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Extended Practice at Bingo: An Examination of the Effects of Skilled Performance on Age-Cognition Relations

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ABSTRACT

EXTENDED PRACTICE AT BINGO: AN EXAMINATION OF THE EFFECTS OF SKILLED PERFORMANCE ON AGE-COGNITION RELATIONS

By Julie Winstone

The purpose of this thesis was to gain a deeper understanding of the mechanisms underlying skilled performance and to explore the effects of skilled behaviour on age-cognition relations.

Examination of the empirical findings in this area led to the construction of several hypotheses. The first was that Bingo players would exhibit superior performance to non-Bingo players on a domain-specific task of visual search. The second hypothesis, was that older Bingo players would demonstrate comparable levels of performance to younger Bingo players on a test of the molar (overall) skill. The third hypothesis, predicted that Bingo players would be able to positively transfer the cognitive skills used in Bingo to a new task comprising the same contextual information. It was further hypothesised that older Bingo players would demonstrate a lesser degree of positive transfer to younger Bingo players. A final hypothesis predicted that Bingo players would demonstrate superior performance to non-Bingo players on domain-general cognitive tasks comprising familiar stimuli. Finally, domain-general tasks were used to test the maintenance and compensation hypotheses of cognitive ageing.

The results revealed that Bingo players were both more efficient and proficient at the domain-specific task of visual search. Further, older Bingo players performed as well as the younger Bingo players on this task. Bingo players were also able to positively transfer some of the skills underlying Bingo performance to a new task. However, as predicted, the older Bingo players did not exhibit the same amount of positive transfer as younger Bingo players. Bingo players also demonstrated superior ability to non-Bingo players on visual search tasks that did not follow the same rules as Bingo. However, the performance of older Bingo players was found to be negatively affected by age on many of the general cognitive ability measures.

In conclusion, the experiments presented in this thesis provided some support for the notion that certain cognitive abilities are maintained into older adulthood through continued practice. However, the tasks that produced comparable levels of skill for both younger and older Bingo players tended to be specifically related to the molar skill. It is therefore suggested that older Bingo players have implemented a compensatory strategy in order to maintain performance. Further research will seek to determine the nature of this compensatory mechanism.

This thesis is dedicated to my parents Dave and Doreen and to my partner Tim.

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Preface: Aims and Structure of the Thesis

The purpose of this thesis is to gain a deeper understanding of the mechanisms underlying skilled performance and to explore the effects of skilled behaviour on age-cognition relations. Studying Bingo players provides a unique opportunity for answering the following theoretical questions: (a) What are the effects of extended practice with the game of Bingo on elementary cognitive processes, and (b) Does extended practice at Bingo have a moderating affect on cognitive limitations in older adulthood? More specifically, this thesis aims to investigate whether cognitive abilities underlying skilled performance at Bingo are maintained with practice in older adulthood or whether compensatory mechanisms are employed by older adults in order to achieve comparable levels of performance to their younger counterparts. This thesis, thus, encompasses two research areas, namely, skilled performance and cognitive ageing. Although each of these areas has been thoroughly investigated in the past, relatively little work has been conducted with a view to uncovering the mechanisms which enable older adults to perform at the same level as younger adults on skilled tasks.

The first two chapters of this thesis present an overview of literature surrounding the areas of skilled performance and cognitive ageing. Chapter 1 introduces the concept of skilled performance and provides a historical overview of the literature including descriptions of the theoretical approaches pertaining to the acquisition of skilled performance. Chapter 2 describes the concept of cognitive ageing and presents a historical overview of the research that has been conducted on this topic, including the theoretical approaches that have been put forward to explain the phenomenon of cognitive ageing. Chapter 3 integrates the two research areas and provides a review of research findings in the area of ageing and skilled performance which are relevant to the experiments reported in subsequent chapters. The final introductory chapter introduces the game of Bingo and provides the rationale for the experiments presented in this thesis.

An initial attempt has been made to understand the influence of extensive practice with a cognitive skill on certain elementary cognitive processes. In particular this thesis provides new data concerning the influence of extensive practice at varied-mapping visual search. Much of the research that has been conducted thus far into the effects of practice on visual search performance has taken place in the laboratory. Such training studies, although valuable and extremely well controlled, cannot provide the amount and type of practice undertaken by, for example, a Bingo player who has been playing the game five times per week for a period of thirty or forty years.

An initial attempt has also been made in this thesis to determine the mechanism(s) responsible for maintaining skilled performance in older adulthood. Previous research has provided many demonstrations of compensation in older adulthood for complex cognitive skills such as chess (1981b), bridge (Charness, 1979, 1983, 1987), and typing (Salthouse, 1984). However, with regard to the remediation of cognitive processes underlying skilled performance, research findings have been inconsistent. In contrast to previous research, this thesis examined the effects of age and experience on performance of a relatively simple cognitive skill and found some correlational evidence to suggest that some of the elementary cognitive processes underlying this skill are maintained in older adults who practice this task on a regular basis. The experiments presented in this thesis also address a number of the methodological criticisms levelled at much of the ageing and skill research. For instance, detailed information concerning the nature and amount of practice an individual has had with the activity was gathered. Furthermore, because the game of Bingo calls upon simple cognitive skills and comprises well-defined rules, the nature of practice at Bingo is comparable across all individuals; that is, there is much less room for interindividual variability in the way the activity is performed than in some tasks that have been tested. Moreover, performance at Bingo as opposed to more complex cognitive skills such as chess and bridge is not likely to improve beyond a certain point; thus, it is likely that once the basic skill has been acquired practice only serves to maintain performance. This has important implications for the validity of the age-comparative experiments presented in this thesis. In the experiments reported here, performance of the same level of skill for both older and younger adults is being measured despite the fact that participants in the older age group have had many more years of experience with the activity.

The research contained in this thesis also has a number of practical implications. For instance, the data that have been presented here offer a useful contribution to the existing training research. Further, it offers a starting point for exploring some of the less cognitively complex social-recreational activities that are enjoyed by a significant percentage of the population. Moreover, if both the amount and regularity of practice needed to maintain important elementary cognitive processes in older adulthood can be determined therapeutic benefits may be derived by providing cognitively stimulating adaptations of activities in care settings that are already enjoyed by older adults.

CHAPTER ONE

HUMAN SKILLED PERFORMANCE

Introduction

The purpose of this introductory chapter is to present the concept of skilled performance and its theoretical assumptions. The chapter is divided into two major parts. The primary goal of the first part is to present a historical overview of the literature surrounding the area of skilled performance while the second part of the chapter provides a review of the main theories of skill acquisition and performance.

An historical Review of the Literature

Skilled performance refers to the ability to routinely reliably and fluently perform goal-directed activities as a result of practice with those activities. Further, *cognitive skill* refers to performance that exemplifies knowledge and encompasses the generation or manipulation of mental representations (Carlson, 1997). Skilled performance and activities of daily living go hand in hand. A large proportion of our time is spent carrying out actions that are highly practiced. For instance, consider the skills involved in our occupational and leisure pursuits as well as those involved in day-to-day activities such as driving a car and shopping. Typically, to attain a high level of skilled performance many years of study and substantial amounts of practice are required (Bosman & Charness, 1996). For example, doctors within the field of psychology spend many years at university before acquiring their PhD, following which, several years of postdoctoral study are often undertaken. However, not all skills are as complex or take as long to acquire. For instance, even a cognitively undemanding task such as a simple reaction time task will display changes in performance with practice (Matthews, Davies, Westerman, & Stammers, 2000).

Research into the acquisition of human skill can be traced back to the monograph on learning and memory presented by Ebbinghaus in 1885. The experimental analyses carried out by Ebbinghaus although not directly linked to skill research introduced two very important concepts that have subsequently been the focus of much attention in the skill literature. The first concept, *savings,* refers to the difference, for example, in the number of repetitions required for relearning a list of nonsense syllables compared to the number of repetitions required for the original learning. Ebbinghaus took this difference between learning and relearning to be a sensitive measure of retention that can reveal evidence of learning when overt recollection fails to do so. The second concept introduced by Ebbinghaus is that of *transfer* and refers to the influence of the original list on the subsequent learning of another.

Studies of skill acquisition proper began with an early example of field experimentation carried out by Bryan and Harter (1897, 1899). Bryan and Harter conducted research into the acquisition of telegraphic language, a major form of communication at the turn of the century. Specifically, they investigated performance differences in relation to experience. One of Bryan and Harter's initial findings was that for messages to be transmitted and received both swiftly and accurately a minimum period of two years experience in the job was required. Further, they found that there was a great deal of interindividual variability in the performance of operators and that experts were less susceptible to interference from their surroundings than novices. Moreover, Bryan and Harter found that there was a decrease in the variability of performance with increased skill level. Interestingly, Bryan and Harter reported that for a certain period of time the performance of participants would plateau such that there would be no further improvement in performance for a number of weeks. Interestingly, this period of arrested progress was found only for the receiving and not for the sending of telegraphic messages. This finding promoted the idea that plateaus in performance form part of the normal skill learning curve and was accepted by many researchers at the time. However, subsequent research carried out by Keller (1958) provided no evidence for a plateau in performance. Indeed, the phenomenon has since become known as the *phantom plateau.* Plateaus in performance have since been reported within the telegraphic domain but have been interpreted by Keller as being artefacts of the testing procedure as the observed plateaus tend to occur when sub-sections have been completed (Pfisterer, 1988, as cited in King and Pribram, 1996).

In spite of the criticisms, however, Bryan and Harter's (1897, 1899) influential work highlighted the value of studying skill acquisition in its natural environment.

Effects of practice on performance

The research presented so far demonstrates the importance of practice in determining how quickly a skill is acquired. Practice refers specifically to the repeated performance of the same routines (Carlson, 1997). It is important to note here that practice does not necessarily make for perfect performance as it is entirely possible to practise the *wrong* routines. However, research into the effects of practice on performance remains the focal point of much of the skill research conducted today. Practice can influence performance in a number of different ways

Consistency and practice

Carlson (1997) suggests that "Perhaps the most powerful variable influencing the acquisition of cognitive skill is the *consistency* of practice, the degree to which repeated trials evoke the same mental processes" (p.56). The seminal work carried out by Schneider and Shiffrin (1977) and by Shiffrin and Schneider (1977) demonstrated the effect of consistency on performance and acted as a springboard for a plethora of research on this issue. Schneider and Shiffrin put forward an argument for two types of processing modes: controlled and automatic. To demonstrate the development of these different processing modes Schneider and Shiffrin employed two methods of training in a series of visual and memory search experiments using both letter and digit search arrays. The greatest gains in performance with practice were found when the task was consistently mapped (CM) as opposed to being variably mapped (VM). A task is consistently mapped when a stimulus designated a target on one trial does not then appear as a distractor on a subsequent trial. In other words, the stimulus assumes the same role throughout the task. Conversely, a VM task is one in which a target stimulus on one trial becomes a distractor on another trial. Thus, in a VM task a stimulus can assume either role on any trial. In sum, there is a correspondence between stimulus and response on a CM task but not for a VM task.

Most importantly, Schneider and Shiffrin argue that with practice consistent mapping produces search performance that is fast, effortless, unconscious and parallel. In other words, they claim that the processes underlying the task become *automatic,* or more precisely, that CM training in visual search results in the propensity for targets to attract attention automatically and for distractors to repel attention automatically (Lightfoot, Czerwinski, & Shiffrin, 1992). Varied mapping on the other hand, produces search performance that is slow, effortful, conscious, and serial. The following quote from Shiffrin and Schneider's (1977) paper neatly sums up the dichotomy between the two processing modes:

> Controlled search is highly demanding of attentional capacity, is usually serial in nature with a limited comparison rate, is easily established, altered, and easily reversed by a subject, and is strongly dependent on load. Automatic detection is relatively well learned in long term memory, is demanding of attention only when a target is presented, is parallel in nature, is difficult to alter, to ignore, or to suppress once learned, and is virtually unaffected by load (p.127).

