed in section 11.4 prior to analyses using criteria 1, 2 and 3, but not criterion 4, as this is already age adjusted.

11.10.3 Results

11.10.3.1 <u>Criterion 1</u> Employee to be referred if the age corrected hearing level in one or both ears exceeds a given fence level at 6 kHz.

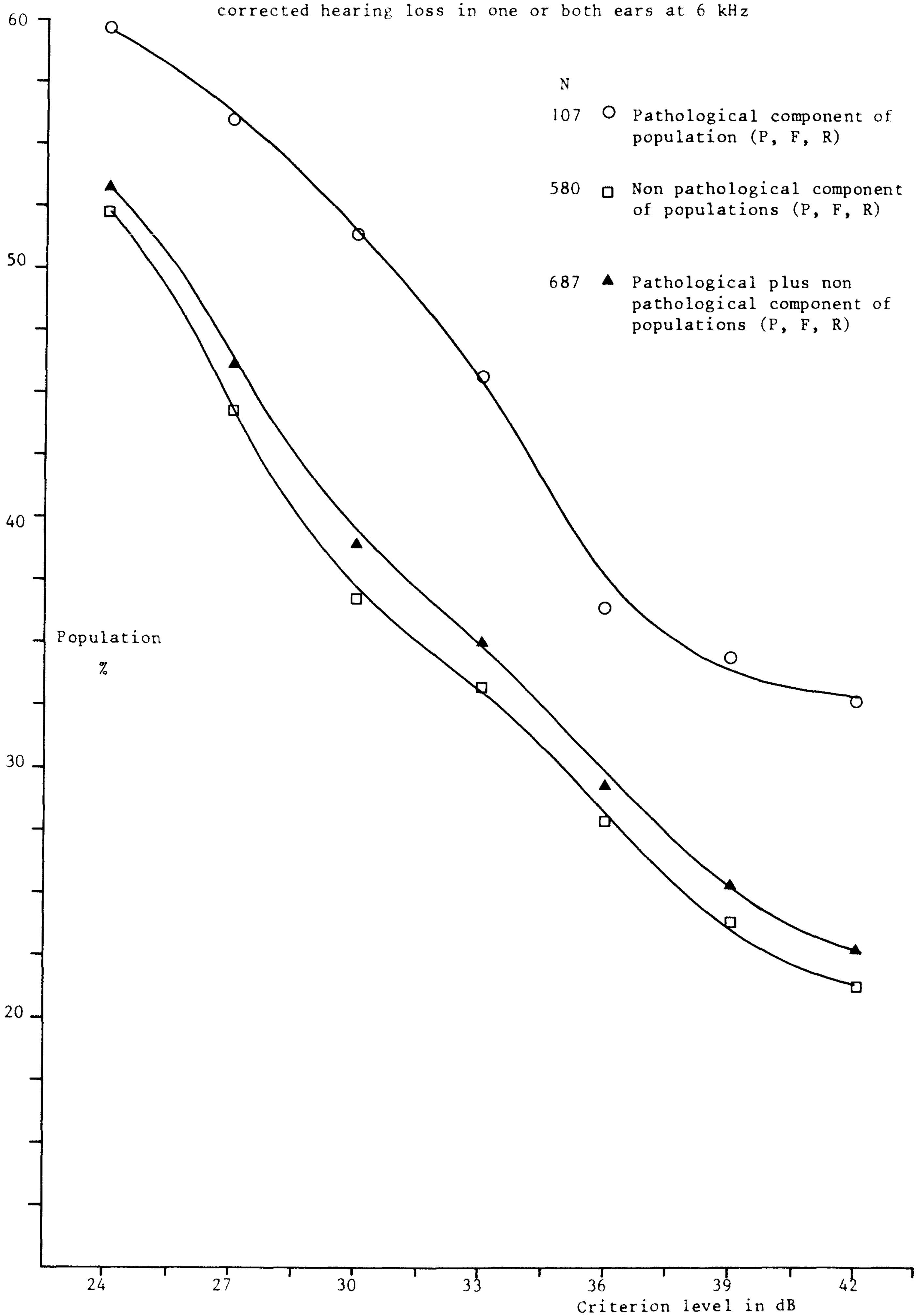
A computer program was written which incremented the fence value from 24 dB to 42 dB in 3 dB steps, calculating the percentage of the audiometric population exceeding the given level at each stage. The results of these calculations are shown in figure 11.5.

A clear difference can be seen between the population percentage profile of the "pathological" subpopulation and the "non-pathological" subpopulation. This indicates that the simple questions used in the pre-audiogram questionnaire were sufficient to identify a section of the population with a greater probability of exhibiting a hearing loss.

The smaller difference between the general population profile and the "normal" profile shows the effect of the "pathological" component of the population upon the percentage exceeding the criterion at 6 kHz. This difference is in the order of 1% to 2% across the criterion range investigated.

Figure 11.5 also shows that it would be impracticable to use criterion 1 as an action level in an audiometric programme. Even after population age correction, the percentage of employees exceeding moderate criterion levels at 6 kHz are high. If, for example, the 6 kHz acuity level at which employees were to be warned that their hearing was showing signs of damage was set at 30 dB, and the level at which they would be referred for further audiometric tests was set at 42 dB, then 17% of the population would receive a warning, and a further 22% would be referred. Thus after a programme of audiometric testing, some further action would be initiated in the cases of almost 40% of the employees. If the criteria levels were made more stringent, to reduce the percentage of employees exceeding them, inspection of the average audiogram shape in figure 11.4 indicates that hearing loss would have become unacceptably large before an employee crossed the warning threshold.

Figure 11.5 The percentage of the population exceeding a given age corrected hearing loss in one or both ears at 6 kHz



It should be noted that not all industrial populations will exhibit a maximal hearing loss at 6 kHz. The classical noise induced hearing loss notch appears at 4 kHz. However, there is no reason to believe that the results given in this section for the 6 kHz notch would be significantly different at 4 kHz in a population exhibiting a notch at this frequency.

11.10.3.2 Criterion 2 British Standard (BS) Criterion

British Standard 5330 (1976) states "The hearing of a person is deemed to be impaired sufficiently to cause a handicap if the arithmetic average of the hearing threshold levels of the two ears combined at 1 kHz, 2 kHz, and 3kHz is equal to or greater than 30 dB referred to the audiometric zero of BS 2497".

Following this definition of handicap, hearing loss in one or both ears averaged over 1 kHz, 2kHz and 3 kHz was matched against various warning and referral criteria levels.

A computer program was written which performed the necessary averaging and incremented the proposed criterion value progressively from 24 dB to 42 dB, calculating the population percentage exceeding this value at each stage. The programme is shown in Appendix 11.

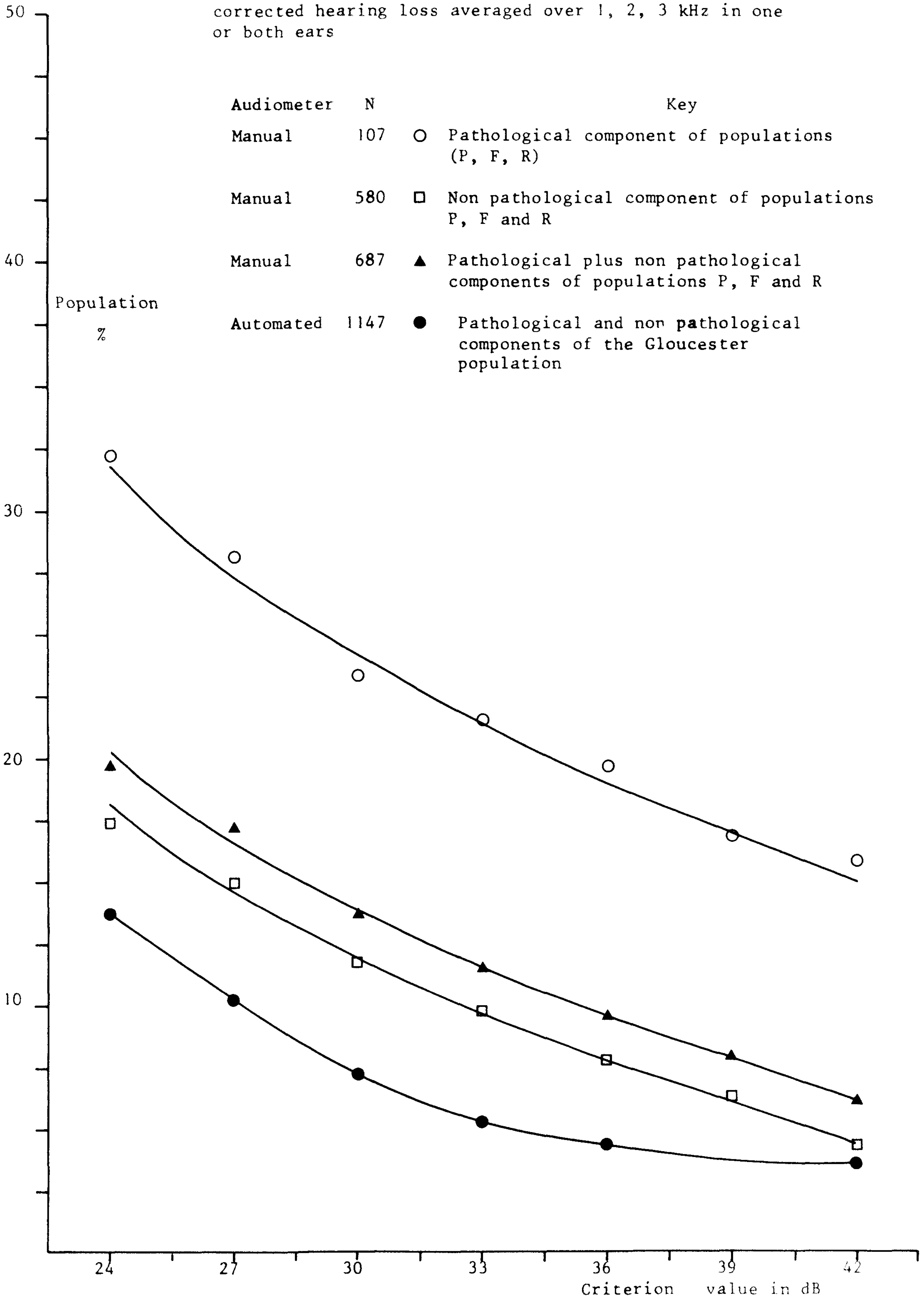
The results are shown in figure 11.6. Similar trends are evident to those observed in figure 11.5 in that the pathological component of the population is identified as possessing a much greater hearing loss than the non-pathological section.

Criterion 2 would appear to hold some promise as a referral level, for at the previously defined handicap level of 30dB, a manageable 14% of the general population would be referred for further medical action.

If a 24 dB warning level was set to permit remedial action to be taken before the hearing loss of an employee became a perceptible handicap, then 6% would exceed this warning level, but not the referral limit of 30 dB.

Wilton site medical officers were of the opinion that the industrial doctor should be able to complete follow up work on approximately 15% of the

Figure 11.6 The percentage of the population exceeding a given age corrected hearing loss averaged over 1, 2, 3 kHz in one or both ears



audiometric population for which they were responsible, without overstretching medical resources. It will be shown below that the warning and referral levels discussed above will yield a follow-up percentage close to this recommended maximum if automated audiometers are used in the audiometric programme.

In view of the potential usefulness of this audiometric criterion, it was decided to test its general applicability against data drawn from a second ICI site. Audiograms from 1147 employees working at ICI Brockworth, Gloucester, were used. These employees were exposed to levels of continous noise between 90 and 96 dB(A) L_{Aeq} in halls of machinery producing man-made fibres. No attempt was made to verify the existance of noise induced hearing loss in this employee population as had been achieved with the Wilton data; the Gloucester data pool was simply used as a typical industrial population subjected to industrial audiometry.

The audiograms had been obtained using a regularly calibrated Amplaid 255 automated audiometer. In order to compare these results with those obtained during the Wilton study using a manual audiometer, it was necessary to consider the difference in measured acuity between results obtained on a manual and an automated machine.

Many authors have described the differences in auditory thresholds measured by manual and automated machines, with the automated audiometer yielding the better, lower, thresholds of hearing. (Burns 1957, Harris 1964, Delany 1965, Knight 1966, Robinsons 1973, Erlandsson 1978). The exact correction factors to be used in equating threholds measures using one method to those measured using the second would appear to vary according to the operating parameters of the automated machine, the type of subject tested, and the hearing loss delineated. After consideration of these factors it was decided that the correct adjustment factor would be 3dB at each of the audiometric frequencies tested. This quantity will be used when comparisons are made between the results obtained on each of the two sites. The 1147 audiograms drawn from the Gloucester site were age corrected and subjected to the same computer analysis as used to evaluate the validity of utilising criterion 2 on the Wilton audiometric population , and described above.

The results are also shown in figure 11.6 and indicate that the hearing loss on the Gloucester site averaged over the three frequencies is slightly better than on the Wilton site by approximately 2-4 dB, allowing for the 3 dB manual to automated audiometer correction factor discussed earlier.

If it is assumed that the present trend towards the use of automated audiometers continues, and industrial audiometry in the future will predominantly be performed with these machines, then the hearing loss of 11.6% of the Wilton population would exceed the 30 dB BS criterion, as would the hearing acuity of 7.3% of the Gloucester population. A further 5.4% would exceed the 24 dB warning level discussed earlier, on the Wilton site, as would a further 6.54% on the Gloucester site. The total warning plus referral percentages on the Wilton and Gloucester sites would, therefore, be 17% and 13.8% on each site respectively after an allowance for age had been made. Both figures are close to the maximum population follow up percentage of 15% discussed earlier in this section.

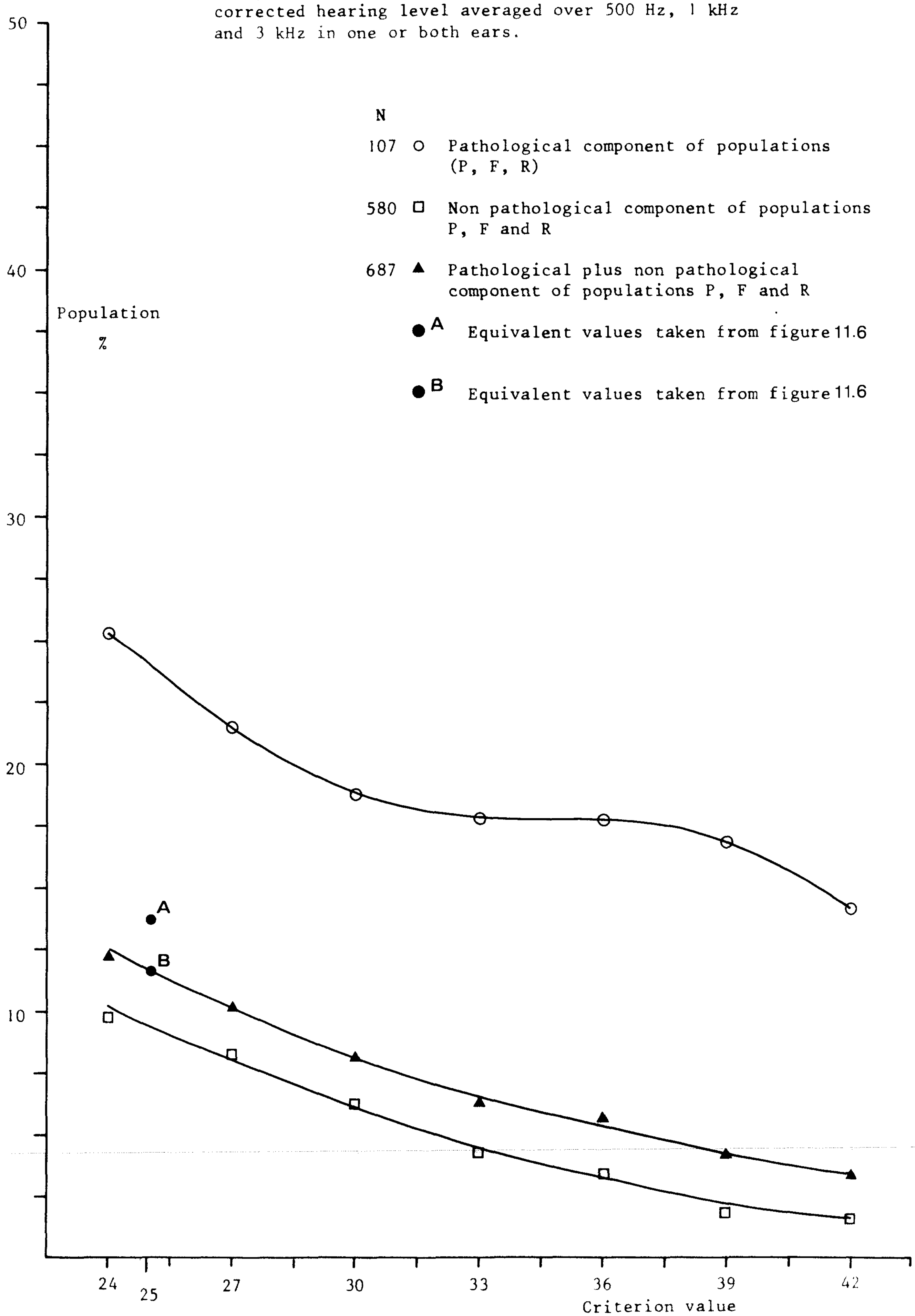
11.10.3.3 Criterion 3 International Standards Organisation (ISO) criteria

ISO Standard R1999 (1971) states "... the recommendations and data are based primarily on the impairment criterion that hearing is considered impaired if the arithmetic average of the permanent threshold shifts for the three frequencies 500 Hz, 1000 Hz, and 2000 Hz is 25 dB or more".

This concept was tested for possible use in hearing conservation work by evaluating the average age corrected hearing threshold at 500 Hz, 1 kHz and 2kHz of populations "P", "F" and "R", against gradually increasing fence levels, or potential criterion values.

A similar computer program to that used for the evaulation of criterion 2 was written, and the results are displayed in the same manner in figure 11.7. Comparison of figures 11.6 and 11.7 indicates that the criteria given in ISO R1999 and BS 5330 are approximately equivalent. The ISO reduction of the criterion value to 25 dB from the 30 dB level used in the BS criterion appears to be counterbalanced by the use of a frequency range which is characterised by a smaller loss in hearing acuity than is the case for the range used in the BS criterion.

Figure 11.7 The percentage of the population exceeding a given age corrected hearing level averaged over 500 Hz, 1 kHz and 3 kHz in one or both ears.



Data drawn from figure 11.6 are plotted on figure 11.7 so that the effect of the ISO and BS criteria can be directly compared. It can be seen that use of the ISO criterion instead of the BS criterion leads to a reduction of approximately 2.5% in the numbers exceeding the fence value.

The similarity in figures 11.6 and 11.7 of the slopes of the curves describing the hearing acuity of the pathological and the non-pathological population components, and the difference between them, suggests that the distribution of hearing loss in the test population at 500 Hz and 3 kHz are similar. The slight decrease in the separation of the "pathological" and the "non pathological" curves in figure 11.6, when compared to that in figure 11.7 describing work on the ISO criterion would suggest that the effect of a pathological condition of the ear is greater at 500 Hz than at 3000 Hz. The ratio of the number of individuals in the pathological population to the number in the non pathological population exceeding the relevant fence level is 0.47 under the ISO regime, and 0.37 when use is made of the BS criterion. It would appear therefore, that the BS criterion is more suitable for adoption in a hearing conservation programme designed to prevent noise induced hearing loss. Additionally the BS based criterion is more stringent, with a higher percentage of the population being referred for further medical action than is the case when the ISO based criterion is used.

11.10.3.4 Criterion 4 Health and Safety Executive criteria

The Health and Safety Executive published in 1978 the discussion document "Audiometry in Industry", which was produced to act as a guideline for good audiometric practice within the United Kingdom.

The audiogram analysis technique described within the document employs certain criteria defining acceptable hearing acuity.

Data from the Wilton study were used to investigate the feasibility of using the HSE criteria in audiometric programmes.

In order to discuss the results of this study, it is first necessary to describe the audiogram analysis method itself.

The low frequency hearing loss in each ear is calculated separately by summating the measured thresholds of hearing at 0.5 kHz, 1 kHz and 2 kHz. The high frequency hearing loss in each ear is similarly derived by addition of the hearing thresholds at frequencies of 3 kHz, 4 kHz and 6 kHz. The four summated levels of hearing loss thus obtained are then compared with various criteria defined within the discussion document, "Audiometry in Industry", in order to classify the hearing acuity of the individuals into one or more of five categories.

(i) If low frequency or high frequency hearing loss sums have increased by 30 dB or more when compared with those of the preceding audiogram, or 45 dB or more when the interval between the two tests exceeds 3 years, then the individual is placed in category 1.

(ii) If the difference in hearing acuity sums between the two ears exceeds 45 dB at the low frequencies or 60 dB at the high frequencies, then the individual is placed in category 2.

(iii) If the low frequency, or high frequency hearing loss sums exceed the referral or warning level criteria for the given age group, then the individual is placed in category 3 or 4 respectively. Membership of category 3, the referral category, takes precedence over membership of category 4, the warning category. Criteria for membership of categories 3 and 4 are given in Table 11.10.

(iv) If the hearing acuity of an individual does not fall into categories 1 to 4, then he is categorised 5 which represents normal hearing acuity for the age of the employee.

The 688 audiograms drawn from the Wilton site populations "P", "F" and "R" were coded for computer storage and analysed initially according to the criteria given within the discussion document "Audiometry in Industry". The analysis was then repeated, progressively adding decibels to the referral and warning levels, which effectively reduced linearly the stringency of Table 11.10. Thus with each addition, fewer employees were classified as belonging to categories 3 or 4, as shown by curves (a) and (b) on Figure

11.8. This shows a plot of the results of the analysis. In completing the analysis, the hearing acuity of any given employee was allocated to a single category. Membership of category 3 took precedence over membership of categories 4 and 2. In turn, category 4 membership took precedence over category 2 membership.

It can be seen from figure 11.8 that if the criteria values for membership of category 3 or 4 are applied as they appear in "Audiometry in Industry" the hearing acuity of 27.4% of the population will be deemed to be poor enough to exceed the referral levels, whilst a further 39.6% will receive warnings concerning their loss of hearing acuity. These percentages are taken from the zero dB added point on figure 11.8.

In a large site manually testing 2000 employees each year, the implication is that during the first year of the audiometric programme further action will have to be taken in the case of 1340 employees. Even if no significant action is undertaken in the case of those employees who fall into the warning category, other than the issue of a warning letter, the 548 employees in the referral category will still require at the very least a second examination by the works Medical Officer. It would appear that a large number of Works Medical Officers intend to send any employee falling into the referral category either to the Ear, Nose and Throat (ENT) Department of a hospital, by special arrangement, or to the relevant general practictioner, who will probably then refer the majority of those individuals to the ENT Department. Given only six industries of the size described earlier in a catchment area, the numbers of employees thus referred would total several thousand.

This load would be spread unevenly over the country, with hospitals in the industrialised areas being most heavily stressed. If accepted by these hospitals, the waiting list for further audiometric tests would become so long as to substantially reduce the value of the procedure and cause the audiometric programme to slow gradually to a halt.

If a further screening stage is introduced at the Works Medical Officer level, in an effort to reduce the number of referrals to local hospitals, the problem will simply be reflected back down one level of the chain.

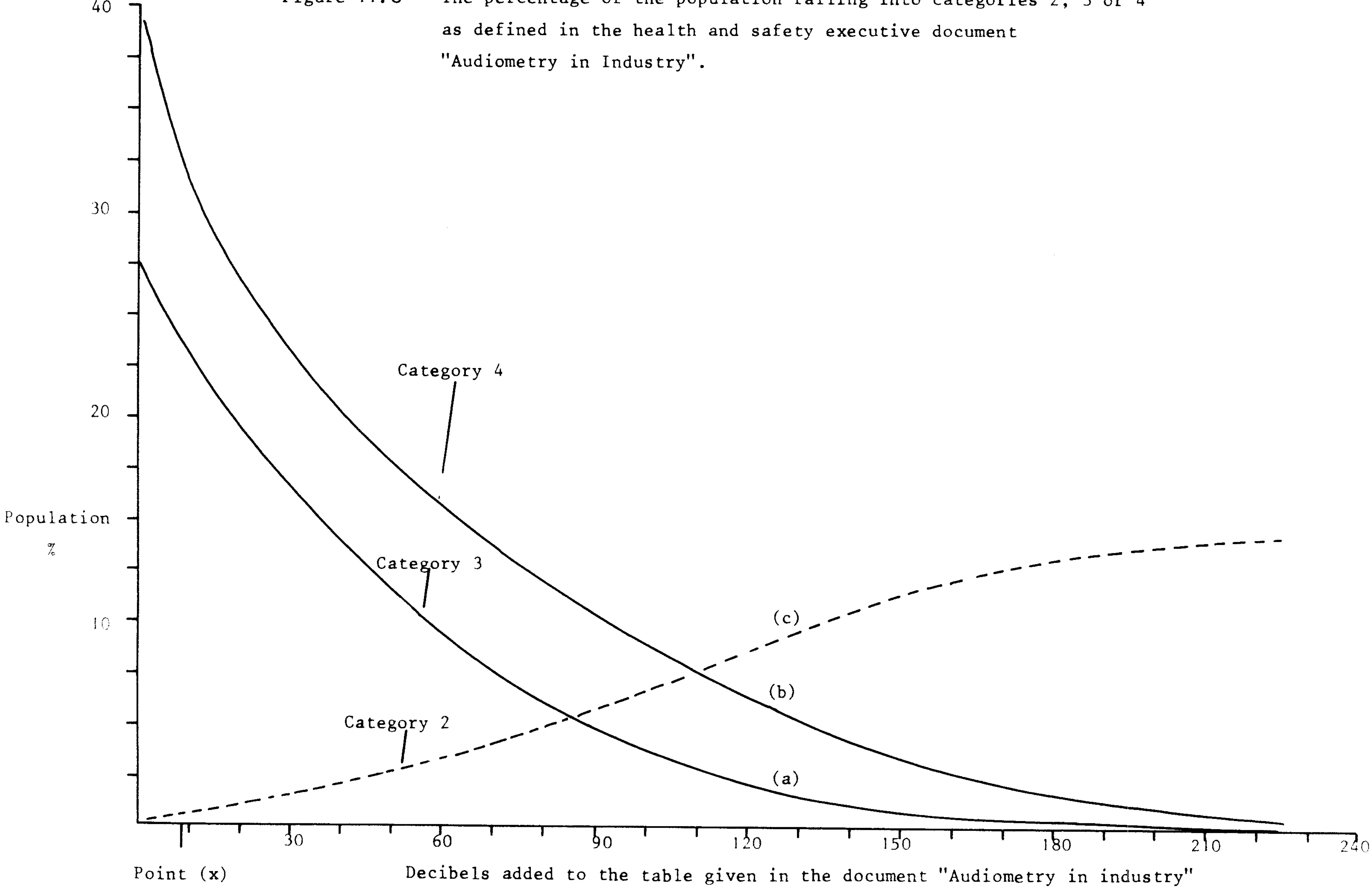
Table 11.10 The chart for the categorisation of hearing acuity given in "Audiometry in Industry" (H.S.E. 1978)

Sum of hearing levels				
Age in years	0.5, 1, 2 kHz Low frequency		3, 4, 6 kHz High frequency	
	Warning level Category 4	Referral level Category 3	Warning level Category 4	Referral level Category 3
20 - 24	45	60	45	75
25 - 29	45	66	45	87
30 - 34	45	72	45	99
35 - 39	48	78	54	111
40 - 44	51	84	60	123
45 - 49	54	90	66	135
50 - 54	57	90	75	144
55 - 59	60	90	87	144
60 - 64	65	90	100	144
65 -	70	90	115	144

Category 2 criteria

H.F. hearing acuity difference: 60 dB
L.F. hearing acuity difference: 45 dB

Figure 11.8 The percentage of the population falling into categories 2, 3 or 4 as defined in the health and safety executive document "Audiometry in Industry".



It is felt that the difficulty arises because the HSE warning level and referral level criteria are unrealistically stringent.

Normal hearing is defined in this thesis to lie between -10 dB HL and +20 dBHL. Using the discussion document criteria, an employee aged 24 years need only exceed the lower limit by 5 dB at 3, 4 and 6 kHz to be placed in the referral category. This relationship between the discussion document criteria and normal hearing plus an allowance for presbyacusis is maintained approximately throughout the age brackets, with a small relaxation towards the older end of the age spectrum.

The hazard to hearing represented by intense industrial noise is now recognised, but for many decades this was not the case. As a consequence a large group of industrial employees with auditory deficiencies now exists. Furthermore, the criteria given within "Audiometry in Industry" make no recognition of the level of hearing loss existing in the general population as a consequence of the action of many harmful agencies unrelated to industrial noise. These include recreational noise, various pathological conditions of the ear, service in the armed forces, and hereditary hearing loss. The analysis scheme described in the document "Audiometry in Industry" is striving to clear this audiometric "backlog" in one cycle of the programme of monitoring audiometry.

This strategy is against the interest of noise exposed employees, for the volume of individuals scheduled for re-examination will cause the audiometric programme to stagnate. The necessity to examine individuals with a relatively low hearing loss will also cause unacceptable delays in identifying and examining those employees in need of immediate attention.

It is thought that at this time the optimum procedure would be one which permits the progressive examination of employees in need of further medical attention, with those individuals exhibiting the worst hearing problems being investigated first.

Accordingly it was felt that the warning and referral criteria described in the discussion document should be revised. Such a revision need not affect the capability of the analysis strategy to protect the employee from receiving a noise induced hearing loss, for the criteria governing category

1 membership could remain unchanged, or be modified in a minor manner. In this way deterioration in hearing acuity between two tests would receive immediate attention.

Adding a constant decibel value to the referral criteria described in table 11.10 would have had the undesirable effect of biasing the age distribution of individuals falling into category 3 towards the older end of the range. This effect is the opposite to that which is to be desired.

In an analysis designed to achieve a more acceptable result, the 688 audiograms drawn from populations "P", "F" and "R" were subdivided into the nine HSE specified age groups.

A computer program was written so that the nine age groups were subjected to five computer analyses such that 0 dB, 20 dB, 40 dB, 80 dB and 120 dB were added progressively to the referral level values given in "Audiometry in Industry". The population referral percentages were calculated at each step. The results of these analyses are displayed in figure 11.9.

The intercept drawn at the 10% level, cutting the parameter lines, gave a guide as to the number of decibels which could be added to each of the referral values given in table 11.10 with the result that the worst 10% of each age group would fall into the referral category. Two main exceptions were made to this procedure of modification. Firstly, the referral criteria for the youngest age group were left unchanged so as to maintain their original stringency. Secondly those criteria relating to the 60-64 year age group were not changed by as large an amount as they should have been in order to reduce the age group referral percentage to 10%. This age group was numerically so small that a referral percentage in excess of 10% would be of no practical consequence.

The warning level criteria were altered by similar amounts, and the result of this tailoring process can be seen in table 11.11.

Finally the HSE recommended criteria for membership of category two were also altered as shown below.

Figure 11.9 SHOWING THE PERCENTAGE OF EACH AGE GROUP OF THE POPULATION FALLING INTO CATEGORY 3, AS DEFINED IN THE HEALTH AND SAFETY EXECUTIVE DOCUMENT "AUDIOMETRY IN INDUSTRY" THE PARAMETER SHOWS THE NUMBER OF DECIBELS ADDED TO THE TABLE GIVEN IN THE DOCUMENT.