A large body of evidence has since provided support for Schneider and Shiffrin's (1977) claims. For instance, despite extensive practice VM tasks produce strong set size effects; response times increase systematically with the number of items in the search array. This suggests that participants are conducting an item by item search. Conversely, set size effects diminish considerably following practice on a CM task suggesting that items are being searched simultaneously.

However, like most concepts in psychology automaticity appears to be a much more complex phenomenon than first thought. For instance, Hoffman and Nelson (1984), among others, have provided evidence for attentional limitations in tasks that were thought to be governed by automatic processing. Still other theories have been put forward which propose that resources other than attention may limit performance (e.g. Navon & Gopher, 1979; Wickens, 1984).

Cheng (1985), for example, challenged the view that improvement in performance is due to the development of automatic processing. Instead, Cheng suggests that with practice the components of a task are restructured so that a more efficient task procedure is created. She posits that participants in Shiffrin and Schneider's (1977) experiments could have restructured the CM task by adopting a category strategy as memory set targets were digits but memory set distractors were letters. This, argues Cheng, would negate the need for an item-by-item search and therefore produce a flat response curve. She also notes that previous visual search experiments (e.g. Brand, 1971; Ingling, 1972) have reported that when targets and distractors belong to different categories detection is both faster and more accurate. Further, Duncan and Humphreys (1989) found that the physical similarity between targets and distractors was an important determinant of response curves for both between and within category searches. For instance, Rabbitt (1967) found that when participants were asked to locate a target letter from a designated set among letter distractors, typical set size effects were found early on in practice. With continued practice, however, set size effects diminished so that they no longer had a significant effect on performance. Yet, when the distractor set was replaced set size effects appeared once more (unless the new distractor set comprised letters that were physically similar to the original distractor set). Rabbitt suggested that participants were learning to categorise targets and distractors by specific key features. In reply to Cheng's criticisms, Schneider and Shiffrin (1989) acknowledged the possible existence of restructuring via categorisation within their own results but argued that it could not account for many of their key findings and that automatic processing provides the best explanation for these.

Other criticisms of automaticity theory that specifically address its assumptions concerning visual search have been made by Fisher (1982, 1984, & 1986) and Fisher, Duffy, Young, and Pollatsek (1988). Fisher and colleagues argue that the unlimited capacity in visual search proposed by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) only holds for search arrays of four items or fewer (even for consistently mapped visual search). Perhaps more importantly, Fisher (1986) identified a potential confound in the experimental procedure employed in typical CM/VM training experiments. He argues that researchers have equated the number of trials administered in CM and VM conditions. However, not only are there more targets in the VM condition there are also fewer training trials with any given target-distractor combination. He thus suggests that the superior performance demonstrated by participants following CM training may be due to the imbalance of training rather than as a result of CM training per se.

As a result of his criticisms of automaticity theory, Fisher (1986) put forward his own feature overlap model of visual search. This model views both the degree of featural overlap between a target and its distractors and the amount of training given for particular target-distractor combinations as being essential determinants of the efficiency with which visual search is performed. Fisher proposes that the same mechanisms underlie both CM search and VM search, namely, that stimuli are filtered through a series of parallel feature detectors that are limited in capacity and arranged hierarchically. Fisher describes the process of search as a parallel elimination of distractors which do not comprise the target feature. One feature is first selected and those distractors that do not possess that feature are eliminated. Then a second target feature is selected and those distractor features which do not comprise the second target feature are eliminated, and so on and so forth, until one stimulus is left (or none if it is a target absent trial). Fisher suggests that improvements with training occur as participants become more familiar with specific target-distractor combinations and therefore learn the *optimal feature comparison sequence*.

Lightfoot, Czerwinski, and Shiffrin (1993) put both Fisher's (1986) criticisms of automaticity theory and the feature overlap model of visual search to the test. They conducted a series of visual search experiments that controlled for the confound pointed out by Fisher (1986), that is, the imbalance in the number of trials in CM/VM tasks. In support of Fisher, Lightfoot et al. reported that when the number of trials administered in both the CM and VM conditions was equated, similar response slopes for both tasks were found. However, they also noted that the stimulus set for the VM task was considerably smaller than that of the CM task. Lightfoot et al. therefore argued that the removal of the problem of trial inequality introduced another confound of increased familiarity with the VM stimulus set. Thus, another series of experiments were carried out that increased the overall processing load of participants by introducing a secondary concurrent task. Automaticity theory predicts that in such circumstances a CM advantage will be found. Conversely, the feature overlap model (which argues a single mechanism for both CM and VM search) predicts comparable impairment for both searches when the second task is added. The results reported by Lightfoot et al. provided support for the former.

Yet another theory of automatic processing was put forward by Logan (1988). Logan's *Instance Theory* of *Automatisation* claims to provide a description of the mechanisms underlying automaticity. Logan (1988) and Logan & Etherton (1994) propose that automatic knowledge restructuring occurs only for learning and solutions that can be retrieved from memory. The theory proposes that when an individual practices a task, instances of the performance are stored separately in memory as copies or exemplars. Logan suggests that when an individual encounters a task for the first time and thus has no stored instances, the individual will use whatever strategic, rule-based tools they have available to them. This is referred to as a task *algorithm*. However, as practice with the task continues the individual will not only have the task algorithm available but also the collection of past instances stored in memory. When the task is subsequently carried out, performance will be based either on the task algorithm or on a past instance depending on which is the first to be retrieved from memory. Logan posits that the time to retrieve each instance is based on a probability function determined by the number of previous instances and that when enough instances have been stored it is unlikely that the algorithm will be retrieved more quickly than the fastest instance. Thus, performance will eventually be determined exclusively by past instances. Automaticity, according to Logan, occurs when performance shifts from algorithmic to instance-based retrieval. However, as noted by Druckman and Bjork (1994), the tasks used by Logan to demonstrate his theory place only minimal importance on conceptual structures and therefore favour the retrieval of instances.

Thus, the debate concerning the nature of automatic processing continues. It is important however, that research into the effects of practice on performance considers the changes that take place for tasks that are not automatically controlled as differences in performance with practice occur even when the stimulus and response are not consistently mapped.

Practice increases fluency of performance

The most pervasive effect of practice on performance is increased fluency. Fluency is usually expressed both in the laboratory and in real life situations as speed of performance. Importantly, the greatest changes in performance occur early on in practice.

Snoddy (1926), as a result of his experiments into the acquisition of a motor skill (mirror drawing) went further to suggest that learning can be described as a linear function of the logarithms of time and trials using the following equation:

$$\log C = \log B + n \log x$$

where C is a measure of performance, x is the number of trials or time on a task, and B and n are constants. Thus, there are large increases in speed of performance from trial to trial early in practice and smaller increases with additional practice.

A field study which yielded a large amount of data about the effect of extended practice on performance was carried out by Crossman in 1959. Crossman studied operators of hand-operated cigar machines with varying levels of experience at the job and plotted their speed of performance as a function of experience. Operators varied in the number of cigars made prior to testing from 10,000 to over 10 million. Crossman found that speed of performance increased linearly for a period of four years (approximately 3 million cigars) before asymptote was reached and performance plateaued (see figure 1.1).

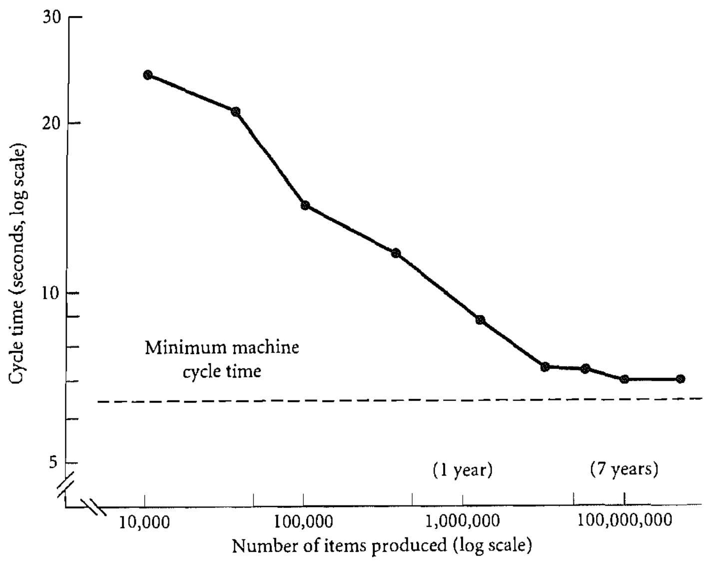

Figure 1.1. Cycle time as a function of experience (Adapted from Crossman, 1959)

However, as noted by Proctor and Dutta (1995), the asymptotic performance reported was possibly due to the limitations of the machinery rather than to the cognitive limitations of the operators.

Seibel (1963) in a further study into the effects of practice on learning reported certain irregularities in learning curves. Participants were trained in using a ten-finger key board which allowed all possible combination of keys to be activated (1023 patterns in total). The experiment continued for a period of several months totalling more than 75,000 responses. The resulting learning curves for participants supported those found by Crossman (1959) and Snoddy (1926) except that at around 30,000 responses the slope of the function changed. Seibel found that for a certain number of responses participants' performance would be either reduced or raised in a systematic way. Subsequent research has reported similar irregularities in most learning curves (see Stevens & Savin, 1962). It appears that if a large number of trials are administered close together, the slope of the curve is reduced only to recover following a decent period of rest.

This relationship between practice and performance has become known as the *power law of practice* (Newell & Rosenbloom, 1981) and is described by the following equation and its equivalent log-log form:

$$T = BN^{-\alpha}$$

$$\log(T) = \log(B) - \alpha \log(N)$$

where T is *time* to perform a task, N is the *number* of trials and B is the *baseline*, the performance time on the first trial ($N = 1$). The rate of improvement, α, is the slope of the learning curve, which forms a straight line when the function is graphed in log-log space (see Figure 1.2). In other words, the time taken to complete a task decreases directly in proportion to the number of trials raised to the above power function. Newell and Rosenbloom suggested that this power function can not only be applied to perceptual motor skills but also to simple cognitive skills.

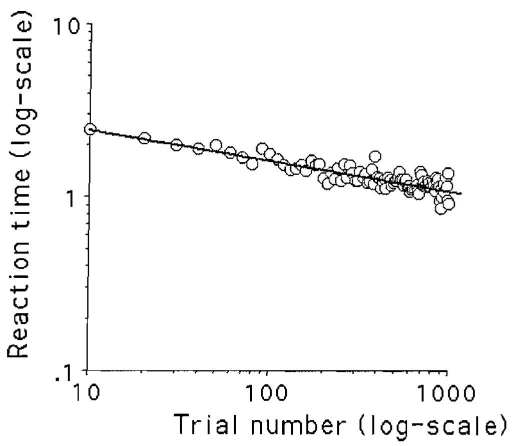

Figure 1.2. The logarithmic form of the Power Law of Practice (adapted from Newell & Rosenbloom, 1981).

The explanation for the Power-law given by Newell and Rosenbloom is that practice results in the chunking of small general pieces of knowledge into larger specific pieces of knowledge. Therefore, speed of performance can be described as a function of the number of chunks to be implemented. However, not all theorists explain speedup of performance in this way. McKay (1982), for instance, views increased fluency with practice as resulting from the faster implementation of the processes underlying the task. It must also be noted that the purported ability of the Power Law to describe all skill learning has been challenged by a number of researchers (e.g. Carlson & Lundy, 1992; Heathcote, Brown, & Mewhort, 2000; Newell; 1991). Carlson (1997), for instance, argues that an increase in task speed is not always the primary objective of skill learning and provides the examples of music performance and public speaking to demonstrate that smooth, accurate performance with correct timing is perhaps more important for these abilities. However, it has also been suggested that *accuracy* on certain tasks also develops according to the power law (Logan, 1988). Heathcote, Brown and Mewhort (2000) on the other hand argue that a Law of Practice is better described by an exponential rather than a power function (see also Myung, Kim, & Pitt, 2000). Furthermore, a growing body of research suggests that power law learning occurs within the strategies that are employed and not within the task as a whole (Rickard, 1997; Delaney, Reder, Staszewski & Ritter, 1998). Indeed, Compton and Logan (1991) argue that improvements in task performance occur as a result of the adoption of more efficient strategies.

The numerous studies that have examined the acquisition of skilled performance have also yielded a number of factors which affect the ability of practice to facilitate skill learning, for instance, spacing, independence, and feedback.

Spacing of practice: Acquisition vs. retention

The manner in which practice is administered and its effect on skill learning has also received considerable attention. Baddeley and Longman (1978) reported findings from a study involving trainee postal workers learning to type in postal codes. Baddeley and Longman manipulated the training schedules so that one group were given massed practice and the other distributed practice. They found that massed practice resulted in faster acquisition of skill and was preferred by participants because they could do the skill sooner. However, distributed practice produced better retention of the skill and is therefore viewed as a superior training technique. Further, Shea and Morgan (1979) examined the acquisition and retention of rapid, multiple-component arm movements. Participants made movements either in set order (blocked) or in random order (random). They found that blocked trials produced faster skill acquisition. However, randomly administered trials elicited superior retention.

Feedback: Acquisition vs. retention

Experiments looking at the effect of feedback on learning have found that learning speed is improved when feedback about correctness or error is given (Salmoni, Schmidt, & Walter, 1984). Salmoni et al. for example, in a study investigating the acquisition of complex arm movements found that the speed with which the skill was acquired increased with the amount of feedback that was given. However, when the participants were tested several days later it was found that the group who received the least amount of feedback demonstrated better retention of the skill. The amount of time between action and feedback has also been shown to be important (Patrick, 1992). The action must still be in memory to understand what led to the error. However, it has also been demonstrated that immediate feedback or too much feedback can actually impair learning as participants become too dependent upon the feedback and processing the feedback itself can interfere with the task. Individual differences in the effect of feedback on performance have also been found. For instance, administering trial-by-trial feedback has been shown to impair the performance of older participants (Hines, 1979).

Transfer: concept and predictions

The learning of an entirely new skill following the first few years of life is rare; more often than not skills are developed from those that already exist. Thus, the learning of skills is therefore largely a matter of transfer of prior habits to new situations (Fitts & Posner, 1967). It is therefore not surprising that a large proportion of skill research has investigated Ebbinghaus's (1885) concept of transfer. Three types of transfer have been defined. Firstly, *positive* transfer occurs when a previously learned skill facilitates performance of another skill. Secondly, *negative* transfer occurs when a previously learned skill interferes with the performance of a subsequently acquired skill, and thirdly, *zero* transfer occurs when a previously learned skill has no effect on the ability to acquire a new skill.

The principles of transfer can be demonstrated both in activities of daily living and in the laboratory. For example, if an individual learns to drive a car which has the indicator arm on left of the steering wheel and the windscreen wiper on the right but then purchases a car which has these functions on opposite arms, several months will most likely be spent wiping the windscreen while turning a corner. However, while the committing of such errors causes a minor irritation for the individual concerned, they could have more serious consequences in a situation where a pilot who has learned the layout of controls in one kind of aircraft is then moved on to flying in other (Proctor & Dutta, 1995). Numerous laboratory experiments have also provided a demonstration of the principles of transfer. In a typical experiment, there is an Experimental Group that gets both tasks and a Control Group that gets only the transfer task. The researcher then compares the two groups' rates of learning on the transfer task. Faster learning by the Experimental Group indicates positive transfer; slower learning indicates negative transfer.

A number of formal models have been put forward which postulate the conditions under which transfer occurs (e.g. Higginson, 1931; Osgood, 1949; Thorndyke & Woodworth, 1901). It was once commonly believed that practising cognitive tasks fostered general ability. For instance, according to the *doctrine of formal discipline* formulated by the empiricist philosopher John Locke in 1700 (for a review see Higginson, 1931), the mind is made up of general faculties such as attention and reasoning and that the learning of difficult subjects such as mathematics or Latin for example, leads to the development of *general* abilities that underpin most mental activities. In other words, broad-based abilities that can be applied to a variety of learning situations are acquired rather than a specific set of stimulus-response associations. Moreover, the doctrine proposes that the mind can be exercised like a muscle and that only the level of exertion is important. However, results from studies conducted during the early 1900s suggest that transfer is much more limited and specific in nature than that purported by the doctrine of formal discipline. A series of experiments conducted by Edward Thorndyke and Robert Woodworth in 1901 provided evidence against the suggestion that practice on one task can result in the development of general skills that can then positively transfer to related tasks. They stated that:

> The mind is ...a machine for making particular reactions to particular situations. It works in great detail, adapting itself to the special data of which it has had experience.... Improvements in any single mental function rarely brings about equal improvement in any other function, no matter how similar, for the working of every mental function group is conditioned by the nature of the data of each particular case(pp. 249-250).

Thorndyke and Woodworth (1901) instead proposed the *theory of identical elements.* According to this theory the mind is not made up of general faculties but rather specific habits and associations. The theory posits that training in one kind of activity will transfer to another only if the activities share common situation-response elements. However, a problem with Thorndyke and Woodworth's theory is that the concept of identical elements is not clearly defined. Identical elements are usually expressed in terms of stimulus-response connections. It has been suggested that Thorndyke and Woodworth used the term to describe mental elements (Druckman & Bjork, 1994). The theory has also been criticised for being too narrow and subsequent research has suggested that transfer isn't tied to the identity of stimulus elements (see Polson, Muncher & Kieras, 1987). An instance of transfer between non-identical elements, for example, was reported by MacKay (1982) in a study using English-German bilingual speakers who were asked to repeat out loud the same sentence in the same language for a total of twelve times at twenty second intervals. However, in the last twenty second interval, participants were instructed to produce the same sentence but in the alternate language. The speed of production for the last sentence was found to be the same for that of the previous trial. Thus, transfer occurred despite a change in the stimulus-response connection as different motor movements were necessary for production of the final sentence. Conversely, Logan and Klapp (1992) found only a small amount of transfer from training on a set of alphabetic arithmetic problems when the stimulus set was changed. The results from both Mackay and Logan and Klapp's studies suggest that the nature of the identical element is important in determining whether transfer occurs.

Empirical research carried out by Osgood in (1949) attempted to determine more precisely the conditions under which transfer does or does not occur. Osgood put forward a model characterised by three principles: (1) positive transfer occurs when responses made to stimuli are identical (amount of transfer increases with stimulus similarity), (2) negative transfer occurs when stimuli are identical but responses to the stimuli are varied (amount of negative transfer increases with response dissimilarity), and (3) transfer is negative when both stimulus and response are varied (see Figure 1.3 below).

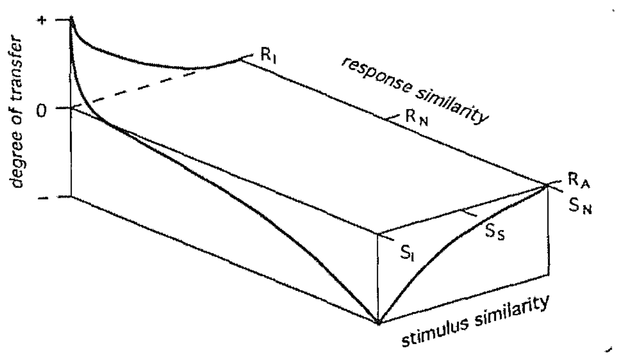

Figure 1.3. *Depiction of Osgood's transfer surface from Proctor & Dutta (1995). Response similarity is represented on the X axis, marked by "identical" (I), "neutral" (N), and "antagonistic" (A) responses.* Stimulus similarity is on the Z axis, where I represents *"identical", S represents "similar", and N represents "neutral". The Y axis shows the expected degree of positive or negative transfer.*

Figure 1.3 above illustrates that positive transfer increases with both stimulus and response similarity. Indeed, Postman and Underwood (1973) found evidence to support this from studies of verbal learning. However, as Singley & Anderson (1983) point out, the skill literature does not always bear this out. Further, the predictions made by Osgood's (1949) model, especially those relating to negative transfer have not always proven accurate (Bugelski & Cadwallader, 1956). For example, when learned stimuli were paired with novel, but similar responses to the original ones, negative transfer was found to be unusually strong. This effect is commonly referred to as the Skaggs-Robinson paradox (Robinson, 1927). Interestingly, Singley & Anderson (1989) in a test of transfer using text editors that were designed to interfere with one another found that negative transfer occurs largely during the early stages of learning the transfer task. Other transfer surface models have subsequently been put forward (e.g. Holding, 1965) but all may be criticised for ignoring important factors that influence transfer such as training schedules, nature of training, and feedback (Druckman & Bjork, 1994).

In summary, the factors affecting skilled performance are both numerous and complex. However, in spite of this, formal theories describing how skilled behaviour is acquired have been put forward. The next section in this chapter, therefore, will outline the main theories of skill acquisition.

Theories of Skill Acquisition

Introduction

Skill acquisition according to Rosenbaum, Carlson, and Gilmore (2001) refers to the "attainment of those practice-related capabilities that contribute to the increased likelihood of goal achievement" (p. 454). During the acquisition of a skill, changes in performance are both qualitative and quantitative. Thus, not only are there improvements in overall efficiency of performance but there are also enhancements in the nature of performance (Neves & Anderson, 1981). Qualitative differences in skilled versus unskilled performance can be evidenced in the seemingly effortless way a skilled performer carries out a task. Conversely, the same task carried out by the unskilled performer looks clumsy and effortful by comparison as they struggle to deal with the overload of new information (Matthews, Davies, Westerman, & Stammers, 2000). An observation of skilled performance by Annett and Kay (1956) characterised the skilled performer as being able to take advantage of redundancy in task sequences along with making predictable and consistent responses. Annett and Kay also observed that skilled performers and unskilled performers make different types of error. Namely, skilled performers are likely to make errors by selecting the wrong *sub-routin*e, whereas unskilled performers are more likely to commit errors of sequence or timing. Since the 1960s a number of theories have been developed which seek to explain the transformation from unskilled to skilled performer. A discussion of the main contributors will now follow.

Fitts' phases of skill acquisition (1962, 1964)

In 1962, Fitts put forward a theory of perceptual-motor skill acquisition which arose from experimental research conducted mainly with sports persons and pilots. He proposed that skill acquisition is characterised by three phases through which an individual progresses: *cognitive*, *associative*, and *autonomous* (also referred to as early, intermediate, and late by Fitts in 1964).

Cognitive phase

This phase is so-named because of the heavy reliance placed by the learner on conscious or effortful cognitive processing. During this early phase of skill acquisition, the learner is trying to comprehend the nature of the task and the requirements for successful performance before applying them. Hence, this phase is characterised by the learner's dependence on reading, discussion and general information gathering about the task. The learner may then attempt to carry out the task during this phase; however, errors or inefficiencies in performance usually occur.