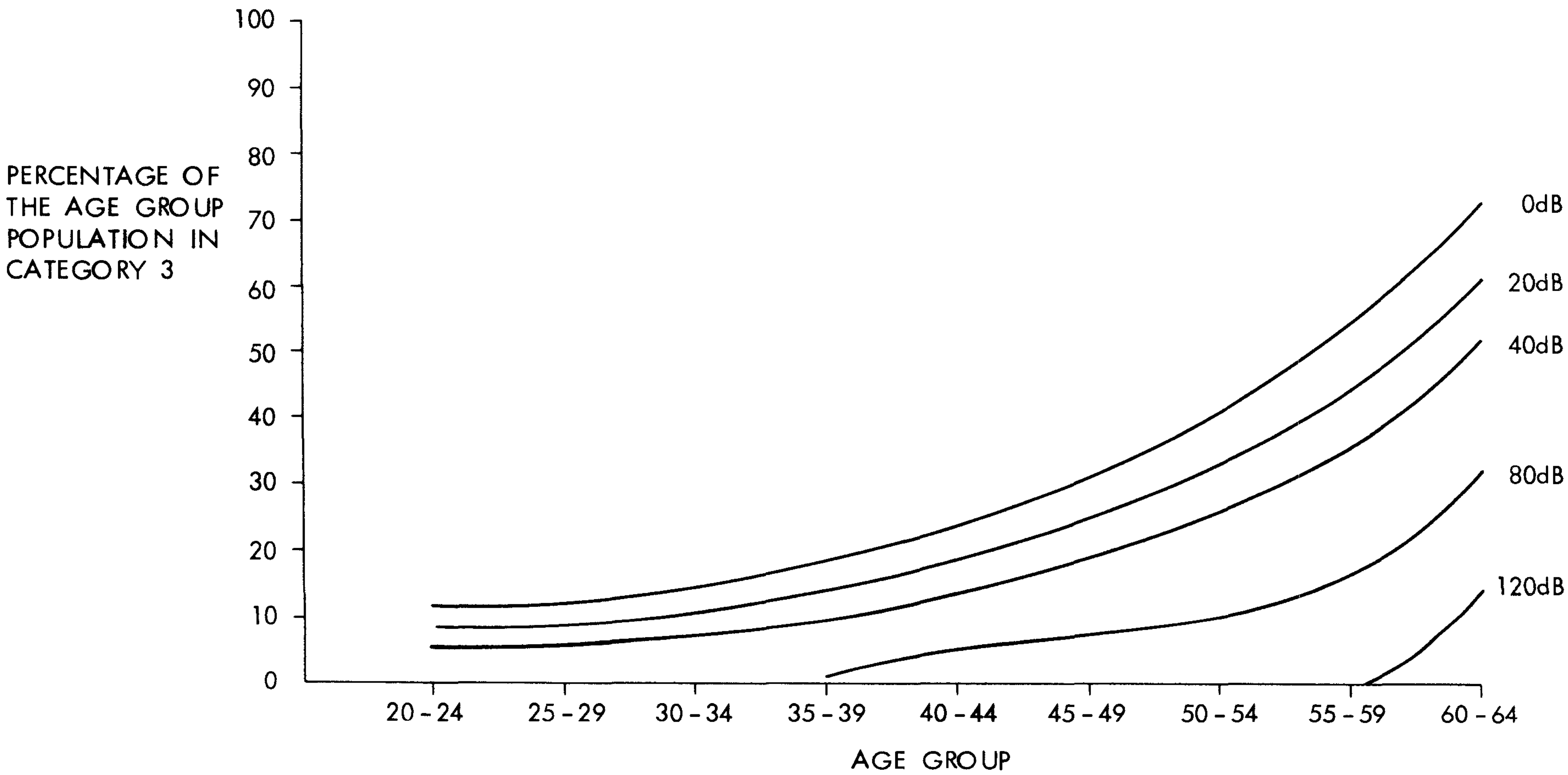


Table 11.11 The final table of referral and warning criteria developed fron those given in the discussion document "Audiometry in Industry (H.S.E. 1978)"

	Sum of hearing levels		Sum of hearing levels	
	0.5, 1, 2 kHz low frequency		3, 4, 6 kHz high frequency	
Age in years	Warning level Category 4	Referral level Category 3	Warning level Category 4	Referral level Category 3
20 - 24	45	60	45	75
25 - 29	66	87	66	108
30 - 34	75	93	75	120
35 - 39	99	117	105	150
40 - 44	120	144	129	183
45 - 49	123	150	135	195
50 - 54	147	171	165	225
55 - 59	171	189	198	243
60 - 64	176	189	211	243
65 -	181	189	226	243

Category 2 criteria

H.F. hearing acuity difference: 90 dB

L.F. hearing acuity difference: 75 dB

As membership of category 3 or 4 was set in the computer program to take precedence over membership of category 2, inspection of figure 11.8 shows that the incidence of employees exhibiting a one sided hearing loss and thus categorised 2, is approximately zero, if the criteria values remain unchanged from those specified in "Audiometry in Industry". Only when the values in the table defining entry into categories 3 and 4 are relaxed, as shown in figure 11.8, does the size of the category 2 component within the population become evident, at 14.5%. If for category 2 membership, the required difference between the two ears of the summated hearing losses at the three low frequencies is changed from 45 dB to 75 dB, and the corresponding high frequency criterion is changed from 60 dB to 90 dB, then the category 2 population percentage is reduced from 14.5% to 6.26%.

On this evidence it is felt that the original criteria for category 2 membership are too stringent, and are not detecting a true one sided hearing loss in a large majority of cases, but rather the condition in which probably both ears are deteriorating from some unspecified cause at differing rates.

The complete set of revised HSE criteria are shown in table 11.11. Audiograms from Wilton populations "P", "F" and "R" were then reanalysed using the revised criteria. The results of this work are shown in table 11.12. It can be seen that the desired effect has been achieved, with a referral level of 10.2%. The population percentage exceeding the warning level is still somewhat high at 15.6% giving a total follow-up percentage of 25.8%.

This is, however, substantially less than the unacceptable 67% falling into categories 2, 3, or 4 when the original HSE criteria values were used.

The Gloucester data were again utilised to test the general applicability and validity of the results derived on the Wilton population.

Table 11.13 compares the percentages of the Wilton and Gloucester populations falling into categories 2, 3, and 4 when the original, unrevised HSE criteria are used. The Gloucester population percentages are compared with their Wilton counterparts at the point x on figure 11.8. This effects the necessary 3 dB per frequency allowance between the results

Table 11.12 Analysis of Wilton population "P" + "F" + "R" audiometric data, using the HSE amended criteria given in table 11.11

Category	Exclusive Population % Wilton
2	0.72
3	10.20
4	15.59
n	686

Category 3 membership takes precedence over category 4 or category 2 membership

Category 4 membership takes precedence over category 2 membership.

Table 11.13 Comparison of the audiometric population percentages categorised 2, 3, or 4 on the Wilton and Gloucester sites using the original HSE criteria. The Gloucester percentages are compared with their Wilton equivalents at point (x) on figure 11.9 to allow for the 3dB difference per frequency between the hearing acuity measurements made using the manual Wilton audiometer and the automated Gloucester instrument.

Category	Exclusive Population % Wilton	Exclusive Population % Gloucester
2	0.4	0.17
3	22.9	21.53
4	32.5	30.60
n	686	1147
	Column 1	Column 2

Category 3 membership takes precedence over category 4 or category 2 membership

Category 4 membership takes precedence over category 2 membership.

of the Wilton manual audiometry, and the automated audiometry used in the Gloucester site.

The agreement between the Wilton and Gloucester results is remarkable, and would imply that the referral problem will be a national one if the criteria for membership of categories 2,3 and 4 are implemented as described in "Audiometry in Industry".

A further analysis was then performed to test the applicability on the Gloucester site of the new referral, warning and one-sided loss criteria developed for use on the Wilton Site.

Table 11.14 shows the result of this analysis, compared with those results of the same analysis performed on the Wilton site data. The manual to automated audiogram correction factor has been effected by adding 3 dB per frequency to the individual audiograms comprising the Gloucester data.

The correspondence of category 2 and 4 membership between the two sites is good, but the category 3 population percentages differ by approximately 5%. It can be concluded that the Wilton and Gloucester sites possess the same percentage of noise exposed personnel exceeding the normal limits of hearing acuity, but the amount by which these limits are exceeded is greater in the former than in the latter.

It would appear, therefore, that revised criteria could cause a smaller percentage to be referred than would otherwise be desired, without a commensurate reduction in the percentages falling into the warning category.

It seems that the frequency groupings used within the analysis scheme are such that it may be difficult to adjust the criteria values so that a reasonably constant ratio between the numbers referred and warned is maintained from site to site.

In this respect the evidence presented in section 11.10.3.2 suggests that the referral and warning criteria based upon BS 5330 and discussed in section 10.10.3.6 may be easier to develop to achieve the required end.

Table 11.14 Comparison of the audiometric population percentages categorised 2, 3, or 4 on the Wilton and Gloucester sites using the revised HSE criteria. The Gloucester site data has been corrected by the addition of the 3dB per frequency factor to permit direct comparison with the Wilton data obtained on a manual audiometer.

Category	Exclusive Population % Wilton	Exclusive Population % Gloucester
2	0.72	1.31
3	10.20	4.8
4	15.59	15.52
n	686	1147

Category 3 membership takes precedence over category 4 or category 2 membership.

Category 4 membership takes precedence over category 2 membership.

This latter method also possesses the advantage of involving simpler computations.

Conclusion

The referral and warning criteria defined within the discussion document "Audiometry in Industry" would appear to be too stringent for use in industry at the present time. The design of the scheme is such that it is not easily ammended.

As an alternative a simple fence value at 6 kHz would have to be set at an unacceptably high hearing level, possibly 50 dB, before this analysis procedure would present a usable audiometric action criterion.

A parameter based upon the ISO R1999 criterion of 25 dB loss averaged over 500 Hz, 1 kHz, and 2 kHz would appear to yield no real advantage over use of the BS 5330 criterion of 30 dB averaged over 1 kHz, 2 kHz and 3 kHz. It also suffers from the disadvantage that an unnecessarily low percentage of employees would be referred for further medical atttention, and of these a slightly higher percentage with a non noise induced hearing loss would be referred than would be the case if the BS criterion was used.

Moreover, the correlation betwen the results achieved using the BS and the ISO crteria is such that both would probably be equally good indicators of aural disability, even though the ISO criterion frequency band covers more of the important frequencies for speech. However, the use of the BS type criterion does remove the necessity to obtain accurate audiometric results at 500 Hz, a frequency at which experience has shown that it is usually difficult to meet the ambient noise requirements for audiometric booths. (Berry (1973), Health and Safety Executive (1978)). The BS type criterion does include 3 kHz, omitted by its ISO counterpart, but a frequency substantially affected by noise.

The BS type criterion yielded results which were practical to use, and produced similar effects in the two test populations.

It would appear that a set of BS type age corrected criteria, based upon a warning level set at 24 dB and a referral level at 30 dB would assist in the early detection of possible noise induced hearing loss, be simpler to use than the HSE type criteria, and yet offer a scheme which would not cause medical resources to become overstretched. Furthermore, hearing loss averaged over 1, 2, and 3 kHz was shown by Taylor (1972) to perform well as an indicator of aural disability. An index based on these frequencies was shown to be the joint second most successful test of impairment of six used on a group of 300 weavers. The six tests involved averages across different frequency bands, the most successful being the "Dundee Index" based on a combination of 2, 4 and 6 kHz. Taylor stated that use of a classification based on an average at 1, 2 and 3 kHz resulted in an underestimate of the numbers impaired compared to that obtained from utilisation of the "Dundee Index".

11.11 Overall Conclusions

The conclusion of each investigation detailed in this chapter has been discussed at the end of each section. However, the principal conclusions from each study have been brought forward to this section for ease of reference.

11.11.1 Drawn from section 11.4

Noise induced hearing loss exists in the Wilton population at such a level that it should be possible to use its existence to increase hearing protector usage.

The presence of substantial noise induced hearing loss in the Wilton population means that the responses of the employees to the attitude questionnaires were made after experiencing, in many cases, the permanent effect of noise upon the hearing.

Furthermore the proven existence of noise induced hearing loss in the population made their audiometric records an ideal database for analyses completed later in the chapter.

11.11.2 Drawn from section 11.5

Attendance for industrial audiometry should be mandatory in a hearing conservation programme. The daily test rate should be kept low, to maximise the educational effect in a plant or area. Two employees each day should suffice for this purpose.

11.11.3 Drawn from section 11.6

No evidence was found to suggest that those employees with the worse hearing losses would not attend for an audiometric test if the programme was voluntary. The audiometric data obtained during this study could therefore be taken as representative of the industrial population. Audiometric programmes relying upon voluntary attendance should not, therefore, repeatedly miss those employees with the worse hearing levels.

11.11.4 Drawn from section 11.7

More employees would miss their audiometric test appointment if this was scheduled during a shift than would miss their appointments if it was scheduled for the start of the shift. A good level of co-operation is required from foremen if an audiometric programme is to be concluded smoothly, and foremen must be kept well informed of the progress of work during the programme.

11.11.5 Drawn from section 11.8

The policy recommended by the HSE of allowing hearing tests to be conducted after the start of a shift, provided that employees make full use of hearing protection in the hours worked in noise before test, does not lead to an elevation in the measured population auditory threshold. This procedure can therefore be adopted during an audiometric programme.

11.11.6 Drawn from section 11.9

Eye colour is not a direct predictor of susceptibility to noise induced hearing loss. The tenuous relationships established during the present study, and others reported in the literature, are thought to be due to an undefined relationship which eye colour has with the true indicator of susceptibility.

11.11.7 Drawn from section 11.10

The HSE criteria described in "Audiometry in Industry" (Health and Safety Executive 1978) defining the levels of hearing loss at which certain follow-up actions are to occur after an audiometric test, are too stringent. Their use will lead to the hearing conservation programme falling into disrepute, and medical resources becoming overstretched. The criteria do not appear to be amenable to alteration so that they achieve comparable and more realistic results in different sites.

An alternative criterion based upon the average of the hearing loss in one or both ears at 1, 2, and 3 kHz is the most viable of the four possible criteria evaluated. A referral level of 30 dB, with a warning level of 24 dB, were found to be appropriate levels.

It is thought that the various studies reported in this chapter have successfully investigated the most important of those practical problems which could have caused difficulty when performing industrial audiometry as part of a hearing conservation programme designed to increase hearing protector usage.

CHAPTER 12

A SUMMARY OF THE MAIN RESEARCH FINDINGS AND A COMMENT ON THEIR IMPORTANCE AND IMPLICATIONS

12.0 Introduction

Having demonstrated the value of industrial audiometry in a Hearing Conservation Programme, the main research findings are drawn together in this final chapter, and some of the ideas are developed to show the optimum manner in which industrial audiometry should be conducted.

This work is described in section 12.2, together with comment upon the type of educational film which should be shown during a Hearing Conservation Programme.

Section 12.1 evaluates the hypotheses stated in section 1.4.1 in the light of the research findings. The final section in this chapter discusses the importance of the results of the research in relationship to the intention of the HSE not to introduce widespread industrial audiometry, and to relegate industrial audiometry to a low level of importance within a hearing conservation programme.

12.1 Evaluation of the study hypotheses

12.1.1 Hypothesis 1

Industrial audiometry can produce significant long term changes in attitudes held by employees.

Conclusion: Proven

Industrial audiometry was shown in chapter 9 to be capable of causing long term changes in attitude.

Comparing the attitudes held before and after treatment by means of the attitude questionnaire, showed that industrial audiometry had caused a positive change in employee attitudes towards the frequency of use of hearing protection, the hearing conservation programme, the sense of isolation caused by using hearing protection, and the deleterious effect of noise on behaviour.

12.1.2 Hypothesis 2

Education alone can produce a significant long term change in the attitudes held by employees.

Conclusion: Disproven

In the case of only one attitude scale, PROG, did the programme of education cause a long term change in attitude in both the treated plants. This particular scale is related to the manner in which the employee perceived the adequacy of the Hearing Conservation programme and is not obviously linked to whether or not he will use the protection provided or increase his efforts to preserve his hearing.

The programme of education did cause a change in attitude in one of the two plants on the scale COMPET, but this was thought to be a short term change apparent at the time the post treatment questionnaires were completed as a consequence of the late showing of the film to two of the four shifts.

12.1.3 Hypothesis 3

Industrial audiometry is more effective than education in causing long term changes in the attitudes held by employees.

Conclusion: Proven

On four scales, NONUSE, PROG, ISO and BEHAV both plants receiving industrial audiometry alone as a treatment showed a positive change in attitude towards the objectives of the hearing conservation programme. On only one of these scales, PROG, did the education programme cause the same effect.

Evidence was discussed in chapter 9 which showed that changes produced by the components of a programme of education were usually shortlived, and therefore of no lasting value to the hearing conservationist.

12.1.4 Hypothesis 4

Industrial audiometry plus education is more effective than either of the two components used singly to change the attitudes of employees.

Conclusion: Disproven

On no attitude dimension measured did the combination of audiometry and education prove to be more effective at changing attitudes than either audiometry or education used singly.

A positive change of attitude towards hearing conservation procedures was measured on only two scales, NONUSE and PROG, on plants on which both audiometry and education had been used as a treatment. On other scales substantial evidence was presented indicating that adding a strong component of education to a programme of industrial audiometry caused an overall reduction in the efficiency with which the audiometry could produce a positive attitude change.

12.1.5 Hypothesis 5

Industrial audiometry can produce long term changes in the behaviour of employees.

Conclusion: Proven

Section 9.2.2.3 showed that hearing protector useage increased substantially in those plants in which industrial audiometry was conducted.

12.1.6 Hypothesis 6

Education alone can produce significant changes in the behaviour of employees.

Conclusion: <u>Proven</u>

Section 9.2.2.2 showed changes in hearing protector usage which were ascribed to the effects of various education components of the hearing conservation programme. However, these changes were relatively short lived in nature.

12.1.7 Hypothesis 7

Industrial audiometry is more successful than a programme of education in changing the behaviour of employees.

Conclusion: <u>Proven</u>

Data given in chapter 9 showed that industrial audiometry caused a steadier increase in hearing protector usage than a programme of education. The effects of the components of such a programme of education tended to decrease fairly swiftly after their initial onset. The maximum gain in hearing protector useage, however, was the same in both cases.

12.1.8 Hypothesis 8

Hearing protector usage can be increased more effectively by a programme of industrial audiometry with education than it can by a programme of audiometry alone or education alone.

Conclusion: <u>Disproven</u>

Sections 9.2.2.3, 9.2.2.4, and 9.2.2.5 showed that the effects of the industrial audiometry and those of the education were not additive, and that the maximum gains made in those plants receiving both audiometry and education were less than those observed in certain of the plants in which either audiometry or education had been conducted singly.

It is apparent, however, that if education is combined with industrial audiometry, the increase in usage is smoother, and not prone to relapses. However, the discussion in chapter 9 commented upon ways in which industrial audiometry could be organised to give a smoother increase in hearing protector usage than was observed in the present study.

It is not thought possible that the same effect can be achieved with programmes of education without making them prohibitively expensive.

12.2 The manner in which audiometry should be conducted in a Hearing Conservation Programme, and a discussion of the main research findings

Leventhal (1965(b)) studied attitude and behavioural change towards having a tetanus injection, by arousing in subjects a fear of the possible consequences of not having the injection. He noted that specific information alone on the topic was insufficient to cause behavioural change, but that the information needed to be supported by fear-arousing communication. In the present context, therefore, it is suggested that a Hearing Conservation programme utilising industrial audiometry should commence with a simple film giving the specific information relating to noise induced hearing loss, and that feedback of the audiometric results should be arranged to maximise the necessary fear-arousing stimulus. Lack of feedback of the audiometric results in the present study has already been discussed, sections 9.2.4 specifically suggesting that feedback of the results would have increased the behavioural response to industrial audiometry.

The importance of feedback of the audiometric results is best evaluated by examining the three most crucial variables in fear appeal, as specified by Rogers (1976). These are (a) the magnitude of noxiousness of a depicted event (b) the conditional probability that the event will occur provided that no adaptive activity is performed, and (c) the effectiveness of a coping response that might avert the noxious event.

The brief discussion between the audiometrician and the employee at the end of the audiometric test in the present study and also information imparted during the film where applicable served to indicate the noxiousness of the depicted event. However, lack of authoritative and quantitative feedback of the audiometric results prevented employees from being able to assess the conditional probability that the event, industrial deafness, would occur. Additionally lack of feedback of the results of the second audiometric test in the monitoring series made it more difficult for an employee to assess the effectiveness of the coping response, which in this case was the increased utilisation of hearing protection.

Application of the three criteria given above indicates that the fear appeal of industrial audiometry would be increased by feedback of results. It is an expression of the power of industrial audiometry to increase protector usage that it was found in the present study to be capable of producing this effect, despite the lack of feedback.

The third of the three criteria, the effectiveness of the coping response, deserves further evaluation in the light of work by Rogers (1975).

This author shows, as a result of general experimentation in the field of fear arousal, that if industrial audiometry is to have the desired effect of increasing hearing protector usage then the suggested film giving specific information, described earlier in this section, must stress the effectiveness of the use of hearing protection in preventing noise induced hearing loss. If this is not achieved, Rogers shows that "regardless of the noxiousness of a threat, when expectancy of exposure to a threat is strongly aroused, but not fully relieved by belief in the efficiency of the recommended coping response, individuals may resist the communicator's recommendation". Leventhall (1970) even suggests, after a review of the literature, that this resistance may extend to the taking of the reverse action from that desired by the communicator.

Leventhall (1965(b)) in the previously described study, examined the relationship between fear arousal and behavioural response, in terms of success in persuading students to have tetanus vacinations. This author found that although the fear arousal techniques caused changes in attitude, significantly more students had the vacinations when they were given specific recommendations on how these could be obtained, compared to the number of students asking for a vacination when only general recommendations were issued. Leventhall also stated that "specific information alone is insufficient as action is influenced only when specific information is combined with one of the fear-arousing communications"

The various works described above, therefore, indicate that the efficiency of industrial audiometry to cause behavioural change in hearing protector usage would be greatly improved if the industrial audiometry was accompanied by highly specific information on the steps to be taken by the employee to prevent noise induced hearing loss, and strong assurance that these steps would be effective. In all probability the most cost effective method of achieving this would be the production of a special booklet to accompany the audiometric test. This booklet could also be used by the audiometrician at the end of the audiometric test as an aid memoire with which to conduct the necessary post-test discussion.

It was concluded in chapters 9 and 10 that attitudes towards the conservation of the hearing had changed in response to the content of the stimuli, but that it was most likely that the observed behavioural changes were more directly linked to changes along a general attitude dimension, and caused by the frequency of occurrence of the stimuli. Specifically, it was thought that the behavioural change brought about by the type of audiometry used in the present study was linked more firmly to the onset of the various stimuli than to the attitudes formed by the content of the stimuli themselves. Discussion above suggested that the lack experienced by employees of a precise plan of action, and proof of the effectiveness of hearing protection reduced the efficiency with which the long term attitude changes engendered by the audiometry were translated into long term behavioural changes. Now that this lack has been identified, it can be easily remedied to improve the efficiency with which industrial audiometry can cause behavioural change.

The somewhat peaked, but otherwise excellent, behavioural response to the audiometry used alone as a treatment is thought to have occurred because employee interest in the stimulus represented by the audiometric activity waned slightly on occasions.

This underlines the importance of translating the positive attitudes formed into behavioural change to reduce the reliance upon the frequency of stimulus to cause an increase in hearing protector usage. Prolonged reliance upon the effect of repeated stimuli to maintain or increase protector usage would probably end in expensive failure, as demonstrated in part by the unconvincing performance of education alone as an experimental treatment.

A secondary theory was advanced in chapter 10, to explain the experimental results. It may only be necessary to change one key attitude to cause the required behavioural change. The attitude most likely to be such was ientified as that measured by the scale NONUSE. Two items of significance contained within that scale measure the likelihood that the employee would simply forget to take hearing protection onto the job with him, and the personal assessment made by each employee of the subjective loudness of the noise in which he was required to work. These two factors could provide areas in which a hearing conservationist wishing to increase hearing protector usage could concentrate effort.

The education used as a treatment was unsuccessful in causing long term attitude changes, although it is apparent that it may have caused short term changes. It was, however, capable of causing behavioural change with little latency, but this change decayed swiftly. Typically the effect of the film decayed within 2-3 months, the effect of the posters within 6-7 months, and the effect of the combined film and poster campaign decayed within 10 months. It is likely that education could cause the same behavioural changes as audiometry, but repeated and varied stimuli would be required, a problem which is discussed later in this section. The solution is shown not to be cost effective.

The addition of education to audiometry to form the combined treatment appears to have limited the success of audiometry in changing attitudes. It is also apparent that the behavioural result of the combination of audiometry and education was not the summation of the effects of the individual components. Indeed, the maximum gain achieved by the combined treatment was 10% less than that noted in response to either audiometry alone, or components of the education programme alone. Work described in chapters 9 and 10 indicated that a delicate balance must be preserved between too many stimuli in a Hearing Conservation programme, and too few. Application of the results of the research programme described in this thesis allows a balance to be defined btween the relative amounts of industrial audiometry and education which should be undertaken during a Hearing Conservation programme, and is discussed below.

Education is an expensive component of any Industrial Safety programme. It necessitates the withdrawal of employees in groups from the workplace to hear talks or watch educational films. Withdrawing labour in blocks will affect production in a way that releasing individuals for audiometric test will not. Additionally education sessions usually necessitate managerial supervision even if the session is conducted by a member of the medical or para-medical staff, again increasing expense. By way of a contrast industrial audiometry requires only that employees be released individually for test, and does not required managerial supervision. The results of the present study indicate that educational sessions would need to be repeated at least twice each year if they were to be successful, and that posters would lose their effectiveness even if changed regularly. It is not even certain that education on the hazard represented by industrial noise could be given such a continuously high priority throughout a year, in view of the other industrial hazards needing similar attention.

Furthermore, expenditure on programmes of education results in only one outcome: an educated workforce. Even this is open to some question in view of the lack of significant long term attitude change caused by the education programme used in this study. In contrast, however, industrial audiometry yields other benefits of a medical nature in addition to providing the final check on the efficiency of the hearing conservation programme.

Given the above facts and that the results of this study have shown industrial audiometry to be a more powerful method than education by which to cause attitude change, and that audiometry produces steadier changes in hearing protector usage than a programme of education, but has its attitude changing efficiency reduced when coupled with standard programmes of education, then it can be concluded that a good Hearing Conservation programme should rely mainly upon industrial audiometry to increase or maintain hearing protector usage. The standard educational component in such a programme should be reduced to a minimum.

Programmes of education will always be necessary in Hearing Conservation, but in view of the findings of the present study, these should be designed to pass to the workforce basic facts concerning hearing and industrial deafness, the maintenance of hearing protection, and safe working practices aimed at reducing noise exposure. The emotive part of such a programme, designed to change the attitude of the employee so that he takes steps to conserve his hearing, should be deleted. Such reduced programmes of education could be run less frequently than would be the case for attitude changing education programmes, and may lend themselves to a greater number of different formats.

Less frequent education sessions would also lessen the observed tendency of education components to reduce the effectiveness of audiometry in changing attitudes, when both are undertaken together. Additionally, the cost saving could be used to fund the audiometric programme.

The main purposes of the work described in this thesis were twofold. Firstly to investigate the capacity of industrial audiometry to change attitudes towards the conservation of the hearing, using carefully developed attitude scales and involving a general industrial population of over 2000 employees working in 20 plants or areas within one site. Secondly, to investigate the power of industrial audiometry to increase hearing protector usage. Throughout the study comparisons were made between the ability of audiometry alone, audiometry with education, and education alone, to cause atttitude and behavioural change. Additionally however, other studies were completed during the research programme, designed to evaluate certain counterforces acting to reduce the efficiency with which audiometry could increase hearing protector usage.

Results drawn from the Pilot Hearing Conservation study indicated that one such major factor was discomfort experienced by employees when wearing earmuffs, the main type of ear defender used on the site. Accordingly a study of earmuff comfort was undertaken, described in chapter 4, which resulted in a specification for a comfortable earmuff. This specification was adopted by the British Standards Institution, and now forms the core of the recently published BS6344.

The need for well designed hearing protection was also revealed in chapter 3 where it was shown that approximately 75% of users removed their hearing protection for periods during the working day to alleviate auditory problems caused by wearing them. Audiometric records were used to establish a link between poor hearing thresholds and the probability of experiencing auditory problems when using hearing protection, a relationship hitherto suspected, but not proven in the literature.

Additionally, the audiometric records obtained during the research programme, which numbered approximately 1000, were analysed, to evaluate any factors which could make difficult the running of a programme of industrial audiometry in industry, or affect its outcome.

The analysis indicated the presence of substantial noise induced hearing loss in the Wilton population and also showed that the decision to attend for the voluntary audiometric test was not a function of the degree of hearing loss possessed by an employee. This later finding goes some way towards answering critics of other large scale industrial hearing loss surveys performed on a voluntary attendance basis, showing that their claims of possible bias are unfounded.

However, analysis of the numbers attending for audiometric test in the present study indicated that this should be made compulsory in future Hearing Conservation programmes if the full value of the test as a means of changing attitudes and behaviour is to be realised. Feedback of the audiometric results to employees is essential, and numbers tested each day should be kept low to enhance the stimulus value.

Analysis of group auditory thresholds justified the HSE recommendation for mid shift testing of employees using hearing protection in the hours before test, as no evidence of disturbance of thresholds by TTS could be detected in these employees. However, a smaller percentage of individuals attended for a mid-shift test than attended for a pre-shift test, indicating the need for the greater involvement of foremen in the aims and objectives of the audiometric programme, irrespective of whether or not attendance for a test was made compulsory.

Eye colour was shown not to be an index of susceptibility to noise induced hearing loss. The tenuous link detected during the research programme was thought to suggest that eye colour was itself loosely linked to the true determinator of susceptibility.

The problem of the medical management of the employee after the audiometric test is one which is central to the success of an audiometric programme. Data from the Wilton site and one additional ICI site were used to evaluate the HSE criteria for audiometric classification and subsequent action after an audiometric test. The HSE scheme was shown to be too stringent. Use of this scheme would lead to stagnation of the hearing conservation programme if it were to be applied by industry unaltered.

Several other possible analysis schemes were evaluated. The method which showed the best potential was based upon the average hearing threshold over the frequencies 1, 2 and 3 kHz.

12.3 Comment upon the value of the conclusions of the research work

Sections 12.1 and 12.2 have drawn together and discussed the conclusions drawn from the research work. In summary, the results of the main experiment showed that Industrial Audiometry is a good tool for improving attitudes and behaviour towards the conservation of hearing in noisy industries. It is felt that the information presented in this thesis should assist in reaching a decision upon the level of industrial audiometry to be required of UK industry under the new legislation which is to be promulgated in response to the 1986 European Directive regulating industrial noise.

Tasked with producing the draft of this legislation, the HSE has stated "however, such legislation (the introduction of widespread audiometry) needs to be supported by solid evidence that extensive compulsory audiometry would actually deliver the benefits that its advocates claim. Such evidence is difficult to obtain. The HSE is continuing to seek information on the uses that have been made of the results of audiometry programmes which have been run on a voluntary basis (some of which have now been running for over twenty years) and how these have benefited workers". (Dove 1985). It is felt that the work described within this thesis has demonstrated the value of industrial audiometry when used to improve attitudes and behaviour towards the conservation of hearing in noisy industries. As indicated by the conclusions discussed in section 12.2, audiometry could form the major part of any hearing conservation programme with a consequent reduction in the need for constant, and expensive, repetition of "propaganda" type education. This must weight any cost benefit analysis of the value of audiometry towards the conclusion that it is a worthwhile component of a hearing conservation programme.

Simply including industrial audiometry in a hearing conservation programme, however, will not automatically bring the benefits described in the previous paragraph. If maximum effectiveness is to be achieved, well trained audiometricians are required, capable of providing the feedback of audiometric results in a sensitive manner designed to encourage the usage of hearing protection. Such audiometricians or designated individuals, must be capable of dealing with, for example, a minority of noise exposed employees who may suffer no apparent deterioration in auditory ability and yet claim not to be using hearing protection. Audiometricians, therefore need to be well advised of the "missionary" value of industrial audiometry, and be able to use facts concerning the more insiduous effects of noise exposure upon health and auditory ability, to encourage hearing protector usage even within the difficult group of employees described above.

An officially recognised training programme for audiometricians should be established, together with an agreed Code of Practice dealing with audiometry and the maintenance of audiometric equipment, so that variability in audiometric measurements can be minimised. Additionally, sensible analysis schemes for audiometric data are required if audiometric programmes are not to stagnate or lose their credibility, as was discussed in Chapter 11. The development of such analysis methods is thought to be the most fertile area for further research.

It is not felt that further large scale attitudinal studies similar to that described in this thesis would offer cost effective use of research time. Instead some of the attitude scales developed during the present study could be used to assess the value of particular educational films or other hearing conservation training material. Using the scales on selected employee groups before and after expesure to the material and repeating the experiment with alterations in the educational material on each occasion, would permit eventual refinement.

Research effort should also be expended in addressing once again the question of the test/retest reliability of audiometric measurements. The design of industrial audiometers has progress greatly since the research work of other authors, discussed in Section 1.2.4.1, was conducted. Particular examination should be made of the improvement in test/retest reliability which should be achieved by use of one of at least two microprocessor-driven audiometers available on the UK market. These check the validity of the trace obtained and repeat any audiogram sections not meeting the HSE defined criteria of reliability.

A most important topic for further research, however, could be the examination of the proposition that industrial audiometry together with the issue of hearing protection provides a safety system of work. The value of a positive result in such a research project would be profound. It would mean that UK industry could not be required to implement noise control at source, if reasonably practicable, ahead of the issue of hearing protection as a solution to the problem of excessive noise exposure. Ruheman (1984) confirms this point, quoting solicitors acting for the Health & Safety Executive. Certainly the results described in this thesis suggest that combining the issue of hearing protection with a programme of industrial audiometry would help greatly to ensure that the strategy succeeded, by increasing protector usage. Additionally it has already been stated within this thesis that the results achieved by the programme of industrial audiometry would probably have been improved had the official feedback of audiometric results to employees been permitted. Drawing together all the above points would suggest a full research programme designed to evaluate whether audiometry performed using modern audiometers with the audiometric results being returned via a doctor or well trained audiometrician to the employee could, in association with the issue of hearing protection, ensure a safe system of work in a noisy environment.

The results of such a programme would be of value in drawing up the new UK legislation, the final form of which is awaited with interest. Dove (1985) of the HSE, and Cullen (Health and Safety Commission 1986) both suggest that industrial audiometry will have a relatively low level of importance in a hearing conservation programme. The 1986 European Directive requirement for industrial audiometry to be made available to employees exposed to LA_{eq} levels of 85 dB(A) and above would be met by referring such employees to their General Practitioners for a hearing test, to be conducted within the National Health Service system. An article discussing this attitude has been published by the author of this thesis, and is shown in Appendix 11.7 (Karmy 1986).