Associative phase

Once the learner has understood both the instructions for carrying out the task and the requirements of the task, progression then continues to the next stage, namely, the associative stage. According to Fitts (1964), during this stage, the task is practised by the learner until it is performed accurately and with the right timing characteristics. Further, this is also the stage in which sequences of events underlying the activity are chunked together so that the task becomes more smoothly implemented. Moreover, as practice with the task continues the learner is able to dual-task (carry out additional tasks at the same time as the principal task). Thus, the advancements made at this stage lead to more flexible performance. Importantly, Fitts suggests that for many skills, transition to the third and final stage will not occur for many people. The key, according to Fitts, for progression to the autonomous stage, is practice.

Autonomous phase

This stage is only reached after a prolonged period of intensive practice. Activity carried out during the autonomous phase is very different to that described in the previous two stages. For instance, in the autonomous stage the learner becomes increasingly unaffected by distracting information that is not relevant to the task (Hartley, Morrison, & Arnold, 1989). In addition, the ability to dual-task is further enhanced (see Bahrick & Shelly, 1958). Thus, performance at this stage has often been referred to as *automatic*, *unconscious*, *involuntary*, or *resource-free*. However, a number of experiments have produced dissociations in these constructs (e.g. Paap & Ogden, 1981). In light of these reported dissociations, researchers within the field of visual attention have proposed a more activation-based model of automaticity that views control of processing as being influenced by both stimulus-driven and voluntarily controlled activation (Cohen, Dunbar, & McClelland, 1990; Cave & Wolfe, 1990). Thus it may be concluded that skilled performance becomes at least partially automatised with extensive practice. Other theories of skill acquisition have subsequently been developed, all of them based on the initial model put forward by Fitts (1962, 1964).

Anderson's (1982, 1983, 1995) ACT Theory

Anderson's take on Fitts' three phases produced a framework specifically for the acquisition of cognitive skill (Proctor & Dutta, 1995). In addition to the transitional process, Anderson was particularly interested in the cognitive processes underlying performance at each stage and unlike Fitts describes skill acquisition as comprising two stages; *declarative* and *procedural.* These two stages parallel the *cognitive* and *autonomous* stages proposed by Fitts. Anderson negates the need for an intermediary stage *per se* and instead views the transition between the two stages as being the result of the process of *knowledge compilation* whereby declarative knowledge is proceduralised.

Declarative stage

During this stage the learner receives elementary information relating to the skill. In other words, a set of facts about how to carry out the task is acquired, for example, the rules needed to carry out a mathematical calculation. This basic information, referred to as declarative knowledge, must be rehearsed in working memory to keep it available so that the means of accomplishing the desired goal can be deduced.

Procedural stage

As the learner practises the task, the declarative knowledge is *compiled* into procedural knowledge (often referred to as production rules) which enables the task to be performed without the active maintenance of declarative knowledge. An interesting feature of skilled performance is that the declarative knowledge is no longer available in its original form; that is, the task can be carried out quickly and accurately but the facts and rules underlying the skill cannot be accessed (Anderson, 1980). As an example, Anderson (1980) describes showing a novice how to change gear in a car with a manual gearbox. To successfully convey the declarative rules of sequence to the learner the teacher has to sit in the driving seat and work through the task in slow motion. Once the procedural stage has been reached, refinement of the procedures continues to improve performance. Anderson refers to the process of refinement as *tuning* and results in an individual committing fewer errors and becoming more skilled at making task-related decisions (Bosman & Charness, 1996). The amount of practice required to acquire a given skill depends upon the complexity of the tasks that underlie it. Gentner (1988), for example, suggests that to achieve a typing speed of 60 net words per minute approximately 600 hours of practice are required. Very simple skills, on the other hand can be acquired after just a few hours of practice, whereas, more complex skills such as chess and piano playing require at least ten years of intensive, deliberate practice to achieve elite performance (Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Römer, 1993).

Rasmussen's Skill (1979, 1982, 1986, 1987), Rule, Knowledge (SRK) based approach

The SRK classification system put forward by Rasmussen (1979, 1982, 1986, 1987) proposes three modes of performance: *knowledge-based*, *rule-based*, and *skill-based.* These three modes refer to the amount of conscious control that an individual exercises over his or her activities. Rasmussen equates these with Fitts's (1962, 1964) cognitive, associative, and autonomous phases respectively (Proctor & Dutta, 1995).

Rasmussen's (1979, 1982, 1986, 1987) knowledge based mode, like Fitts's (1962, 1964) cognitive phase characterises performance here as being dependent on verbal mediation and effortful conscious processing. During this stage, an individual exerts considerable mental effort to assess a given situation and as a result produces slow responses. However, whereas Fitts views the cognitive phase as the early stage of skill acquisition, Rasmussen regards knowledge based behaviour as just being the present mode of performance (Proctor & Dutta, 1995).

Performance during the rule based stage is like the knowledge based stage in that it also characterised by effortful and conscious processing. However, rather than behaviour resulting from the knowledge of a system it takes the form of stored rules (productions) that have been acquired either through interaction with the task environment, formal training, or working with individuals experienced in the task (Rasmussen, 1983).

Finally, performance during the skill-based stage is characterised by "smooth, automated, and highly integrated patterns of behaviour" (Rasmussen, 1983, p.258) in which conscious thought is not required.

Rasmussen's model, although having elements in common with both Fitts's phases of skill acquisition and Anderson's framework of cognitive skill acquisition has an important difference; progression through the stages of skill acquisition is not fixed (Proctor & Dutta, 1995). Rasmussen, instead, views skill acquisition as a dynamic process whereby new skills can be integrated with existing ones and existing skills can adapt and change to task demands and novel situations in which an automatic response is not always appropriate.

In summary, all theories of skill acquisition regard the learning of a new skill as a process whereby the mechanisms underlying performance early on in practice are qualitatively different to those that characterise performance following extensive practice (with the amount of practice needed to achieve skilled performance determined by the complexity of the skill). However, these theories differ in terms of both the number of stages involved in the skill acquisition process and whether these stages are invariant.

The next chapter will outline the effects of another variable on performance, namely, age. It will become apparent, as the following chapter progresses, that the variable of age has somewhat different effects to that of skill on performance.

CHAPTER TWO

COGNITIVE AGEING

Introduction

Research into the effects of ageing on mental abilities has a long and somewhat chequered history. Nonetheless, the results from over seven decades of both cross-sectional and longitudinal studies indicate that there is some decline in cognitive function in older adulthood (Horn, 1967; Horn & Noll, 1997). This chapter will outline the major traditions within this area, namely, the psychometric and experimental approaches, before discussing the main theories of cognitive ageing.

An Historical Overview of the Literature

The psychometric approach

The psychometric approach initially associated cognitive abilities with the unified construct of general intelligence (g) devised by the English psychologist Charles Spearman (1904, 1927). The construct of *g* came about after Spearman noted that individuals who performed well on tests measuring one type of mental ability tended to do well on tests measuring other types of ability. Thus, Spearman argued that all types of cognitive skills, for example, verbal, spatial, and numerical, are determined by a single basic ability (g). Spearman's g has remained an important player in psychometric research but now tends to be used statistically to describe the overall score on a battery of ability tests. Subsequent research suggests that intelligence is not a unitary concept but is rather multidimensional in nature with most researchers claiming that it is made up of a number of *interrelated* skills (see Eysenck & Kamin, 1981; Kail and Pelligrino, 1985; Rebok, 1987). The most influential theory in psychometric research, however, is the hierarchical approach put forward by Cattell (1971). This approach, akin to that of Spearman, argues that all mental abilities draw on a general intellectual ability. However, it also suggests that specialised skills are additionally employed according to task demands.

Cattell (1971) and Horn (1967, 1978) suggested that the specialised skills underlying intelligence should be divided into two classes: crystallised intelligence (Gc) and fluid intelligence (Gf). Crystallised intelligence refers to an individual's knowledge that has accrued over a lifetime of experience. Tasks purporting to measure crystallised abilities include tests of verbal comprehension and vocabulary. Crystallised intelligence tests also assess a person's practical or moral knowledge and can only be successfully completed if that person already has the required information stored in memory. Conversely, fluid intelligence refers to aspects of cognition that are somewhat independent of knowledge such as the ability to solve novel problems. Further, fluid abilities are most often assessed by tests that require rapid responses.

Early cross-sectional studies of age changes in intelligence found that intelligence test scores increased until they reached asymptotic levels in early adulthood and then decreased steadily from about age thirty onwards. However, Horn and Cattell (1967) made a distinction between two different patterns of age-related changes on intelligence measures that consistently emerged on intelligence tests. Namely, they found an age-related decline in test scores for tasks measuring fluid abilities but no such decline for tasks measuring crystallised abilities. Indeed, most of the subsequent research that has been conducted has found support for the notion that crystallised and fluid intelligence are differentially affected by the ageing process. The results of such research suggests that fluid abilities are particularly sensitive to age but that crystallised abilities tend to remain stable or even improve with age (e.g. Denny, 1982; Horn, 1982; for a review see Schaie, 1994).

The cross-sectional method often used in psychometric research has been criticised, however, for exaggerating age differences in fluid cognition due to possible cohort effects (e.g. Salthouse, 2000). Further, longitudinal evidence suggests that small declines in fluid intelligence are not apparent until approximately fifty years of age. For instance, a large-scale longitudinal study carried out by Rabbitt, Donlan, Bent, McInnes, and Abson (1993) found that individuals in their 50s, 70s, and 80s differed in terms of their performance on tests of fluid cognition but not on measures of crystallised abilities. However, longitudinal research has its own set of methodological issues. For example, a different type of cohort effect can occur in longitudinal search; that is, studying a group of participants born in 1930 might elicit a different pattern of age-related change in comparison with a group born in 1950 (Stuart-Hamilton, 2000). Also, longitudinal studies tend to suffer attrition as many participants drop out of this type of study. A reason for participant drop-out could be geographical relocation. However, participants might also lose their enthusiasm for taking part. The latter reason for quitting is more perturbing as it could result in only the most motivated participants being left in the participant pool which could potentially bias the results.

Despite the aforementioned methodological issues, there has been widespread use of psychometric testing in cognitive ageing research. The validity of psychometric tests as a means of assessing age-related changes in cognitive abilities has, however, been criticised. Firstly, it has been noted that the tests were originally designed to ascertain the requirements of children with special education needs (see Binet & Simon, 1905, as cited in Kausler, 1991) and only subsequently were they adopted for adults. Thus, the abilities exhibited by children may no longer be relevant in adulthood (Baltes & Willis, 1979). Secondly, there may be categories of abilities that are more relevant in older adulthood that are not tapped into by standard psychometric tests (Salthouse, 1991). Moreover, Salthouse argues that psychometric tests, with their tendency to group abilities together cannot determine if fluid abilities themselves are differentially affected by age. In an attempt to address this criticism, researchers have developed batteries of tests that purport to distinguish between different cognitive abilities. One such test battery is the Primary Mental Abilities Test (PMA) developed by Thurstone (1941, 1947) and refined by Thurstone and Thurstone (1958). The PMA claims to measure five different facets of cognition: number ability, reasoning ability, visual-spatial ability, verbal meaning ability, and word fluency skill. Larger test batteries such as the Weschler Adult Intelligence Scale-Revised (1981) have also been developed which comprise numerous sub-tests designed to measure both fluid and crystallised aspects of intelligence. However, in spite of the continued refinement and development of these tests, Rabbitt (1993) argues that they can only ever provide a description of age-related changes in cognition and not an explanation of the mechanisms responsible for these changes. Nevertheless, psychometric tests provide a useful means of comparing the performance of groups of individuals and are a valuable adjunct to the experimental approach to cognitive ageing that will be outlined next.