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APPENDIX

CONTENTS

Appendix 2.1

TGWU

Transport and General Workers Union

TRANSPORT HOUSE SMITH SQUARE WESTMINSTER LONDON SW1P 3JB

OUR REF ACB/FS/15444/3/H TELEPHONE 01-828 7788 TELEGRAMS 'TRANSUNION LONDON SW1' TELEX No 919009

YOUR REF 28th November, 1974

LEGAL DEPARTMENT
Secretary: A. C. BLYGHTON

Mr. John Grace,
16 Garvin Close,
Middlesbrough,
Yorkshire.

Dear John,

OCCUPATIONAL DEAFNESS

Thank you for sending me the documents that have been received from the Southampton University in respect of their Hearing Conservation Research Programme. This is very interesting and I would recommend that full co-operation be given to the University in regard to their researches. These people are recognised as probably the world's foremost authority on industrial deafness and, obviously, they require answers to their questions in order to assess:

(a) the history of exposure to noise

(b) the difference between the wearing and non-wearing of protection in relation to degrees of deafness that they may find in our members.

I think that this is a good step to take but, of course, if anything results which is not satisfactory to us please do not hesitate to contact me although I doubt very much whether this will happen apart from the odd man who might have hearing which has deteriorated and which the employers may not like to prolong further in respect of exposure to noise. If such a situation develops I know that your own approaches will be adequate enough to ensure that the individual will not suffer.

With best wishes.

Yours sincerely,

Albert Blyghton

SECRETARY: LEGAL DEPT.

General Secretary J. L. JONES, M.B.E. *Asst. General Secretary* C. H. URWIN

A2.1 Letter received by a Wilton Union official from the T and GWU.

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH
Telephone 559122

HEARING CONSERVATION UNIT

HEARING CONSERVATION RESEARCH PROGRAMME

In association with I.C.I., Wilton, and Amplivox Ltd.

PRIMARY QUESTIONNAIRE

To be completed by Interviewer

SECTION A

Name of Interviewer ____________________ Subject Code No ____________

Age ____________

Date ____________

Present Occupation

A1 (i) Location of Work ____________________

Status ____________________

Nature of Work ____________________

How long have you been working in your present job ________

Do you consider your job to be in a noisy area ________

Previous Occupation

(ii) Have you ever worked at any job which had a noisy environment, either at ICI or elsewhere?

Type of Job	Duration in Years	Did you have to shout to make yourself heard?		
		All of the time	Some of the time	Never

A3.1 Hearing conservation study questionnaire.

(iii) Has an apprenticeship ever been served? YES/NO

A2 (i) Have you ever fired guns, rifles or pistols? YES/NO

What kinds? ______________________

(ii) When? __________ How many rounds of each? 10/100/1000/10,000

Did you wear hearing protectors? ______________________

(iii) Were there any immediate after-effects on your hearing?

State ______________________

A3 (i) Have you any noisy hobbies? Shooting/Band or Orchestra playing/ motor cycling/motor racing/anything to do with pop music/others.

(ii) Duration? __________ Did you wear any form of hearing protection? ______________________

(iii) Have you noticed any immediate after-effects on your hearing?

State ______________________

(iv) Have you ever been exposed to a severe explosion? YES/NO

SECTION B

Audiological Examination

B1 (i) Do you consider your hearing ability to be average? YES/NO

(ii) Have you suffered from: Excess wax, Discharge, Abscesses in your ears? ______________________

When? Childhood (Do not state age) ______________________

Adult (State age) ______________________

(iii) Do you suffer from Otosclerosis L ______ R ______

Ménières Disorder L ______ R ______

Other ear disorders? (state) L ______ R ______

(iv) Is there a family history of deafness? YES/NO

Which relatives? ______________________

B2 (i) Have you suffered from Measles/Mumps/Chicken Pox/Scarlet Fever/ Meningitis?

When Childhood (Do not state age) ______________________

Adult (State age) ______________________

(ii) Have you ever received a serious head injury? YES/NO

When? ______________________________

(iii) Have you ever received Streptomycin? YES/NO/DON'T KNOW

(iv) Have any of the above had any effect upon your hearing? YES/NO

State ______________________________

B3 (i) Tinnitus: Have you ever had ringing, whistling, singing or hissing in your ears lasting more than a few moments? YES/NO

(ii) If so, is there/was there any particular time or event associated with onset? ______________________________

B4 (i) Have you had an audiometric test before? YES/NO

SECTION C

Description of Working Area

C1 (i) Do you work indoors/outdoors/both

If both, give percentage of time Indoors ______ Outdoors ______

(ii) Work temperature. Ring the most appropriate:

Inside Cold/Warm/Hot/Seasonal/Intermediate

Outside Cold/Warm/Hot/Seasonal/Intermediate

Are you subjected to high levels of radiant heat?

YES/NO/SOMETIMES

(iii) Is the working area (very humid; normal; very dry)

(very dusty; dusty; not dusty)

(clean, mildly dirty; very dirty)

Ring one in each group.

(iv) Does the work involve little physical effort/some physical effort/much physical effort.

(v) Do you work as part of a team? YES/NO

SECTION D

Hearing Protectors

D1 (i) When in a noisy environment do you wear hearing protectors all the time; most of the time; half the time; some of the time, little; never?

If you answered some, little or never, why? ____________________

____

In the past have you worn hearing protectors when in a noisy environment all the time; most of the time- half the time; some of the time- little; never?

If you answered some, little or never, why? ____________________

____

If you started to wear hearing protectors, but then stopped, state why.

____

(ii) What factors do you think ⌣eter people from wearing hearing protectors?

____

____

D2 If hearing protectors are/were worn

(i) How long did it take you to become accustomed to using hearing protectors?

____

(ii) Did/do you use earplugs or earmuffs? ____________________

Can you identify their types?

Type	Comfortable	Uncomfortable	FIT			If uncomfortable, why?
			Tightly	Well	Loosely	

(iii) Have you any further comments/problems with your hearing protectors not mentioned so far?

____

____

D3 (i) Are there any audio warning signals at your place of work? YES/NO

When wearing hearing protectors do you think your ability to hear warning sounds is: UNCHANGED/MADE WORSE/MADE BETTER

(ii) Do you have to use your ears to judge the direction from which a sound comes whilst working? (e.g. mobile machinery) YES/NO/SOMETIMES

If you answered 'YES' or 'SOMETIMES', do you think that the presence of hearing protectors affects your ability to do this? YES/NO

If this is so, do you ever remove your hearing protectors for a time to overcome this difficulty? YES/NO Duration __________

(iii) Is the sound of the noise made by your machine/plant important to you in deciding if it is functioning properly? YES/NO

If you answered 'YES' do you think that the presence of hearing protectors affects your ability to do this? YES/NO

If this is so, do you ever remove your hearing protectors for a time to overcome this difficulty? YES/NO

D4 (i) After putting on hearing protectors whilst working, do you think your ability to communicate with your colleagues is then: IMPROVED/WORSENED/UNCHANGED.

If worsened or unchanged, do you remove them in order to communicate YES/NO

(ii) Have you noticed any improvement in your hearing since wearing hearing protectors? YES/NO State __________________________

Have you noticed any beneficial effects since wearing the hearing protectors? (e.g. less tired, reduction of tinnitus, etc.) YES/NO State ____________________________________

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH Telephone 559122

25th March, 1975

Dear Sir,

SURVEY OF INDUSTRIAL NOISE AT WILTON SITE, MIDDLESBROUGH

May I ask for your help in a survey we are conducting? We are trying to find out some facts about people's attitude to noise and hearing protection in Industry.

I am sending this letter to you and a cross-section of people chosen at random from the payroll at Wilton Site, asking you to give me your opinions.

To make sure that we hear all points of view, we are anxious to get a reply from each person to whom we write. I hope you will be willing to co-operate.

You will find the questions on the enclosed questionnaire. Would you please fill in your answers and either send it back to the Medical Centre, Wilton Site, or bring it back personally to the Medical Centre.

All replies will be kept strictly confidential and will be analysed at Southampton University.

Please note that it is your own view that we want. Do not ask anyone else to answer the questionnaire instead of you, or we will not have a true section of opinions.

We should be grateful for your help.

Yours faithfully,

Steve Karmy

S. J. KARMY

This program has been approved by the Senior Shop Steward's Committee and the Management. Information from individual respondents will be confidential to Southampton University.

A7.1 Letter accompanying the pilot questionnaire.

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH Telephone 559122

SK/dmh

September 1975 .

Dear Sir,

Could I remind you about the questionnaire that I sent to you some time ago? As yet I have received no reply from you. I have enclosed a fresh copy of the questionnaire in case you have mislaid the original.

It is very important to us that everybody completes the questionnaire. May I ask you to help us by filling out the questionnaire and returning it to the Medical Department at Wilton.

Yours faithfully,

S. Karmy

S.J. KARMY

Encl:

A7. 2 Reminder letter for the pilot questionnaire

A 7.3 Skew and kurtosis values for various sample numbers and probabilites.

	Skew *		Kurtosis			
n			Lower tail		Upper tail	
	1%	5%	1%	5%	5%	1%
25	1.06	0.711	1.78	2.00	4.14	5.42
86	0.575	0.418	2.224	2.305	3.826	4.502

* Skew 1% and 5% values represent 2% and 10% two tailed test values

INDUSTRIAL NOISE AT WILTON SITE

Please state your age . ____________________

and the type of job you do ______________________________

Which plant do you work in? ______________________________

Questionnaire No. ______________

Please think carefully about the following questions. Indicate your answer by putting a tick in the appropriate box. An example is given below:

		Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
Example: Safety helmets are necessary		✓				
1. The area in which I work is noisy enough for me to need to wear hearing protection.	NEN	37.4	39.3	13.1	10.3	0.0
2. I like working in noise.	LIKE	0.9	0.0	8.4	28.0	62.6
3. It does not take long to get used to the noise at work.	USED	1.9	25.2	14.0	36.4	22.4
4. I wear hearing protectors only when the noise levels are very high.	NHIGH	4.7	43.9	4.7	31.8	15.0
5. The loud noises only last a short time, so there is no point in wearing hearing protection.	SHORT	0.0	2.8	2.8	52.3	42.1
6. Working in a noisy area makes me feel irritable or depressed.	IRIT	12.1	33.6	34.6	17.8	1.9
7. If the noise was not so loud, I could get a lot more work done.	LOUD	3.7	22.4	34.6	36.4	2.8
8. I have not worn hearing protection in the past, so I can see no reason to start now.	PAST	0.0	1.9	4.7	44.9	48.6
9. Wearing hearing protection will not prevent my hearing from being damaged by loud noise.	NGOOD	0.9	10.3	10.3	41.1	37.4
10 If I work in a loud noise, wearing hearing protection some of the time should be sufficient to protect my hearing.	SOME	0.0	12.1	4.7	50.5	32.7

A 7.4 Pilot attitude questionnaire. The question mnemonics are shown together with the responses from the 107 employees, given as percentages.

	Statement	Code	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
11	When working in a loud noise I should wear earmuffs and Bilson Down together to give sufficient hearing protection.		–	–	–	–	–
12	Bilsom Down on its own gives enough hearing protection when I work in a loud noise.	BILS	0.0	25.2	20.6	44.9	9.3
13	Earmuffs give sufficient hearing protection: there is no need to use Bilsom Down as well.		–	–	–	–	–
14	I prefer to use the rubber plug type of hearing protector.		–	–	–	–	–
15	Hearing protectors are efficient at keeping out the noise.	EFF	7.5	69.2	11.2	7.5	4.7
16	When I wear hearing protectors I feel enclosed in a world of my own.	ENC	13.1	41.1	17.8	27.1	0.9
17	People who wear hearing protectors have just not got the stamina needed to work in noise.	STAM	0.9	3.7	3.7	43.0	48.6
18	Wearing earmuffs makes me feel conspicious.	CONSP	0.0	14.0	13.1	61.7	11.2
19	Going deaf is something that I worry about.	WORRY	28.0	40.2	26.2	5.6	0.0
20	Most people go deaf when they get older, so why worry about a little extra deafness now ?	PRESB	0.9	1.9	5.6	42.1	49.5
21	I will only take steps to protect my hearing if I think I am going deaf.	STEPS	1.9	2.8	1.9	44.9	48.6
22	Going partly deaf would prove to be a handicap in my social life.	SHAND	51.4	39.3	3.7	4.7	0.9
23	My family would not mind if I became partly deaf through working in noise.	FAMI	5.6	0.9	5.6	24.3	63.6
24	The partly deaf person would have difficulty in finding and keeping a job he wanted to do.	JHAND	25.2	51.4	19.6	2.8	0.9
25	The partly deaf person is a hazard to himself on most jobs around the plant.	WHAND	20.6	39.3	23.4	14.0	2.8
26	People become worried about the prospect of noise sending them deaf.	NDEF	15.9	53.3	24.3	6.5	0.0
27	Being partly deaf would not prevent me from doing my job well.	PDEF	2.8	38.3	15.0	32.7	11.2

No.	Statement	Code	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
28	Being partly deaf would ruin the enjoyment I get from most things in life.	ENJ	40.2	47.7	7.5	3.7	0.9
29	Noise damages your hearing.	DAMAGE	72.0	26.2	0.9	0.9	0.0
30	In my experience, most people's hearing appears to be immune to damage from noise.	IMM	2.8	8.4	15.9	29.9	43.0
31	I have seen no evidence that noise damages the hearing, and so do not believe it.	EVID	0.9	0.9	9.3	33.6	55.1
32	The people who are carrying out this campaign are doing a worthwhile job.	WORTH	45.8	36.4	13.1	0.9	3.7
33	Anybody who tries to get me to wear hearing protectors is wasting their time.	WASTE	0.0	0.0	3.7	40.2	56.1
34	The management is carrying out this noise safety campaign.	MANAG	7.5	36.4	29.9	25.2	0.9
35	The people who are carrying out this noise campaign have probably never worked in noise - so what do they know about the problems?	THEOR	2.8	8.4	46.7	37.4	4.7
36	The Southampton University research team have a lot of control over this noise safety campaign.	STON	2.8	27.1	61.7	7.5	0.9
37	The Southampton University research team are being employed by the Management to carry out this noise safety campaign.	SEMPLY	4.7	29.0	47.7	16.8	1.9
38	I think this noise campaign could be run better.	BETTER	5.6	12.1	64.5	16.8	0.9
39	The safety people are paying too much attention to the problems of noise.	ATTEN	0.9	0.0	4.7	53.3	41.1
40	I should not be pressurised into wearing hearing protection.	PRESS	1.9	21.5	15.0	42.1	19.6
41	I.C.I. are making a good job of the noise safety campaign.	GJOB	10.3	52.3	27.1	9.3	0.9
42	I.C.I. is concerned about my health.	ICIH	15.9	64.5	11.2	6.5	1.9
43	The company wants me to wear hearing protectors to cover themselves against any legal liability.	LEGAL	12.1	27.1	30.8	26.2	3.7
44	I.C.I. should do more to encourage me to wear hearing protection.	ENCOU	11.2	46.7	21.5	19.6	0.9

			Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
45	The company benefits more than I do when I wear hearing protection.	BENEF	0.0	4.7	17.8	59.8	17.8
46	Wearing hearing protectors should be made compulsory.	COMPU	14.0	38.3	24.3	21.5	1.9
47	Somebody should be made responsible for seeing that we wear our hearing protection,	RESPON	1.9	29.0	26.2	31.8	11.2
48	We get too many safety talks.	TALK	19.6	63.6	15.0	0.9	0.9
49	It is useful to see films about hearing protection.	FILM	0.0	1.9	5.6	66.4	26.2
50	I remember very little about any safety film or talk afterwards.	MEMOR	0.0	3.7	9.3	72.9	14.0
51	I would rather hear a safety talk than see a safety film.	PREF	0.0	7.5	36.4	51.4	4.7
52	Posters describing the dangers of noise are effective.	POST	2.8	47.7	24.3	24.3	0.9
53	Nobody has ever satisfactorily explained the possible effects of noise on hearing to me.	EDUC	4.7	22.4	2.8	63.6	6.5
54	I do not want to know how good my hearing is.	HEAR	0.0	0.9	3.7	66.4	29.0
55	Seeing the results of a hearing test reminds me of the possibility that noise may be damaging my hearing.	RESUL	17.8	61.7	15.9	4.7	0.0
56	Hearing tests are not as important as chest X-ray examinations.	XRAY	15.0	43.9	22.4	16.8	1.9
57	I would not be prepared to give up my tea break in order to have a hearing test.	TBRK	19.6	64.5	8.4	7.5	0.0
58	Going to the clinic for a hearing test is useful.	CLINIC	22.4	74.8	1.9	0.9	0.0
59	Going to the clinic for a hearing test gives me the opportunity of talking to someone about problems that can arise with hearing.	DISCUSS	13.1	59.8	20.6	5.6	0.9

60 During a working day I wear hearing protection:

(1) Less than a quarter of the time.	PERCEN	41.1
(2) Less than half the time.		16.8
(3) Less than three-quarters of the time.		9.3
(4) Nearly all the time.		32.7

		Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
61 It is difficult to wear earmuffs with a safety helmet.	HELM	13.1	43.0	22.4	17.8	3.7
62 Hearing protectors usually fit well.	FIT	3.7	61.7	15.0	15.0	4.7
63 Earmuffs are too heavy.	HEAV	1.9	21.5	27.1	47.7	1.9
64 I keep forgetting to take hearing protectors onto the job.	FORG	1.9	22.4	12.1	53.3	10.3
65 There is a wide enough selection of hearing protectors available from which I can choose a pair.	SELEC	2.8	43.9	12.1	31.8	9.3
66 Earmuffs press too much on the side of the head.	PUSH	0.9	42.1	24.3	26.2	6.5
67 It is too hot where I work to wear hearing protectors comfortably.	HOT	7.5	31.8	22.4	38.3	0.0
68 It is too cold where I work to wear hearing protectors comfortably.	COLD	0.0	0.9	19.6	70.1	9.3
69 It is too dirty where I work to wear hearing protectors comfortably.	DIRT	0.0	3.7	11.2	80.4	4.7
70 It is too wet where I work to wear hearing protectors comfortably.	WET	0.0	0.9	15.0	79.4	4.7
71 Wearing hearing protectors makes me forgetful of the dangers from the equipment with which I am working.	DANG	4.7	10.3	13.1	63.6	8.4
72 Wearing hearing protection does not make it any more difficult to communicate with my workmates.	COMM	0.0	31.8	11.2	45.8	11.2
73 I cannot tell if my equipment is working properly when I wear hearing protectors.	MACH	3.7	22.4	15.0	56.1	2.8
74 Wearing hearing protectors does not make it any harder for me to hear warning sounds.	WARN	1.9	32.7	15.0	43.9	6.5

Please check that you have not accidentally missed out any questions.

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH Telephone 559122

Appendix 8.1

3 October 1975

Dear Sir

SURVEY OF INDUSTRIAL NOISE AT WILTON SITE, MIDDLESBROUGH

May I ask for your help on a survey we are conducting? We are trying to find out some facts about people's attitude to noise and hearing protection in industry.

I am sending this letter to you, and the majority of men in your particular area, asking you to give me your opinions.

To make sure that we hear all points of view, we are very anxious to get a reply from each person to whom we write. I hope you will be willing to co-operate.

You will find the questions on the enclosed questionnaire. Would you please fill in your answers, and either send it back to the Medical Centre, Wilton Site, or return it personally to the Medical Centre.

All replies will be kept strictly confidential, and will be analysed at Southampton University.

Please note that it is your own view that we want. Do not ask anyone else to answer the questionnaire instead of you, or we will not have a true section of opinions.

We should be grateful for your help.

Yours faithfully

S. Karmy

S J Karmy B.A. (Electron) M.Sc.

This program has been approved by the Senior Shop Stewards Committee, and the Management. Information from individual respondents will be confidential to Southampton University.

A 8.1 Returned attitude questionnaire showing the results obtained in the pre-treatment survey, together with the accompanying letter. The results are shown as response percentages. Where two sets of results are given to one question the second set are those attained if respondees never using hearing protectors are removed.

Q ________

INDUSTRIAL NOISE AT WILTON SITE

Please state your age ________ In which plant do you work? ____________________

and the type of job you do? ______________________________

Please think carefully about the following statements. Indicate your views by putting a tick in the appropriate box. An example is given below:

	Statement	Code	N	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.	
Example:	Listening to the radio is boring						✓		
1	I wear hearing protectors only when the noise levels are very high.	NHIGH	1231	13.1	49.6	4.3	24.8	8.3	
				13.0	47.6	3.1	26.9	9.4	1035
2	If the noise was not so loud, I could get a lot more work done.	LOUD	1233	9.7	34.0	22.7	29.4	4.2	
3	Being partly deaf would ruin the enjoyment I get from most things in life.	ENJ	1241	55.2	38.1	3.2	2.4	1.0	
4	It does not take long to get used to the noise at work.	USED	1239	3.3	38.4	9.2	30.5	18.6	
5	Working in a noisy area makes me feel irritable or depressed.	IRIT	1237	21.7	36.5	19.2	20.8	1.9	
6	When I wear hearing protectors I feel enclosed in a world of my own.	ENC	1239	14.2	43.9	13.8	26.2	1.9	
7	Wearing earmuffs does not make me feel conspicuous.	CONSP	1239	6.0	60.8	11.9	18.6	2.7	
8	I only need to take steps to protect my hearing if I think I am going deaf.	STEPS	1233	4.9	7.5	3.8	43.4	40.5	
9	Most people go deaf when they get older, so there is no need to worry about a little extra deafness now.	PRESB	1242	2.9	1.9	4.4	38.7	52.0	
10	The partly deaf person would have difficulty in finding and keeping a job he wanted to do.	JHAND	1241	14.9	50.4	16.8	15.3	2.5	
11	The partly deaf person is a hazard to himself on most jobs around the plant.	WHAND	1240	15.5	45.6	15.6	20.2	3.1	
12	Being partly deaf would prevent me from doing my job well.	POEF	1242	10.2	41.1	12.6	30.3	5.7	
13	I would find it difficult to work with someone who was deaf.	DIFFIC	1198	11.0	42.4	17.4	24.8	4.4	

	Statement	Code	N	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.
14	In my experience, most people's hearing appears to be immune to damage from noise.	IMM	1225	3.3	11.8	14.0	41.4	29.5
15	I have seen no evidence that noise damages the hearing, and so do not really believe it.	EVID	1228	2.0	5.5	12.0	42.5	38.1
16	The Management is carrying out this noise safety campaign.	MANAG	1208	6.6	43.2	23.4	20.9	5.9
17	The Southampton University research team are being employed by the Management to carry out this noise safety campaign.	SEMPLY	1196	6.6	42.7	31.0	15.3	4.3
18	ICI should do more to encourage me to wear hearing protection.	ENCOU	1229	12.8	43.8	21.6	19.7	2.2
19	ICI is concerned about my health.	ICIH	1226	18.6	61.4	12.2	5.9	2.0
20	ICI are making a good job of the noise safety campaign.	GJOB	1223	2.6	16.1	27.6	43.6	10.1
21	I think this noise campaign could be run better.	BETTER	1225	8.4	37.4	38.3	14.6	1.3
22	The company wants me to wear hearing protectors to cover themselves against any legal liability.	LEGAL	1227	11.0	41.2	24.1	21.3	2.4
23	I should not be pressurised into wearing hearing protection.	PRESS	1226	4.8	28.7	16.5	39.1	10.9
24	Somebody should be made responsible for seeing that we wear our hearing protection.	RESPON	1228	8.3	36.6	19.1	30.9	5.0
25	Anybody who tries to get me to wear hearing protectors is wasting their time.	WASTE	1227	1.3	2.6	9.3	60.8	26.0
26	Wearing hearing protectors should be made compulsory.	COMPU	1223	16.2	34.2	22.1	22.9	4.7
27	It is difficult to wear earmuffs with a safety helmet.	HELM	1211	18.2	41.3	20.9	17.1	2.5
28	There is a wide enough selection of hearing protectors available from which I can choose a pair.	SELEC	1226	5.4	42.1	12.2	31.5	8.8
29	It is too hot where I work to wear hearing protectors comfortably.	HOT	1226	10.3	25.4	22.5	39.1	2.7

30 During a working day I wear hearing protection PERCEN

	1202
(1) Never.	27.5
(2) Less than a quarter of the time.	10.7
(3) Less than half the time.	18.1
(4) Less than three-quarters of the time.	27.0
(5) Nearly all the time.	16.6

Item	N	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.	N
31 Wearing hearing protection will not prevent my hearing from being damaged by loud noise. NGOOD	1208	2.4	18.1	19.0	46.6	13.9	
32 Earmuffs are too heavy. HEAV	1215	4.8	25.3	24.3	42.1	3.6	
33 Hearing protectors usually fit well. FIT	1212	2.1	49.2	17.7	26.4	4.5	
34 Earmuffs press too much on the side of the head. PUSH	1210	9.3	32.8	21.8	34.2	1.9	
35 It is too cold where I work to wear hearing protectors comfortably. COLD	1213	0.3	1.6	21.8	64.5	11.8	
36 It is too wet where I work to wear hearing protectors comfortably. WET	1212	0.7	1.9	19.9	66.2	11.4	
37 It is too dirty where I work to wear hearing protectors comfortably. DIRTY	1209	1.0	5.3	18.4	64.6	10.7	
38 Wearing hearing protection does not make it any more difficult to communicate with my workmates. COMM	1217	1.9	30.9	10.0	46.2	11.0	
		2.0	31.2	9.0	46.6	11.2	1019
39 People who wear hearing protectos have not got the stamina needed to work in noise. STAM	1210	2.2	2.6	11.3	52.9	31.0	
40 Wearing hearing protectors does not make it any harder for me to hear warning sounds. WARN	1211	2.4	32.1	13.4	39.6	12.6	
41 I cannot tell if my equipment is working properly when I wear hearing protectors. MACH	1216	4.4	26.2	23.5	40.6	5.3	
		4.5	26.2	21.5	42.0	5.7	1026
42 I keep forgetting to take hearing protectors onto the job. FORG	1211	1.7	23.2	18.7	46.2	10.2	
		1.6	22.4	15.0	49.7	11.3	1014
43 Wearing hearing protectors makes me forgetful of the dangers from the equipment with which I am working. DANG	1215	2.7	14.7	16.8	52.8	12.9	
		2.3	14.4	14.4	54.6	14.4	1016

No.	Statement	Code	N	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree	Strongly Disagree.	N
44	I believe in going to the dentist for regular check-ups.	DENT	1167	17.8	47.8	22.1	10.0	2.2	
45	Hearing protectors get in the way.	WAY	1184	5.1	32.2	20.2	38.1	4.5	
				5.5	31.3	18.2	40.2	4.9	985
46	If it was quieter at work we would all make less mistakes.	QUIET	1181	13.4	38.7	23.5	22.5	1.9	
47	It isn't noisy enough where I work to make me go deaf.	NEN	1188	2.6	10.9	13.3	44.3	28.9	
48	It should be up to each individual to decide if he wants to wear hearing protection.	IDIV	1190	8.5	36.7	12.4	31.2	11.2	
49	Earmuffs are comfortable to wear.	COMF	1187	2.0	21.0	27.0	38.1	12.0	
				2.2	21.1	25.2	38.8	12.6	989
50	Wearing hearing protection makes me feel uneasy.	UNEASY	1188	3.2	24.7	20.5	47.7	3.8	
				2.9	23.8	19.3	49.8	4.1	989
51	I don't wear hearing protection as much as I should.	WEAR	1182	4.1	43.8	13.9	31.9	6.3	
52	I must wear my hearing protection all the time I am in noise for the protection to do me any good.	TIM	1184	18.6	55.7	13.8	10.3	1.7	
				20.0	56.4	11.9	10.6	1.1	985
53	Working with a deaf person would be difficult.	DIFFI	1186	9.8	50.5	16.6	20.1	3.0	
54	Wearing hearing protection is just a little more trouble than it is worth.	TROUB	1186	1.3	6.0	12.1	62.9	17.8	
55	Everybody who doesn't wear hearing protection when working in noise will end up deaf.	END	1186	7.4	23.6	38.0	27.2	3.9	
56	Wearing earmuffs does not make my ears feel too hot	TOOHOT	641	2.5	30.9	18.4	37.3	10.9	

Please check that you have not accidentally missed out any questions.

If you wish to make any further comments about any topic concerned with noise at work please do so here:-

THANK YOU FOR COMPLETING THE QUESTIONNAIRE. PLEASE RETURN IT TO ME AS SOON AS POSSIBLE.

```
ORTRAN COMPILATION BY #XFAT MK 5A

                    PROGRAM(CODE)
                    INPUT1=CR0
                    OUTPUT2=LP0
                    USE3=ED0/DIRECT
                    TRACE 2
                    END

                    MASTER CODE
                    READ(1/1)N
              C     N=NO OF CASES
                  1 FORMAT(I4)
                    DIMENSION LOG(26)
                    DATA LOG/26*0/
                    DEFINE FILE 3(3000,49,E,ICONT)
                    DO 3 K=1,N,1
                    READ(1/2)(LOG(J),J=1,26)
                  2 FORMAT(2I1,2A1,I4,A1,20I2)
              C     DRUML DRUMR PLANT SHIFT NO APPOINT 8 FREQ L 8 FREQ R AGE
                    WRITE(3'LOG(5),2)LOG
              C     WRITE TO DISC
                  3 CONTINUE
                  8 READ(1,4)P2,S2,L,B
              C     PLANT SHIFT CODE NO JOB TYPE
                  4 FORMAT(2A1,I4,A1)
                    READ(1/5)C,D,I3
              C     HALF NAME  HALF NAME WORK NO
                  5 FORMAT(A8,A7,I5)
                    READ(1/6)M
              C     M IS ADDRESS CARD IDENTIFICATION
                  6 FORMAT(T33,I2)
                    READ(3'L,2)LOG
              C     READ FROM DISC
                    WRITE(2,7)C,D,I3,P2,S2,L,B,LOG
                  7 FORMAT(1H0,A8,A7,I5,2A1,I4,A1,1X,I1,I1,1X,A1,A1,I4,A1,2X,3(
                   18(1X,I2),1X,8(1X,I2),2X,I2)
                    IF(1=31)9,8,10
                  9 WRITE(2,11)

                 11 FORMAT(43H0ADDRESS READING FROM FILESTORE OUT OF SYNC)
                    STOP
                 10 WRITE(2,12)
                 12 FORMAT(31H0NUMBER OF DATA CASES WAS       )
                    WRITE(2,13)N
                 13 FORMAT(T31,I4)
                    STOP
                    END

D OF SEGMENT, LENGTH   1617 NAME  CODE
```

A8.2 Example of a data base handling programme. Links audiometric data to employee address.

OUTLINE OF FILM 'HEAR TODAY, HEAR TOMORROW'

OPENING TITLE

SK

Introduction in studio
Brief mention of research programme
Cutaway shot to dosemeters, reminder of noise measurement

SK IN STUDIO:

Interest in noise and hearing conservation
Introduces educational film

EDUCATIONAL SECTION DEALING WITH:

Mechanism of hearing and noise induced deafness.
Social handicap of deafness
Hearing protection inindustry and the home
Audiometry

SK IN STUDIO:

Emphasises message in film
Cutaway shots to four Plants on Wilton Site
Introduces film of ISVR

ISVR SECTION DEALING WITH:

A 'typical' noise induced case of deafness
The research programme - emphasis on response by men on Wilton Site
Testing and problems of hearing protection
Specialised hearing tests
Research on hearing aids - hinting at the ineffectualness of hearing aids for noise induced deafness
Analysis of questionnaires returned by men on Wilton Site
Warning; 'typical' noise induced case of deafness receiving a largely useless hearing aid

SK IN STUDIO:

Emphasis on main message in film - 'wear your hearing protection'

CLOSING CREDITS

Film length 20 mins (approx)

A9.1 Outline of the film "Hear today, Hear tomorrow" specially made by the author for use in the study.

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH *Telephone* 559122

Hearing Conservation Unit,
Tizard Bldgs.,
University of Southampton,
Southampton.

Dear Sir,

Southampton University Noise Research

I do not seem to have received back from you a completed copy of the noise and industrial deafness questionnaire, which I sent to you some time ago. I respect any reasons you may have for not completing the questionnaire, but must explain my problem to you. You were chosen as part of a sample on Wilton Site, and as such, there can be no substitute for your own special views on the various topics mentioned.

I must get the opinion of everybody to whom I write, otherwise I can never be sure that I have not missed out an important section of views from the study. My report on this research, which will also describe this survey, must be complete and correct, as it will form the basis of many hearing conservation programmes to be set up in the future in industries all over Britain. The report of our survey at Wilton will be responsible for helping to preserve the hearing and health of many thousands of people like yourself who work daily in some type of industrial noise. The Government is also looking to this project to provide data which it can use in writing new noise legislation. Your view could well add something special to the project, and thus could influence future legislation.

I appreciate that you may not have had the time to fill out the large questionnaire, but I would be very grateful if you could possibly help me by completing any, or all of the ten questions overleaf. They have been taken from the original questionnaire. However, if you feel, having read this letter, that you would like to complete a full version of the questionnaire, please telephone Miss Stephenson at the Wilton Medical Centre, who will send you a questionnaire in the post.

If you still feel that you cannot help, could you tell me why, on the bottom of the sheet?

I should stress that information received always has been and always will be treated in absolute confidence as the property of Southampton University.

Should you require any further information, please do not hesitate to contact me through the Wilton Medical Centre, or consult the article which appeared in a recent issue of Wilton News.

Yours sincerely,

S. A. Karmy

S. KARMY, B.A. (Hons), M.Sc., M.I.O.A.

Research Fellow, I.S.V.R.,
Southampton University.