The experimental approach

The experimental approach, in contrast to the psychometric approach, seeks to identify specific causal variables that can explain why many cognitive processes are sensitive to age. Further, cognitive skills are examined in the laboratory within the traditional experimental areas of sensation, perception, attention, learning, memory, concept acquisition, problem solving, and reasoning (Kausler, 1991). Thus, if a researcher was interested for instance, in the effects of age on visual search performance, an experiment might be designed that manipulates the difficulty of search. Visual search performance of younger versus older participants can then be compared. A significant interaction, with older participants exhibiting slower response times on the difficult search in comparison to younger participants would suggest that the processes underlying the difficult search condition are particularly age-sensitive. Scialfa and Joffe (1997) used this method to test for age differences in feature and conjunction search. They found that age differences increased as a function of task difficulty (i.e. age negatively affected conjunction search but not feature search).

The experimental approach, like the psychometric approach has its own set of methodological issues. For instance, most of the experimental cognitive ageing research has employed an age-comparative design (Schaie, 2001). In other words, groups of younger adults (often undergraduate university students) are compared with opportunity samples of older community-dwelling adults (usually in their sixties and seventies). This particular method of participant recruitment means that it is extremely unlikely that both groups of participants will be matched on important status variables such as education. This complicates the processes of isolating causal mechanisms responsible for age-related declines in the variable of interest. Furthermore, age-comparative designs can also not account for individual differences in performance.

Many researchers, however, employ both psychometric and experimental techniques in an effort to gain a more thorough understanding of the effects of age on cognitive functioning (e.g. Stankov, 1998). One common finding is that performance on so-called fluid abilities, as measured by either psychometric tests or experimental methods, show reliable declines with increasing age (for reviews see Birren & Schaie, 1996; Salthouse, 1991,1992).

Theories of Cognitive Ageing

Macro versus micro approach

Broadly speaking, the various theories of cognitive ageing have their roots based in one of two approaches. These two approaches have been at the forefront of cognitive ageing research for the last five decades. Firstly, the *macro approach* to cognitive ageing examines the effects of age-cognition relations on one variable within the context of age-related effects on other variables (Salthouse, 2000). This strategy is closely related to the psychometric approach, and employs correlational techniques to investigate patterns of relations among variables along with multivariate techniques such as structural equation modelling and factor analysis.

Secondly, the *micro approach* which has close links with mainstream experimental psychology tends to examine the nature of age effects on a single variable by attempting to break down the construct into its component parts. This strategy, established by Alan Welford in 1958, is closely related to the information-processing perspective of cognition. In an examination of the effects of age on visual search performance, for instance, the micro approach would tend to look for differences in processing between different types of visual search, for example, parallel versus effortful processing. The macro approach, in contrast, would look for age effects in a single process that underlies performance on the task, for example, attentional capacity or processing resources. Rabbitt (1997), however, argues that if it is found that performance on any single variable can be quantified by performance on another variable, then cognitive ageing studies using response time measures cannot determine whether age negatively affects some mental abilities more than others (Rabbitt, 1997).

Thus, the micro and macro approaches are concerned with different levels of analysis, but as with the psychometric versus the experimental approach, it is likely that a combination of the two methodologies will yield the most fruitful information.

Resource reduction theories: processing speed, working memory, and attention

Resource reduction theories seek to explain age-related changes in cognitive abilities as a reduction in a small number of processing resources. Single resource theorists (e.g. Cerella, 1985) maintain the view that a single processing resource is responsible for the *all* age differences found in cognitive processing. Indeed, research has been provided to suggest that the response latencies of older and younger adults can be explained by a single linear function (Cerella, 1985; Cerella, Poon, & Williams, 1980; Myerson, Hale, Wagstaff, Poon, & Smith, 1990). In light of these findings the 'general slowing hypothesis' of cognitive ageing was formulated (e.g. Birren, 1974; Cerella, 1985, 1990). Although, research has since moved away from the single resource perspective, most cognitive ageing researchers believe that cognitive performance is determined by a small number of independent resources (Kail & Salthouse, 1994; Navon & Gopher, 1979; Wickens, 1984). The fundamental issue of just what constitutes a processing resource has been has been explored by many theorists. Salthouse (1985, 1988), for example, argues that processing resources may be conceptualised in terms of limitations of time, limitations of space, and limitations of energy. Four main contenders for the role of cognitive resource have been specified: *speed of processing* (Cerella, 1985; Salthouse, Rogan, & Prill, 1984); *working memory function* (Baddeley & Hitch, 1974; Craik, 1977); *inhibitory function* (Friedman & Polson, 1981; Kahneman, 1973; Wickens, 1980); and *sensory function.* Further, some theorists have argued that combinations of these processing resources might be a better index of cognitive resource than any one measure (Salthouse, 1991).

Reduction in information processing speed

An early argument concerning age changes in measures of intelligence was that a decrease in the speed of behaviour with age impaired intelligence test performance of older adults (e.g. Jones, 1959; Lorge, 1936). Further, in 1965 Birren put forward the idea that a decrease in the speed that elementary mental operations are carried out was solely responsible for the age-related variance found in performance of older adults on measures of cognitive ability. Subsequently, Salthouse (1991, 1996a) amassed a substantial amount of evidence in support of this theory from pen and paper tasks that were designed to assess perceptual speed. These tasks require participants to make speeded perceptual judgements by comparing pairs of digits, letter strings or substituting digits for a specified symbol. Rate or speed of processing is indexed by the number of accurately completed items within a fixed time period of around one to three minutes. Salthouse argues that knowledge of an individual's processing speed can explain the age-related variance in their performance on a wide variety of cognitive tasks. In other words, age deficits in working memory performance are significantly reduced when the variable of speed of processing is statistically controlled for (Salthouse & Babcock, 1991).

Strong support for the processing speed theory of cognitive ageing has been provided from additional studies carried out by Salthouse (e.g. Salthouse, 1993, 1994, 1996b; Salthouse, Fristoe & Rhee, 1996) and by others (Bors & Forrin, 1995; Lindenberger, Mayr, & Kliegl, 1993; Sliwinski & Hall, 1998). Maylor and Rabbitt (1994) for instance, utilised a technique developed by Brinley (1965) to plot younger and older adult response times on a letter coding and visual search task. The resultant latency slopes were found to be highly linear thus providing support for the regularity of age effects on performance. Further evidence for the processing speed theory of cognitive ageing was supplied by Bryan and Luszcz (1996) and separately by Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, & Gaines, 1996. These researchers reported that correlations between age and free recall, and age and cued recall are significantly reduced when processing speed is statically controlled for. Similar results have also been found for measures of reasoning ability (Salthouse, Fristoe, McGuthry, & Hambrick, 1998). Moreover, the results of a meta-analysis of ninety one studies carried out by Verhaeghen and Salthouse (1997) demonstrated that speed of processing shared 79% variance with the variables age and reasoning. Thus, it appears that statistically controlling for processing speed significantly, although not entirely, reduces the correlation between age and various measures of mental ability.

Two principal mechanisms have been put forward by Salthouse (1996) to explain the relationship between speed of information processing and cognitive ability. Firstly, the *limited time mechanism* purports that the time to carry out later mental operations will be dramatically reduced if a large amount of the available time is spent performing earlier operations. Secondly, the *simultaneity mechanism* proposes that because of the additional time taken by older persons to process information, the results of earlier mental operations will be lost by the time processing of later operations has finished (if they are indeed completed). In other words, older adults do not achieve the same level of performance as younger adults on cognitive tasks because they are slow to process the early components of the task. Further, this may result in them not completing the later components as the results of earlier processing are no longer available to them (Park, 2000). It is important to note that the mechanisms hypothesised by Salthouse also explain how older participants will be impaired on tasks that do not even require a speeded response because they may not be able to complete all the operations necessary for successful performance. Thus, the theory also accounts for the complexity effect in cognitive ageing whereby older participants exhibit larger deficits in performance as the task becomes more difficult.

In summary, the speed of processing theory has received much empirical support from a wide range of studies demonstrating how rate of processing accounts for much of the age-related variance found in cognitive tasks. However, speed of processing does not account for all age-related variance, and thus the results are not definitive. It is possible that other factors yet to be determined play an important role in the process of cognitive ageing. Researchers are currently trying to find exceptions to the results reported above. Such exceptions to the rule of general slowing, for instance, are referred to as dissociations (Perfect & Maylor, 2000). Sliwinski and Hall (1998) reported one such dissociation from the results of a meta-analysis. They noted that the slowing ratios of younger and older adults were smaller for memory search than for visual search. This was further confirmed by the results of a time-accuracy experiment carried out by Verhaeghen (2002). He found older participants to be disproportionately slower on certain components of visual search and memory search. In light of the evidence presented above it is clear that research has yet to ascertain the precise role of slowed processing speed in cognitive ageing.

Reduction in working memory capacity

Memory is not a unitary construct as it comprises a number of dissociable processes that are served by distinct brain regions. Thus, memory is a complex cognitive function that takes a variety of forms, only some of which are negatively affected by age. Further, those types of memory process that are affected usually exhibit only small age differences (Park, 2000). Craik and Byrd (1982) argue that the proficiency of older adults to engage in what they term *self-initiated processing* is impaired. They conclude that the processing resource which best accounts for this observed deficit is that of working memory. Working memory has been separated from other types of memory as a result of its ability to affect performance on a wide variety of cognitive tasks (Salthouse, 1991). In other words, as Baddeley (1986) states, "The essence of the concept of working memory lies in its implication that memory processes play an important role in non-memory tasks" (p. 246). The concept of working memory can be best described as the "amount of on-line cognitive resources available at any given moment to process information" (Park, 2000. p. 11). Further, the amount of information available to us at any given time is something between four and seven items (Miller, 1956). This approximately translates to a few seconds of spoken words. Typical working memory tasks involve participants trying to simultaneously store and manipulate information. The number of items successfully manipulated (e.g. simple arithmetic problems) while correctly recalling the relevant piece of information (e.g. the answer to the previous arithmetic problem) is taken as an index of working memory capacity.

Although age related decrements on working memory tasks are robust, it is important to point out that these performance deficits can be reduced by the provision of *environmental support* (Craik & Byrd, 1982). The notion of environmental support refers to features of a cognitive task that reduce the memory requirement of that task. Park (2000) provides an example of how environmental support, in terms of modality of presentation of survey questions, can act to reduce the demands placed on working memory for older adults. An auditorily presented questionnaire comprising multiple-choice alternatives will place high demands on working memory but be low in environmental support as respondents will have to both store the information and manipulate the response alternatives simultaneously. However, the same questionnaire presented visually will place low demands on working memory but will provide a high level of environmental support as respondents will not have to hold the items in working memory in order to make their decisions. A number of experiments that have manipulated the level of environmental support have provided evidence for its ability to ameliorate age differences on cognitive tasks (e.g. Park, Smith, Morrell, Puglisi, & Dudley, 1990; Cherry, Park, Frieske, & Smith (1996).

Reduction of inhibitory processes

Another factor purported to influence age differences in cognitive function is attention. It is not possible to be simultaneously aware of everything that is in our current environment, not just because the human sensory system lacks the ability to take in such a vast amount of data at once, but more importantly perhaps because certain aspects of our environment are more important to us than others. In other words, it is necessary for us to be able to focus our attention on the road ahead while driving and not be distracted by the cows in the adjacent fields. It is equally important for us to be able to shift our attention to where it's most needed at a particular point in time and to carry out more than one task concurrently. Impairment in the ability to do any of these things can result in disastrous consequences; for example, failing to notice the green traffic light turn to red in time so that you can switch your attention from the radio in order to brake while simultaneously depressing the clutch pedal.