Code ____________

Please state your age ______

	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree.	Strongly Disagree.
Example: Listening to the radio is boring.					
5. Working in a noisy area makes me feel irritable or depressed.					
8. I only need to take steps to protect my hearing if I think I am going deaf.					
11 The partly deaf person is a hazard to himself on most jobs around the plant.					
17 The Southampton University research team are being employed by the Management to carry out this noise safety campaign.					
20 I.C.I. are making a good job of the noise safety campaign.					
26 Wearing hearing protection should be made compulsory.					

32 During a working day I wear hearing protection

- Never ☐
- Less than a quarter of the time ☐
- Less than half the time ☐
- Less than three-quarters of the time ☐
- Nearly all the time ☐

	Strongly Agree.	Agree.	Neither Agree nor Disagree.	Disagree.	Strongly Disagree.
36 Earmuffs press too much on the side of the head.					
38 It is too wet where I work to wear hearing protectors comfortably.					
43 I cannot tell if my equipment is working properly when I wear hearing protectors.					

A10.1 continued

APPENDIX 11

11.1 THE AUDIOMETRIC FACILITY

The test booth was situated within a large room in the clinical complex of the Medical Centre at the Wilton site. Brick built of a double skin construction, it occupied one corner of the room with a double door entrance and a double glazed window permitting natural light to enter the booth.

The internal dimensions of the chamber were 190 cm x 196 cm x 294 cm and it was thus large enough to house both the audiometrician and the subject to be tested, together with the audiometer.

Measurement of the ambient noise within the booth was made using a Bruel and Kjaer (B and K) precision sound level meter type 2203, with a 1" free field microphone, type 4145 and type 1613 octave filter set.

On each occasion two measurements were recorded, the first between 09.00 hrs and 10.00 hrs and the second between 14.00 hrs and 15.00 hrs, these times coresponding to the two periods during the day in which audiometric testing was undertaken as part of the research programme. With the exception of the measurement made in the October of year 1 members of a pair of ambient noise measurements made in one day were identical to within ± 2 dB SPL. Accordingly, only one measurement in each pair, the afternoon observation, is shown in Figure A11.1 except for the October measurements in year 1 which are both given, as they differ significantly.

Criterion B noted in Figure A11.1 shows the permissible noise environment specified by Berry (1973), and given in the Health and Safety Executive Document "Audiometry in Industry" (1978) which will allow the measurement of hearing down to acuity levels of -10 dB HL with an error not exceeding 2 dB. Criterion A represents that permissible noise environment within the booth if Amplivox "Audiocup" noise excluding enclosures are used in conjunction with the TDH 39 audiometer earphones and cushion. (Health and Safety Executive, 1978).

In view of the general stability of noise environment over the 32 month audiometric measurement period as shown by Figure A11.1 it is likely that the measurement identified as year 2 October (b) represents a sporadic occurrence. Nevertheless the ambient noise levels did therefore, appear to rise occasionally, and also the more normal levels of ambient noise within the booth are marginally unacceptable at 500 Hz. The use of the Audiocups was therefore justified in order to obtain an acceptable test environment. These devices have been shown by Stark (1975) not to affect the calibration of the audiometer.

Two audiometers were available on the Wilton site; a Peter's clinical audiometer, model AP6, and a small portable audiometer, an Amplivox model 82. Both audiometers were fitted with TDH 39 earphones. The portable audiometer was used in the case of a failure by the Peters machine, an event which occurred once during the 32 month period.

The AP6 audiometer was calbrated five times between October year 1 and year 4 when audiometric testing as a part of the research programme was completed. The Amplivox 82 was calibrated once, when it was needed for service.

The audiometers were calibrated using a B and K sound level meter type 2203 with an octave filter set, B and K type 1613. A 9-A coupler was also used, B and K type 4152, and a pressure microphone, B and K type 4144. Use was also made of an oscilloscope, and a digital frequency meter.

The audiometers were calibrated according to British Standard 2497 (British Standards Institution 1969), and their specifications checked for compliance with British Standard 2980 (British Standards Institution 1958).

The tonal frequencies and the attenuator step values were in accordance with BS 2980 for both machines. The tonal onset and decay characteristics of the AP6 were in accordance with the British Standard. The corresponding values for the Amplivox 82 were not measured. The spectral purity of the total signals however, appeared to be outside the British Standard Specifications, for both machines. The first harmonic to subharmonic or second harmonic ratio was approximately 25 dB instead of the required 30 dB. However, experimentation in the laboratory showed that this result was an artifact caused by using octave filters to make the measurement. One third octave band filters are required to make the measurement, and it is almost certain on the basis of the 25 dB ratio obtained that the audiometers were within the spectral purity specification.

The calibration factors measured for the tone intensities were small in the case of both machines, ranging between 2.5 dB and 4.75 dB for the Peters audiometer, and -2.75 dB and 0 dB for the Amplivox 82. The majority of calibration factors lay between ± 1.5 dB. Tables A11.1 and A11.2 give the calibration factors for the two audiometers.

As can be seen from Table A11.1 the stability of the AP6 audiometer over the experimental period was excellent, with maximum output intensity drifts of 2.8 dB being recorded, at least 1 dB of which must be ascribed to measurement error over the 32 month period. The calibration factors thus generated were small, and therefore of little clinical importance in routine clinical testing. However, if a programme of industrial monitoring audiometry is to be undertaken in accordance with the HSE document "Audiometry in Industry", the calibration factors of the audiometer used could be of some importance, especially in comparing two audiograms measured on a single individual at two different points in time.

Using the calibration figures given in Table A11.1 for the AP6 audiometer, it can be shown that the most serious consequence of neglecting the calibration factors would be to effectively increase the stringency of the criterion for a significant change in hearing level, over a 3 year period as given in "Audiometry in Industry" from 30 dB to 24 dB in a proportion of the cases, thus spuriously increasing the number of employees to be re-examined.

Calibration factors were entered in the programes written to analyse the audiometric data and used to adjust the thresholds measured.

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH Telephone 559122

TECHNIQUE OF MANUAL AUDIOMETRY FOR INDUSTRIAL PURPOSES

It is recommended that the subject should be instructed in the manner suggested below and this should be followed by the audiometric technique given.

INSTRUCTIONS TO SUBJECTS

1 "Have you had your hearing checked before?"

2 either "Yes? - that's fine, let me remind you what I'm going to do"
or "No? - well let me tell you what I am going to do"

3 "You will be listening for some tones - some will be very high pitched and some will be very low pitched" (demonstrate)

4 "The tones are going to start off very loud but will become quieter and quieter. I want to find the quietest sound you can hear"

5 "No matter how quiet the tone, press the button when you hear it and keep the button pressed for as long as you hear it, no matter which ear you hear the tone in" (demonstrate)

6 "Do you hear better in one ear than the other? Yes? Then we will test that ear first"
or "No? Then we will test the left ear first"

7 "Do you have any questions?"

8 "No? Then we will put the headphones on now" Do so but first remove any spectacles, unless the subject is distressed without them, hearing aids, ear plugs, large ear rings etc. Make sure that any hair is swept back behind the ears and always make the final adjustment to the headphones yourself to make sure they are positioned correctly.

A11. 2 Technique of manual audiometry and patient instructions used.

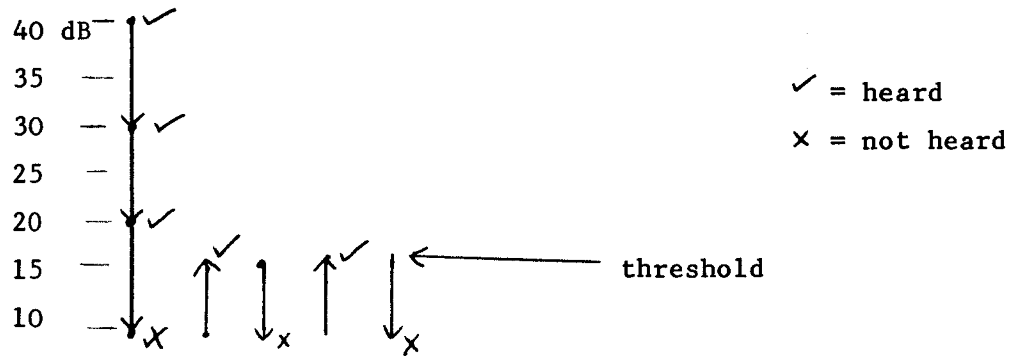
TECHNIQUE

1 Start with a level of 40 dB at 1,000 H_3.

2 Present tones of varying length (½ - 1½ secs) with varying intervals (1 - 3 seconds)

3 If the tone is heard, reduce the level in 10 dB steps until it is no longer heard. If the starting level of 40 dB is not heard, raise it in 20 dB steps until it is heard (or the maximum output of the audiometer is reached) and then descend in 10 dB steps.

4 From the highest level at which the tone was not heard raise the level in 5 dB steps until heard and then down until not heard. Then raise until heard and finally down until not heard. See below.



The above diagram shows the ideal case; a subject giving a very well defined threshold. In a less ideal situation, with the subject giving more variable responses the threshold is defined as the lowest level at which 2, 3 or 4 presentations out of 4 were heard, with at least one of the heard presentations being on the ascent.

5 After testing 1,000 H_3 first, proceed to 2,000, 3,000, 4,000, 6,000 8,000 and then to 250 H_3, 500 H_3 and finally a retest at 1,000 H_3. Place a tick alongside the threshold symbol on the retest.

6 Be sure to vary tone and interval duration to detect when a response is being given that does not coincide with a tone presentation. This may be due to tinnitus (often restricted to a narrow frequency band often near the high tone dip) or to trying too hard, leading to guesswork.

7 Ensure that the subject can obtain no visual clue as to the start of tone presentation, eg operator arm movement.

NOTES ON THE QUESTIONNAIRE

1 The primary questionnaire would be best filled in by an interviewer asking the subject the questions. The interviewer should not hesitate to make the questions clearer, verbally, to the subject but should try to avoid influencing the answers.

2 The personality questionnaire must be filled in by the subject and the interviewer should avoid looking at his answers. The confidentiality aspect should be stressed to the subject.

3 The subject's code number should appear on both questionnaires.

WAX

The subject's ear canals should be examined for excessive wax, by one of the nursing sisters, before audiometry is started. The amount of wax observed or any perforations should be noted down on the form provided. Hearing acuity should not be affected significantly until almost the whole drum is made invisible by wax. If a subject is found in this condition he is in need of medical attention. His ears should be syringed and he should return for audiometry at a later date.

AUDIOMETER

1 Allow the machine to warm up 10 - 15 minutes before use.

2 After this warm up period calibrate the audiometer. Instructions for doing this are in the booth.

3 It is advisable for the operator to check the machine once a day for any obvious malfunction. Place the earphones on the head and listen quickly to all frequencies used and a few intensity steps.

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MEDICAL QUESTIONAIRE

Date	
Interviewer	
Sub. Code No.	
Sub Age	

Location of work			
Nature of work			
Status	Operator	Fitter	Office

How long have you worked in your present job ?

Do you consider your job to be in a noisy area ? YES NO

Have you ever worked on a job in a noisy area, either at I.C.I. or elsewhere? YES NO

Type of job	Duration in years	Did you have to shout to make yourself heard			Was ear protect. worn?
		All the time	Some of the time	Never	

All.3 Medical questionnaire and audiometric form.

Have you ever fired guns, rifles or pistols? | YES | NO |

What kinds ? ______

How many rounds of each? 10/100/1000/10,000
10/100/1000/10,000

When? ______

Did you wear hearing protectors | YES | NO |

Were there any immediate affer effects on your hearing? | YES | NO |

State ______

Have you any noisy hobbies | YES | NO |

Which? ______

Duration? ______

Any after effects on your hearing | YES | NO |

State ______

Did/do you wear any form of hearing protection | YES | NO |

Have you ever received a serious head injury ? | YES | NO |

State

Have you ever been exposed to a severe explosion | YES | NO |

Have any of the above had a permanent effect on your hearing | YES | NO |

State

What percentage of time do you wear hearing protectors when in noise?

Comment on the comfort or discomfort of hearing protectors

	Adult		Childhood			
Have you suffered from Chicken Pox					YES	NO
Menengitis					YES	NO
Scarlet Fever					YES	NO
Measles					YES	NO
Mumps					YES	NO
	ear		ear			
Have your ears suffered from Excess wax	L	R	L	R	YES	NO
Discharge	L	R	L	R	YES	NO
Abscess	L	R	L	R	YES	NO

Have any of the above had any permanent effect on your hearing			YES	NO
Do you suffer from Meniere's disorder	L	R	YES	NO
Otosclerosis	L	R	YES	NO
Any other disorder? ____________	L	R	YES	NO
Is there a family history of deafness?			YES	NO

Which relatives?

Tinnitus: Have you ever had a singing, hissing or ringing noise in your ears lasting more than a few moments?	YES	NO

If so, is there/was there any particular time or event associated with onset?

Do you consider your hearing ability to be average	YES	NO
Have you ever had an audiometric test before?	YES	NO

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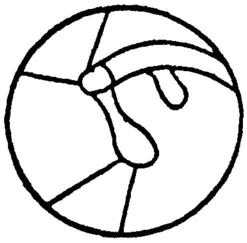
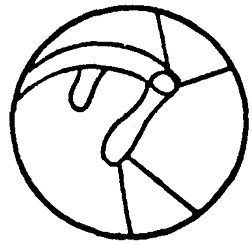
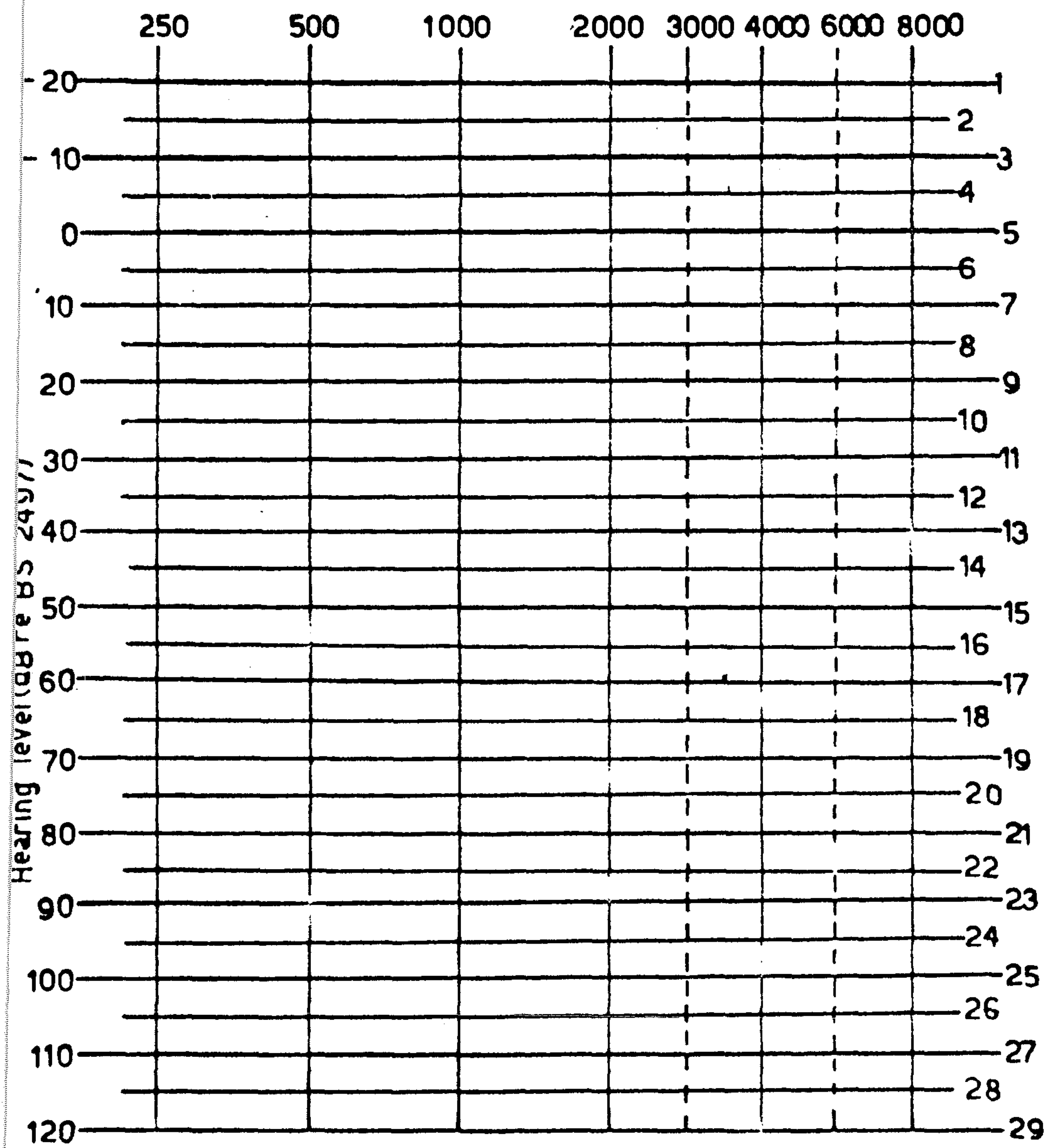
TYMPANIC MEMBRANE

LEFT



RIGHT





No. __________

Date __________

Tested by __________

Aud __________

Unmasked a/c

L	R
X	O

eye colour

LEFT

250	500	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz

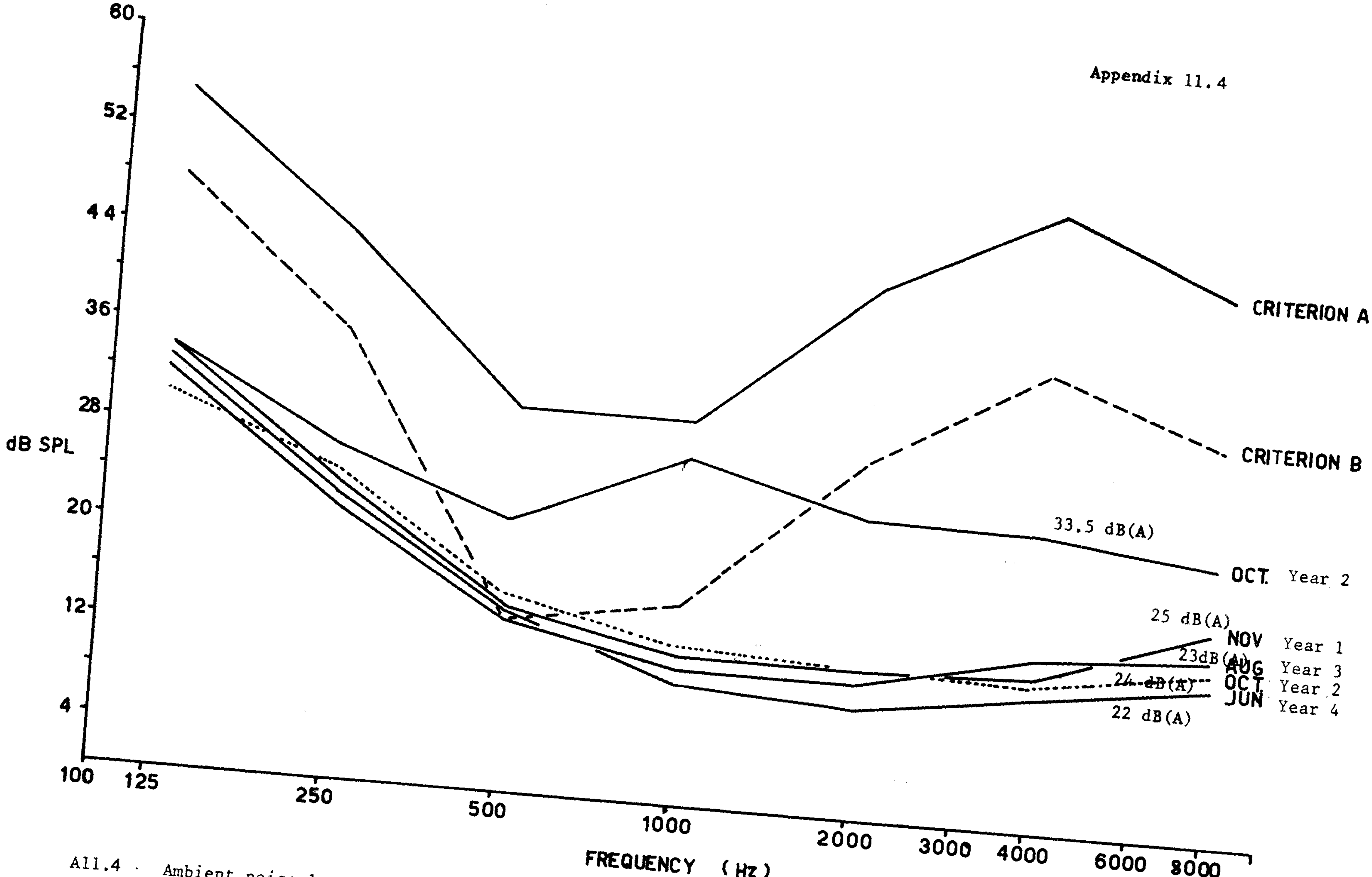
RIGHT

250	500	1kHz	2kHz	3kHz	4kHz	6kHz	8kHz

Table A11.4 Calibration factors measured on the Peters AP6 and Amplivox 82 audiometers.

RIGHT					PETERS	AMPLIVOX
FREQ. Hz.	12 NOV Year 1	13 OCT Year 2	4 MAY Year 3	5 AUG Year 3	7 JUN Year 4	10 JUN Year 4
250	0	0·4	-2·5	-2·5	-2·5	0
500	1·3	1·9	-0·5	-0·9	0·5	-1·7
1000	0·9	1·0	-0·75	-1·0	0·4	-0·5
2000	1·75	1·95	0·5	0·75	1·25	-1·55
3000	3·0	2·5	4·4	4·75	3·5	-1·5
4000	0·3	0·25	-0·5	0	1·0	-2·7
6000	0·15	-0·85	-0·85	-0·25	-0·25	-2·75
8000	0·2	1·4	1·5	1·75	2·0	-0·25
LEFT						
250	-0·4	-0·5	-2·25	-2·0	-0·75	0
500	1·0	0·9	-0·5	-0·5	0	-1·2
1000	0·75	0·8	-1·2	-0·75	0·25	0
2000	1·45	1·35	0·25	1·0	1·75	-0·85
3000	2·0	1·9	4·0	3·75	3·0	-0·75
4000	0·5	0·25	-1·0	-0·1	0·5	-1·1
6000	1·0	-1·25	-1·75	0	0	-2·25
8000	1·5	0·5	0·6	2·35	2·25	0

Appendix 11.4



A11.4 . Ambient noise levels in the audiometric booth

A 11.5 Showing coefficient a used in equation 11.1 Shipton (1979)

Frequency	250	500	1000	2000	3000	4000	6000	8000 Hz
(a)	0.003	0.0035	0.004	0.007	0.0115	0.016	0.018	0.022

```
      PROGRAM BRITISH
      INTEGER HEAR
      DIMENSION HEAR(29),COEFF(25),FINAL(29)
      DATA HEAR/29*0/,COEFF/9*0.0,0.0030,0.0035,0.0040,0.0070,0.0115,0.0
     116,0.018,0.022,0.0030,0.0035,0.0040,0.0070,0.01150,0.016,0.018,0.02
     12/,SEFT,RIGHT,P,P1/4*0.0/,FINAL/29*0/
      L=1
    4 READ(1,7,END=8)HEAR(26),HEAR(5),HEAR(29),HEAR(12),HEAR(13),HEAR(14
     1),HEAR(20),HEAR(21),HEAR(22)
      IF(HEAR(29).NE.10)GO TO 4
      WRITE(9,600,REC=L,REPLY=L)(HEAR(J),J=1,29)
  600 FORMAT(2I1,2A1,I5,A1,3I2,16I3,I2,3I2)
      KARDEND=L
      GO TO 4
    8 DO 9 I=24,42,3
      L=1
   10 IF(L.EQ.KARDEND)GO TO 2
      READ(9,600,REC=L,REPLY=L)(HEAR(J),J=1,29)
      DO 11 K=12,22,1
      FINAL(K)=HEAR(K)-(COEFF(K)*((HEAR(26)-20)**2))
   11 CONTINUE
      P=P+1.0
    7 FORMAT(9X,I2,I5,I3,19X,3I3,15X,3I3)
      RIGHT=(FINAL(20)+FINAL(21)+FINAL(22))/3.0
      SEFT=(FINAL(12)+FINAL(13)+FINAL(14))/3.0
      IF(SEFT.LT.I.AND.RIGHT.LT.I)GO TO 10
      IF(I.LT.40)GO TO 500
      WRITE(2,5)HEAR(5),SEFT,RIGHT
    5 FORMAT(1H ,10X,I5,5X,2(5X,F6.2))
  500 P1=P1+1
      GO TO 10
    2 FAILPER=(P1/P)*100.0
      WRITE(2,6)P,P1,FAILPER,I
    6 FORMAT(1H ,3(10X,F7.2),10X,I3)
      L=1
      P1=0.0
      P=0.0
    9 CONTINUE
      WRITE(2,3)KARDEND
    3 FORMAT(I4)
      STOP
      END
```

Appendix 11.6

Example of a programme used to analyse audiometric records. Age corrects the data and calculates the percentage of the population exceeding a sequence of auditory fence values set as average hearing thresholds at 1, 2 and 3kHZ.

Viewpoint

This *'viewpoint'* has been contributed by S. J. Karmy, BA (Hons), MSc, MIOA.

Will Industrial Audiometry be available to all employees?

On the 5th December 1985 the EEC Labour and Social Affairs Council agreed the European Industrial Noise Directive for which the UK, as a Member State, has been waiting since 1982.

The new Directive, presently being tidied for presentation to the Council of Ministers, requires Industrial Audiometry to be available to all employees working in L_{Aeq} levels of 85dB(A) and above. Or does it?

The HSE, showing a remarkable turn of speed for such an august body, is set to dive through a legalistic loophole in an effort to avoid requiring the UK to increase its commitment to industrial audiometry.

Despite the fact that Article 12 of the new Directive refers the reader to an International Standard, ISO 6189 (1983), which is clearly written to define the manner in which audiometry is to be conducted in industry, the HSE have declared that they intend to interpret the wording of the new Directive to mean that the audiometric clause refers to no more than the present state of affairs in the UK whereby,after referral by a GP, the employee can proceed to a hospital Ear Nose and Throat Department for a hearing test[1,2].

Apart from any other difficulties engendered by this policy, an elementary consideration of the numbers which might be involved shows the lack of realism in this approach.

Using the HSE's own very conservative figures, it is possible to estimate that even they would acknowledge that over 2 million employees would require hearing tests under the terms of the new Directive. Yet in 1982 the Industrial Advisory Council reported to the Rt. Hon. Norman Fowler that the National Health Service had only the capacity to conduct a further 10 000 audiological examinations per annum in support of the Occupational Deafness Industrial Benefits Scheme (Industrial Injuries Advisory Council 1982)[3]. Although the assessment tests required under this pension scheme are somewhat longer than those that would be required for the proposed *'industrial'* tests, given that this capacity is already partially utilised for the purpose for which it was intended, and given the level of cutbacks in the NHS since 1982, even allowing for the presence of existing industrial audiometric facilities a simple comparison of remaining NHS capacity to the proposed *'industrial'* workload shows how the NHS cannot possibly cope! Or — dare I voice the thought — can it be that the HSE feels that the proposed route from the factory floor to the ENT consulting room will be sufficiently torturous to deter the great bulk of all eligible employees from attempting to attend in the first year? If this is the case, why should a UK employee experience great difficulty in obtaining an industrial health surveillance test which is freely available to his European counterpart in a Factory Medical Centre?

To add a delightfully piquant touch, the HSE also appears intent on bringing in a mandatory requirement for the audiometric testing only of those employees exposed to noise levels reaching 105dB(A) L_{Aeq}, of which there are relatively few in the UK. According to HSE lateral thinking, the combination of the availability of NHS clinics and the mandatory requirement for audiometric testing at exposure levels of 105dB(A) L_{Aeq}, would mean that the new UK legislation formulated in response to the EEC Directive would be more stringent than actually required by the EEC!

Why should the HSE take this attitude towards industrial audiometry?

Why should there be a reluctance to introduce audiometric testing into the UK when it is utilised to such effect in other Common Market countries such as France and Germany?

The benefits of audiometry have been laid down repeatedly in the literature and are acknowledged by companies using audiometry at the present time in the UK.

Pre-employment audiometry defines the future liability of the company. If performed at the recruitment stage, or very early in the individual's working career, it can prevent a company from having to pay in the courts for an industrial deafness caused during a prior employment. Awards made by the courts have ranged up to £21 675 in mainland UK (Abramowicz v. Carborundum Co. Limited 1981) although a more average level of damages would be around £5000. These figures exclude the costs associated with bringing a case to court. More importantly, out of court settlements are now reaching very high levels. British Rail have apparently set aside at least £5 million to pay claims[4] and the Iron Trades Employers Association Limited are reputed to have allocated £50 million for the settlement of these claims[5].

Pre-employment audiometry is also valuable in allowing a company to assess the hearing of future employees to assist in job placement. Some jobs require good hearing acuity, or it may be thought unnecessarily hazardous to place an employee with a severe hearing loss in a noisy area. If a case history of prior exposure to noise is also taken into account, industrial audiometry can often indicate those applicants who appear to be susceptible to noise induced hearing loss. The test can also provide a means for the early detection of conditions of the ear unrelated to noise damage, before the employee incorrectly ascribes his increasing deafness to the effects of noise at work.

A11.7 An article published by the author reacting to the HSE attitude towards industrial audiometry.

One often neglected, but important effect of routine industrial audiometry is that it is a strong educational tool, represents an ongoing interest in the noise problem on the part of management, and encourages the workforce to wear their hearing protection. This is shown in the results of a comprehensive study performed on eight industrial plants and reported in Karmy (1980)[6].

The arguments for routine audiometry are just as strong. Audiometry provides the final check that the Hearing Conservation Programme is succeeding in arresting the progress of noise induced hearing loss in the workforce. In many instances control of the noise at source is impracticable for financial or engineering reasons, and reliance has to be placed upon the issue of hearing protection, altering work patterns so that employees do not remain in the noisy areas long enough to receive a hazardous noise dose, or the building of enclosures around the offending machines. All these measures require the conscious co-operation of employees to be successful. Even when noise enclosures are used, the employee is often required to remember to keep closed the door or other access panel to the sound enclosure, in order to maintain the effectiveness of the acoustic insulation.

Many authors have investigated whether or not the reliability of audiometric measurement is such that it is capable of detecting small deteriorations in hearing acuity at a sufficiently early stage for remedial hearing conservation measures to be successful in preventing a disability occurring.

Many of these studies are now outdated by the rapid progress made in the design of modern audiometers, particularly those controlled by microprocessors and exhibiting features which will increase the reproducibility of results. However, an elegant study was conducted by Hetu (1979)[7]. After assuming that it should be possible to set up a good audiometric facility with well trained audiometricians, Hetu assessed the size of the audiometric test/retest errors and concluded that the variance in results was small enough to allow the detection of a slowly growing noise induced hearing loss during at least the first five years of exposure to even moderate levels of noise, and probably throughout the first ten years.

Even Sutton, (1983)[8] writing on behalf of the CBI, which is known to be opposed to the introduction of audiometry[9] has to conclude that the precision of audiometry is such as to make routine audiometry likely to be useful in detecting noise induced hearing loss if "***(i) the actual exposure at the ear exceeds 90dB(A) L_{Aep} (ii) Hearing protectors are used to control exposure to 90dB(A) or below, but the unprotected exposure would exceed 95dB(A).***"

Why then, in view of these facts, does the HSE take the attitude that it does?

The HSE states that although it is prepared to listen, industrial concerns presently running programmes of industrial audiometry have not yet come forward giving clear information on the benefits derived from their audiometric programmes. Although it is probably a lot to ask that medical or other persons working in a busy industrial environment should take the time and effort to volunteer this information, it may be the only way forward.

Alternatively, perhaps the HSE should be persuaded to fund a study of existing audiometric programmes in industry so that it can be in full possession of all the facts.

I can only conclude by asking that if you are concerned over the proposed HSE dilution of the requirement for industial audiometry in the EEC Directive, and the resulting strain on the NHS, then please write to the HSE on this topic.

It would be iniquitous if the HSE viewpoint was allowed to prevail through default, essentially denying UK employees access to medical industrial screening tests freely available to their European counterparts.

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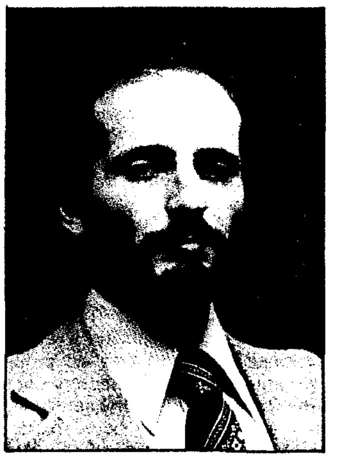

Following a BSc(Hon) in Electronics, Mr. Karmy was awarded a MSc in Audiology. He was the ICI lecturer at the Institute of Sound and Vibration Research, Southampton University, leading a team researching into Hearing Conservation problems in industry. He joined Bilsom in 1982 and is now the General Manager of its Advisory Service. Bilsom, through its subsidiary company, Industrial Audiology Services Ltd., makes available a mobile audiometry screening service.

Mr. Karmy sits on the Hearing Protection Committee of BSI and is a member of the British Society of Audiology Committee dealing with Industrial Audiometry.