Certain researchers have suggested that attention serves as a source of energy for mental operations and that a reduction in the supply of this energy will produce performance decrements on cognitive tasks (e.g. Hasher & Zacks, 1979, 1988; Plude & Hoyer, 1985). However, while the speed of processing theory has received considerable support, the evidence for the attentional resource theory has not been as persuasive (Parkin, 1997). Alternatively, Hasher and Zacks (1988) suggest that a specific attentional deficit is responsible for age-related differences in cognitive function. They argue that with increased age there is a decrease in the ability to suppress distracting (irrelevant) information. Thus, Hasher and Zacks propose that the attentional pool available to older adults is diffused across both relevant and irrelevant information. Further, they suggest that disinhibition results in task-irrelevant information entering working memory. This results in irrelevant information being maintained in memory along with the information relevant to the task at hand, thus, giving the illusion that working memory capacity has declined but in reality the deficiency lies in reduced inhibitory processes. The results from negative priming studies have provided support for Hasher and Zacks's theory (e.g. Hasher, Stoltzfus, Zacks, and Ryma (1991). Importantly, the process of inhibition has been neuroanatomically linked to the frontal lobe of the brain from which there is a prominent loss of neurones with increased age (Balota, Dolan, & Duchek, 2000). Other researchers have argued that the construct of inhibition is not reliable (e.g. Burke, 1997) and that other explanations such as reduced processing speed or decreased working memory capacity are able to provide a better account of the phenomenon of cognitive ageing (McDowd, 1997). Nonetheless, a reduction in inhibitory function could have important consequences for the everyday lives of older adults, and thus research into the role of inhibition in the ageing process continues.

How many mechanisms are responsible for age differences in cognitive function?

The mechanisms of cognitive ageing that have been presented in this section have all received substantial amounts of empirical support. Yet, how is it possible for them all to be responsible for the age differences found in cognitive abilities? As stated earlier, very few researchers now believe that there is only one explanation for age-related cognitive decline. Indeed, the methods of structural equation modelling and path analysis suggest at least three statistically separate influences on age differences in cognitive function (e.g. Park, Davidson, Lautenschalger, Smith, & Smith, 1998; Salthouse & Ferrer-Caja, 2003; Salthouse, 2001). It is certain that ongoing research will continue to provide further insights into the mechanisms responsible for cognitive ageing

The Disuse Hypothesis

A final theory of cognitive ageing to be presented in this chapter is the *disuse theory*. It has been left until last, not because it is the least important, but rather because it is particularly pertinent to the research presented in this thesis. The origins of the disuse theory of ageing can be traced back to Thorndyke, Bergman, Tilton, and Woodyard (1928). The basic tenet of this perspective is that although decline in cognitive functioning with age is as inevitable as decline in physical function, the decrease in cognitive performance with increased age may at least be partially attributable to lack of use or practice at certain skills (see Milne, 1956). This hypothesis has been formally worded by Hultsch, Hertzog, Small, and Dixon (1999) who stated that: "Individuals who engage in activities that make significant loads on their cognitive skills will show greater maintenance or improvement of their abilities than individuals who are exposed to less complex environments with minimal cognitive loads" (p. 246). The belief that continued mental activity in later life may help prevent decline in mental ability is not just advocated by certain sectors of the scientific community but is widely held by the population at large. It is perhaps most often expressed with the older adage *use-it or lose-it*. However, despite such a pervasive belief, empirical support for this theory is surprisingly sparse and contradictory. The theory itself is not an easy one to prove or disprove. If it is established, for example, that older persons practise a particular activity less and their performance on the activity is lower compared to younger persons, it is not possible to claim that their performance is worse because of lack of practice per se. It may be that performance worsens because the motivation for continuing to take part in an activity that becomes more difficult with advancing years (despite extensive practice) is lost. In spite of this criticism, early support for the disuse theory of ageing was obtained in 1970 by Murrell. His experiment involved a single 57 year older woman who received thousands of experimental trials on reaction-time tasks over a period of several months. Results showed that the participant's performance did not only equal that of two younger participants (17 and 18 years of age) but even surpassed it. Unfortunately, however, these results have not been replicated. Further research using extended practice has shown that elderly participants do indeed improve greatly with practice, but so do younger participants. Moreover, the age-related differences in performance that are evident before practice commences are still apparent to the same extent following the practice period (e.g. Erber, 1976). However, as Rabbit and Lowe (2000) argue, it is important especially for applied cognitive research to determine the conditions under which older adults show improvement with practice regardless of whether such improvement matches that of younger adults.

Many researchers have claimed that the disuse perspective can be used to explain age-related declines in fluid abilities. For instance, Sorenson (1933) claimed that the decrease in measures of mental abilities among older adults is most likely due to the fact that as they grow older, adults exercise their minds less and less with the type of tests used in psychometric experiments. Further, Shimamura, Berry, Mangels, Rusting, and Jurica (1995), reporting results from a study of college professors, proposed that sustained mental activity may protect mental abilities from typical age-related changes. A more recent study by Shimamura et al. (1995) reported that university professors exhibited smaller age-related differences in performance on working memory than adults from the general population. Unfortunately, an earlier study conducted by Sward (1945) found marked age-related differences in fluid abilities in a comparison between younger and older college professors. Salthouse (1991) in a review of the literature pertaining to the disuse theory found similar patterns of age differences between studies that differed in terms of the familiarity and ecological validity of the tasks used. Salthouse also reported similar patterns of age differences for experiments that manipulated or controlled for the type and amount of experience or practice an individual has had with a particular skill.

Despite the mixed evidence for the disuse theory of cognitive ageing, neurological evidence from both animal and human studies is beginning to grow which suggests that leading a cognitively stimulating life, especially in older adulthood, may protect against mental decline. A wealth of animal research has also established the importance of environmental influences on brain function (e.g. Wincour, 1998). For instance, numerous studies on aged rats have reliably demonstrated that environmental enrichment brings about a variety of changes in brain architecture such as increases in dendritic growth (Greenough, Jurasks, & Volkmar, 1979), cortical thickness (Diamond, Rosenweig, Bennett, Lindner, & Lyon, 1972), nerve growth factor, and also brain weight (Mohammed, Henriksson, Soderstrom, Ebendal, Olsson, & Seckli, 1993). Moreover, it has been shown that neurones in the dentate gyrus of the hippocampus continue to be produced throughout adult life in rodents, marmosets, macaques, and humans (Greenough, Cohen, & Juraska, 1999). Further, van Praag, Kempermann, and Gage (2000) reported that the survival of newly formed neurones in mice can be increased following exposure to a more complex environment, thus, suggesting that experience may regulate neuronal replacement in adults (Greenough et al., 1999).

Finally, a large-scale correlational study investigating the association between levels of mental activity and incidence of Alzheimer's Disease (AD) found that the increase in time devoted to intellectual activities from early adulthood to middle adulthood was associated with a significant decrease in the probability of developing AD (Friedland, Fritsch, Smyth, Koss, Lerner, Chen, Petot, & Debanne, 2001). In contrast, however, a correlational study carried out by Salthouse, Berish, and Miles (2002) which investigated the relationship between self-reports of mental activity and measures of cognitive ability found little evidence to suggest that a cognitively stimulating environment attenuates age-related deficits in cognitive function.

In light of the conflicting research surrounding the disuse theory of cognitive ageing, it may be concluded that a definitive answer to the question of whether continued mental activity in older adulthood can attenuate age-related declines in cognitive function has yet to be found. The present research aims to provide an original contribution to this area in the hope that a further piece of the puzzle surrounding the effects of experience on age-cognition relations may be revealed.

The following chapter brings together the two literatures presented in Chapters 1 and 2. Chapter 3 presents a review of the research that has investigated the effects of age on skilled performance.

CHAPTER THREE

THE AGEING OF SKILLED PERFORMANCE

Introduction

As discussed in the previous chapter, laboratory studies consistently show age-related differences in performance on a variety of laboratory-based cognitive tasks. However, are those same age-related declines in performance to be found in the real world? One criticism of laboratory research is that tasks given to participants in such experiments are often 'novel' or unfamiliar, while most cognitive tasks that are performed in everyday life are highly practiced and familiar (see Salthouse, 1991). It has also been argued that younger adults are more practiced at carrying out unfamiliar and seemingly meaningless tasks since they are required to do so regularly in the classroom. This chapter will provide an overview of the main findings of the ageing and cognitive-skill research literature. It will then discuss and provide evidence of four possible means by which older adults are able to achieve comparable levels of skilled performance as their younger counterparts.

Historical Overview of the Literature

One way in which age-related changes in practiced or skilled cognitive abilities can be investigated is by looking at differences in job performance between younger and older adults. The perception of the older worker is often a negative one due to a number of commonly held beliefs by employers and younger colleagues. For example, the older worker is believed (a) to be unable to learn (b) to be less motivated to perform well (c) to have a higher incidence of accidents and absenteeism, and (d) to be generally less productive than younger counterparts (see Peterson & Coberly, 1989, for a review). However, empirical data supporting this view is somewhat limited and often conflicting. For instance, the results of comprehensive literature reviews of studies of age and work performance carried out by Rhodes (1983) and separately by Stagner (1985) found equal support for both increases and decreases in job performance with age. Rhodes suggests that the relationship between job performance and age is a complex one and that a number of factors such as type of job, level of experience, and nature of the performance measure used, are important contributors to this relationship. Meta-analyses of data concerning age and job performance carried out by Waldman and Avolio (1986) and by later by McEvoy and Cascio (1989) suggest that age is only a minor contributory factor to work performance. However, McEvoy and Cascio pointed out that most of the studies analysed were cross-sectional in design and comprised limited samples, and therefore, caution should be exercised when drawing conclusions from the data. Avolio (1992) importantly notes that contextual factors relating to aging and work performance have often been ignored and proposes a *level of analysis* framework within which to study ageing and work performance that takes into account such factors as job complexity, pace of job, and type of experience. Overall, it would seem that the relationship between age and job performance is poorly understood and that the relationship between cognition, age and job performance is even less apparent. As discussed in Chapter Two, research has found reliable age related declines in many cognitive abilities. On the other hand, studies have produced evidence of a positive relationship between cognitive ability and job performance. On the basis of these findings it would therefore be reasonable to expect a negative relationship between age and job-related tasks that rely heavily on cognitive abilities. However, this does not appear to be the case since many older adults successfully perform cognitively demanding jobs (Czaja & Sharit, 1998). Research suggests that *skill* may enable older adults to perform at comparable levels to younger adults in spite of age-related declines in elementary cognitive processes (see Bosman, 1993; Charness, 1981; Charness & Bosman, 1990; Rybash, Hoyer & Roodin, 1986; Salthouse, 1987, 1989, 1990). An important goal of both skill and ageing research is to understand why older and younger adults are able to achieve comparable performance levels on skilled tasks but exhibit age differences in laboratory measures of basic cognitive abilities. Salthouse (1986) put forwards several possible explanations for this discrepancy in the performance of older versus younger adults. The first explanation is that observations of everyday life competence are possibly biased as older persons may be more likely to take part in activities that they can perform successfully and avoid activities that they find difficult or demanding (accommodation). The second explanation is that the artificial environment of the laboratory creates a state of low motivation and/or high anxiety for older adults, so that they perform worse than younger adults on laboratory tests of cognition because of the testing situation rather than because of a decrease in ability. The third explanation offered by Salthouse, which he refers to as the *experience hypothesis*, is that the activities performed in everyday life are highly practiced in comparison with the novel and unfamiliar activities performed by participants in laboratory tests. Moreover, by definition, older adults will be much more practiced at everyday activities than younger adults.

In order to examine the effects of experience on performance, four conceptual frameworks have been put forward each proposing a different explanation for the paradox of age-related cognitive decline and the maintenance of skilled performance (Salthouse, 1990). These are accommodation, compensation, maintenance and encapsulation.

Accommodation

According to the accommodation approach, older adults are able to maintain high levels of performance by singling out and avoiding those conditions under which their performance is impaired by age-related declines in cognitive function (Salthouse, 1990). Salthouse argues that older adults are able to achieve this by using the metacognitive knowledge that they have acquired related to their domain of expertise. For example, older adults may give up driving unfamiliar routes or on motorways because their performance becomes dangerous during these conditions as a result of, for example, age-related declines in certain attentional processes. Yet, these same older adults may continue to drive familiar routes and on quieter roads because their performance under these circumstances is not negatively affected by age. They have therefore accommodated or adapted to an age-related decrease in their driving skill. Thus, by avoiding the conditions that impair performance the impression can be given that a skill is being maintained even though the mechanism directly responsible for decline in performance has not been altered by experience (Salthouse, 1986).

Compensation

Unlike the accommodation perspective, which argues for the avoidance of selective conditions in order to maintain performance, the compensation hypothesis suggests that older adults are able to achieve the same performance levels as their younger counterparts by adopting task performance strategies to compensate for age-related declines (e.g. Backman, 1989; Baltes, 1987; Berg, Klaczynski, Calderon & Strough, 1994; Charness, 1981; and Salthouse, 1984). This approach argues for a *qualitative* change with age in the way that a particular cognitive activity is perceived or carried out (Salthouse, 1991), and unlike the accommodation approach involves the exchange of behaviour rather than avoidance (Salthouse, 1986). As Labouvie-Vief (1985) states:

> ...it is still not certain that some differences in the cognitive behaviour of younger and older are primarily a matter of deficit, since it is possible that adulthood and aging bring qualitative changes that may mimic decrements but in fact signal adaptive reorganization (p. 519).

The compensation perspective suggests that the negative effects of ageing on sensory, perceptual and cognitive processes may be offset by the accumulation of domain-specific declarative and procedural knowledge (Anderson, 1983). Further, this acquisition of expert knowledge enables the older adult to either consciously or unconsciously develop effective strategies in order to achieve the same level of performance as younger adults. A strategy may be defined as "one of several alternative methods for performing a particular cognitive task" (Salthouse, 1991 p.187).

In essence, then, this approach proposes that compensatory mechanisms employed by older adults lead to performance being maintained in a qualitatively different way to that of younger adults. Importantly, the compensatory mechanisms themselves may vary in nature (Backman, 1989). *Direct* compensation refers to the use of aids in order to maintain abilities such as glasses to maintain visual performance, hearing aids to maintain auditory performance, or pill dispensers to maintain memory performance (Backman, 1989). However, compensatory strategies can also be *anticipatory*; for example, behaviours may be engaged in which make a forthcoming task easier. Notes may be written to oneself as an aide mémoire, or when driving a particular route may be taken to negate the requirement for fast reaction speed (Bosman &

Charness, 1996). Backman and Dixon (1992) put forward the following definition for cognitive compensation:

> Compensation can be inferred when an objective or perceived mismatch between accessible skills and environmental demands is counterbalanced (either automatically or deliberately) by investment of more time or effort (drawing on normal skills), utilisation of latent (but normally inactive) skills, or acquisition of new skills, so that a change in the behavioural profile occurs, either in the direction of adaptive attainment, maintenance, or surpassing of normal levels of proficiency or of maladaptive outcome behaviours or consequences (p.272).

The goal of compensation is therefore to remove or reduce the mismatch between the expected level of performance on a task and the actual level of performance. This may be achieved through several means. Firstly, the skill itself can be modified in some way, for example by substituting a new skill or one that hasn't declined for the deficient older one. Secondly, the demands of the task may be modified, for example, by allocating more processing resources to the task or by assigning more processing time to carry out the task. Thirdly, the desired goal itself may be modified (Backman & Dixon, 1992).

Maintenance or remediation

The maintenance or remediation approach, in contrast to both the accommodation and compensation hypotheses, which argue that skilled performance is maintained as a result of behavioural changes elicited by older adults, posits that age-related declines simply do not occur in skilled behaviour. That is, older adults are able to maintain the same level of performance as younger adults because the elementary processes underlying the skill have been subjected to extensive practice (Charness & Bosman, 1990; Salthouse, 1987, 1989, 1990). For example, older adults are able to achieve the same levels of driving performance as younger adults because the cognitive processes underlying the skill of driving, e.g. visual attention, psychomotor speed, and working memory etc. are maintained with practice every time a car journey is undertaken. Thus, the maintenance approach, unlike the accommodation and compensation hypotheses, implies that the mechanism responsible for age-related declines in performance is altered in some way by practice. Evidence in favour of the maintenance or remediation hypothesis would provide support for the disuse theory of cognitive ageing which was outlined in Chapter 2.

Encapsulation, compilation, or elimination

The final approach put forward by Salthouse (1991) to account for comparable levels of performance in older and younger adults is that of encapsulation (also known as compilation or elimination). This perspective uses the analogy of a computer program to describe how, with practice skilled behaviour becomes independent of the elementary processes that underlie it, that is, they are eliminated from the performance (Salthouse, 1986). In other words, skilled performance is akin to a computer program which once compiled no longer depends on its subroutines to run (Bosman & Charness, 1996). Most of the theories of skill acquisition that were outlined in Chapter 1 view skilled behaviour as a product of compilation. The specific items of declarative knowledge underlying the skill, convert to procedural knowledge with repeated use so that access to them becomes automated (see Schneider & Shiffrin, 1977). The encapsulation approach therefore argues that performance will not be affected by age-related declines in the component processes of the skill because the skill is no longer governed by them (see Charness & Bosman, 1990; Salthouse, 1987, 1989, 1990; and Westerman, Davies, Gelendon, Stammers & Matthews, 1998).

It has also been suggested that automatic processing itself is not affected by age (Hasher & Zacks, 1979). This would suggest, therefore, that a component process underlying a skill, albeit sensitive to the ageing process, will not decline once automated.

At this point in time, research into the contribution of accommodation, compensation, maintenance and encapsulation to older adult performance is fairly limited, possibly as a result of the problems inherent in manipulating such a complex variable as experience. Further, most of the research that has been carried out in this area has largely focussed on the compensation and maintenance approach to the ageing of skilled performance and, to a much lesser extent on the encapsulation perspective (Bosman & Charness, 1996).

Evidence for compensation

The compensation hypothesis has been investigated using the molar equivalence-molecular decomposition (ME-MD) technique that was first introduced by Charness (e.g.1979, 1981, 1983) and modified by Salthouse (1982). This method involves decomposing the skill (molar task) into its constituent parts (molecular components). Performance on the molecular components of the skill is then examined using participants of different ages who possess comparable levels of skill at the molar ask. Compensation is believed to be taking place if there are age-related performance differences on the component tasks.

A number of quasi-experimental studies have provided evidence for compensatory mechanisms in, for example, chess (Charness, 1981) bridge (Charness, 1979, 1983, 1987), the processing of prose (Backman & Dixon, 1992), transcription typing (Bosman, 1993; Salthouse, 1984; Salthouse & Saults, 1987), and word processing (Westerman, Davies, Glendon, Stammers & Matthews, 1998). The findings from a number of these studies will now be discussed.

Chess

The complex cognitive skill of chess has been the focus of much research into the compensation hypothesis using the ME-MD technique. Chess lends itself well to this method as it is relatively easy to assess an individual's skill level at the game using the *competitive chess rating index* (Charness, 1979). This index is used to categorise players by ability level on the basis of their competition success. Thus age differences in performance on the component processes underlying the game of chess can be examined by comparing different age groups with comparable levels of skill. Charness (1981a, 1981b) found no age differences in tests of player's molar skill (i.e. their ability to select the best move from four different chess configurations), or to predict the outcome of a game from four chess positions. However, a skill-related memory task, given without warning that measured participants' recall of the four chess configurations presented in the earlier task, revealed significant age-related differences in performance. Thus, it appears that the component processes underlying the game of chess were negatively affected by age despite extensive practice. Further, Charness replicated this finding in another study (1981c).

Bridge

Bridge, an activity comprising cognitive complexity akin to chess has also been studied using the ME-MD technique and has produced similar results; tests of the molar skill such as time taken to generate an opening bid or to add up honour card points were performed equally well by both younger and older players. Moreover, when participants were unexpectedly asked to recall bridge hands presented in the previous tasks, age-related differences in performance were found with older players recalling fewer hands than their younger counterparts (Charness, 1979). Some support however, for the maintenance of the component processes of bridge was provided by Clarkson-Smith and Hartley (1990) in a quasi-experiment using younger and older bridge players and age-matched controls. They provided evidence for preserved working memory and reasoning ability in older players who had sustained comparable levels of practice at the activity as younger players, suggesting that the amount of practice undertaken is an important determinant of whether the cognitive processes underlying the activity are maintained. Charness and Bosman (1996) have since argued that the game of bridge might attract the initially more able, and thus, any age-related declines in ability might be masked by the fact that they were superior to controls in the first place.

Thus overall, the results of both the chess and bridge studies argue the case for age-related declines in the component processes underlying the skill despite preservation in the performance of the skill. This would seem to suggest that the older chess and bridge players are somehow compensating for declines in processing. However, as Bosman and Charness (1996) point out, these studies might suggest that compensation is being used to maintain molar performance but they do not elucidate the compensatory mechanisms employed by the older players. The studies on transcription (copy) typing that follow have provided an insight into just how older adults might compensate for age-related declines.

Typing

Typing is a skill that is measured in the work place by calculating the number of words that an individual is able to type in one minute minus the number of errors made (net words per minute). This therefore, provides an index comprising both speed and accuracy that can be used to compare the molar performance of younger and older adults. Such comparisons yielded the finding that age does not produce a deficit in performance (see Bosman 1993; Salthouse, 1984). However, these same studies have found age-related differences in molecular performance (i.e. slower tapping speed and increased choice-reaction times for older typists). Importantly, the study by Salthouse (1984) revealed that older typists look further ahead in the to-be-typed text (preview span) as a means of compensating for decreases in motor speed. This finding has subsequently been replicated by Bosman (1993). However, the picture is not as clear as it first appears as Bosman (1993) found no performance deficits in *high-skilled* older typists on a task measuring motor execution (a molecular component), whereas the performance of *low-skilled* typists on this task was negatively affected by age. This suggests perhaps, that age-related declines in this aspect of processing are being offset by an individual's expertise. Typically though, preview span increases both with age and skill. This provides a means by which older typists can initiate their keystroke preparation before younger adults thus enabling them to achieve comparable levels of performance (Bosman, 1993; Salthouse, 1994).

Evidence for encapsulation (compilation)

The molecular equivalence-molar analysis (ME-MA) technique devised by Salthouse (1989) has been used to test the compilation hypothesis. This technique, analogous to the ME-MD technique uses both molecular and molar tasks. However, in contrast to ME-MD which compares younger and older adults of comparable molar ability, the ME-MA assesses performance of younger and older adults with equivalent molecular ability. A strong relationship between molar and molecular performance suggests a reliance on controlled or effortful processing to carry out the task. Conversely, a weak relationship between the two is taken as being indicative of automatic processing and thus may be taken as evidence for compilation of the molecular components underlying the task. A series of experiments carried out by Westerman, Davies, Glendon, Stammers and Matthews (1998) used the ME-MD and ME-MA techniques to test both the compensation and compilation hypotheses in word processing competence. The molar task comprised the insertion and deletion of words within a passage of text. Molecular tasks including searching for words within a piece of text on screen that had been designated targets in a 'hard copy' version of the text, cursor manipulation, command decisions, command execution, and insertion/deletion/backspace tasks (designed to assess the component processes of the skill) were created following task analysis. Firstly, the performance of younger and older participants of comparable molar ability was examined. Westerman *et al.* (1998) found (a) a non-significant advantage for older participants on typing speed (b) a significant age difference in molecular task response times favouring the younger participants, and (c) a significant interaction between age group and molecular component with older participants exhibiting a disadvantage on all components except for the text insertion task. As Westerman *et al.* argue, this finding concurs with previous research (Bosman, 1993; Salthouse, 1984) and suggests enhanced text insertion skill as a possible compensatory mechanism employed by older word processor operators to maintain performance. Westerman *et al.* tested the compilation hypothesis by comparing the performance of older and younger participants with equivalent molar ability on the molecular tasks. The results however did not support the compilation hypothesis as a significant positive correlation between molecular and molar performance was found for older participants, contrary to what the hypothesis predicts. Westerman et al., however, suggest that differences found in molecular ability of 'good' and 'poor' molar task performers in the older group are possibly due to the maintenance of basic cognitive abilities.

Empirical evidence for maintenance

Bosman and Charness (1996) point out, that in spite of the widely accepted claim that skilled performance remains largely unaffected in older adulthood, there are relatively few demonstrations to suggest that the component mechanisms underlying skilled performance are also preserved. For instance, Salthouse, Babcock, Mitchell, Skovronek and Palmon (1990) investigated the effects of age and experience on spatial visualisation ability for practising architects who varied in age from 21 to 71 years. Matched control groups comprising participants with an engineering background and participants with no specialised spatial visualisation experience were recruited. All groups were asked to complete self-report questionnaires assessing their cumulative and recent experience with spatial tasks. A battery of cognitive measures was then administered, including tests of perceptual speed and reasoning as well as tests relating to spatial visualisation. Two specific hypotheses were tested by Salthouse et al. The first, the *mediation* hypothesis, examined whether age effects in spatial visualisation ability are apparent following the statistical control of experience. The second, the *moderation* hypothesis, investigated whether amount of previous experience with spatial tasks determines the effect of age on spatial visualisation test performance. The results demonstrated age-related differences in spatial visualisation performance for both architects and non-architects. Moreover, the group of architects were negatively impaired on tasks that were supposedly highly relevant to them, in comparison with both the engineers and the non-specialised control group. The additional finding that older architects performed better on tests of spatial ability than older non-architects was interpreted by Salthouse et al. as evidence for preserved differentiation. In other words, the older architects were presumed to have superior spatial visualisation skills to non-architects when they were younger and this differentiation in skill was apparently preserved with age. A possible criticism of this study is that the type of visual-spatial skill measured in this experiment is not necessarily reflective of the type of skill used by architects in their everyday working lives. Moreover, as architects become older their job-related activities might change so that they no longer practice their spatial visualisation skills to the same extent as younger architects (Bosman & Charness, 1996). Yet, Salthouse et al. reports that all the architects rated the measures of spatial visualisation as highly relevant. Nevertheless, the study relies on both the accuracy of participant self-reports concerning the level of cumulative and recent experience with spatial visualisation tasks and on the subjective measure of task relevance. In contrast, Morrow, Leirer, Altieri and Fitzsimmons (1994) found evidence for experience-related attenuation of age effects on domain-specific tasks that participants rated as highly relevant.

The maintenance hypothesis has been further investigated, but such studies have often produced unclear and inconsistent results. For example, Krampe and Ericsson (1996), in an examination of the effects of deliberate practice on the maintenance of music-related abilities, found smaller age-related differences in the performance of expert versus amateur pianists on a task requiring them to reproduce short sequences of notes with both hands. However, they did not find the same interaction between age and experience in another measure of music ability based on the variation of keystroke force. Further, a test of musical interpretation failed to produce a result either way as there was a lack of agreement between the ratings of the judges. Moreover, in a separate test of the maintenance hypothesis carried out by Meinz and Salthouse (1998), age-related differences on measures of musical ability were similar for both experienced musicians and for participants with little or no musical experience. Masunaga and Horn (2000), however, have criticised the index of experience used by Meinz and Salthouse. They argue that "Perhaps the judged level of expertise in this study did not represent intensive practice designed to maintain and improve expertise abilities – those at the advanced levels of expertise were resting on their laurels" (p. 293-294). Masunaga and Horn also suggest that the amount of recent practice an individual has performed is the most crucial factor for maintaining the abilities underlying skilled performance (see Charness, Krampe, & Mayr, 1996).

A significant interaction between age and experience, however, was found by Witte and Freund (1995) in a study investigating the effects of crossword puzzle experience on the ability to solve anagrams. Unfortunately, Hambrick, Salthouse, and Meinz (1999) found no such interaction in a study exploring the same type of experience on age-cognition relations.

In summary, the research that has examined the maintenance hypothesis has produced inconsistent and conflicting findings. However, despite the lack of supporting evidence, Salthouse (1996) states that "Although I have confidence in the results of these projects, I still believe that continued activity must be associated with higher levels of performance". He goes on to say that "The problem may be that we just haven't found the right way to evaluate the true benefits of experience" (para. 8).

The final introductory chapter in this thesis presents a means by which the effects of experience on age-related changes in cognition can be investigated. It will outline the possible benefits of using the social-recreational activity of Bingo to explore the effects of practice on a number of core cognitive abilities that have been found to exhibit reliable decreases in performance with age.

CHAPTER FOUR

HOW BINGO CAN BE USED TO STUDY THE EFFECTS OF AGE ON SKILLED PERFORMANCE

Introduction

In this chapter, the suitability of the game of Bingo as a research tool to examine the effects of ageing on skilled cognitive processes is explored. The chapter will begin with an historical overview of the game. It will then provide an outline of the important differences between the most popular variations of the game which is an important consideration when comparing results from different studies. There will then follow a discussion of a number of important criticisms that have been directed towards much of the ageing and cognitive-skill research conducted to date, and how they might be addressed by utilising the game of Bingo will then be provided.

The History of Bingo

Bingo is thought to have been invented by the Romans, but the game as we know it today descends from the Italian National Lottery – La Giuoco del lotto d'Italia (Snowden, 1986). The name *Bingo* was patented by American Edwin S. Lowe in 1930 after he witnessed a variation of Lotto called Beano being played at a local county carnival. The game of Beano comprised a horseshoe shaped table covered with numbered cards and beans. The caller pulled numbered wooden chips from a bag and at the same time called the number aloud. Players would then check their card to see if they had the number called; if so, they placed a bean on the number (hence the name Beano). Although the name Bingo was patented, the game itself, having come out of the public domain had no chance of being protected. Thus, many variations of the game exist throughout the world (Snowden, 1986).

Game variations

It is important to explain the differences between the game of Bingo that is played in the US and the game that is played in the UK as anyone researching the activity of Bingo should be aware that different skills may be required for different versions of the game.

US Bingo rules

In the traditional US game, each Bingo card has 5 rows and 5 columns, providing 25 spaces. The columns are labelled from left to right with the letters B, I, N, G, O. With one exception (the centre space is free) the spaces in the card are assigned values as follows: Each space in the *B* column contains a number from 1 to 15. Each space in the *I* column contains a number from 16 to 30. Each space in the *N* column contains a number from 31 to 45. Each space in the *G* column contains a number from 46 to 60, and each space in the *O*, column contains a number from 61 to 75. Further, a number can appear only once on a single card (see Figure 4.1 below).

B	I	N	G	O
14	25	34	52	68
1	24	38	51	69
4	26	FREE SPACE	48	74
3	23	41	46	63
6	20	39	56	70

Figure 4.1. An example of a typical Bingo card used in the US.

The numbers are called out along with their corresponding letter, for example, B14, G48. The aim of the game is to create predetermined shapes on the Bingo card, for example, four corners, diagonal line, vertical line, and horizontal line.

UK Bingo rules

A standard UK Bingo card comprises a 9 column x 3 row grid. Each card has fifteen numbers assigned to the spaces in accordance with the following rules:

1. The numbers from 1 to 90 are used
2. Each row must contain five numbers
3. There must be at least one number in each column
4. Numbers ascend across columns, for example, column 1 comprises numbers from 1 to 9, column 2 from 10-19, etc. However, numbers are distributed randomly within a column.

1		23		41		63		80
4			35	48	51		78	
	11		39		57	67		87

Figure 4.2. An example of a typical single Bingo card used in the UK.

Many people play more than one Bingo card simultaneously and most skilled Bingo players play at least six Bingo cards. If six cards are played in one game, every number from 1 to 90 is present once, and therefore, a number is crossed off at each call. Up until several decades ago, numbers were printed on ping pong balls and were randomly blown through a plastic tube to be announced by the Bingo caller. However, clubs now use computerised random number generators and the numbers appear on screens placed around the club as well as being announced by the caller. Hence, the pace of the game is much quicker, with a number being called approximately every 2 to 3 seconds.

Usually, games vary in duration but all last several minutes. In 90 number Bingo, up to 60 numbers will be called before a game is completed (allowing for false calls). In certain of the larger Bingo clubs, the card is taken from a player if a false call is made. Prize arrangements vary from game to game (and from club to club) but are usually available for a *line* – the player who is first to correctly cross off a horizontal line of five numbers, then for two lines (lines may be predetermined, e.g. the top and bottom lines) and finally for crossing off all the numbers on a card (a full house). When players complete the appropriate number of lines, they must shout *House* or *Here* to attract the caller's attention **before** the next number is called. Thus, the player is responsible for stopping the game. The last number called must be on the card in the winning combination because a *late* call will be deemed invalid. Winning cards are then checked by club employers and the prize is handed to the winner(s).

Who plays Bingo?

Bingo is enormously popular all over the world. The game, in its many incarnations, is played in nearly every continent and in 90% of the world's countries (Snowden, 1986). Approximately three million people (about 8% of the adult population) play Bingo regularly in the UK (Gallup, 1991). Further, this number does not include those who play Bingo at their local community centre, social club, or day centre. Moreover, although it has been reported that men are more likely to gamble than women, this position is reversed in the game of Bingo (British Gambling Prevalence Survey, 2000). The ratio of women to men players is approximately 70:30, with the most common age range being 30-40 years (Gambling Review, 2001). Bingo is generally regarded as soft gambling (Bingo Association, 2000). It is also said to be at the heart of many communities as it provides a chance to socialise and make new friends. Further, Bingo clubs are viewed as safe places to visit, especially for women.

Although gambling is a popular pursuit among individuals from all social classes, the type of gambling activity undertaken does vary by social class. For example, according to the British Gambling Prevalence Survey (2000), individuals belonging to Social Class 1 were more likely to visit a casino (5%) than a Bingo hall (3%). Conversely, the opposite was found among for Social Class V; individuals belonging to this group were much more likely to play Bingo (20%) than go to a casino (1%).

Criticisms of previous ageing and skill research

A prominent hypothesis concerning the effects of age and experience on cognitive function is that age-related declines in mental ability are limited to tasks that are unfamiliar or novel (Salthouse, 1990). In support of this assertion, references have been made towards the frequent exposure to novel tasks during school years and the decrease in willingness to participate in what might be perceived as pointless or meaningless tasks in older adulthood (Matthews, Davies, Westerman, & Stammers, 2000). Therefore, it may be predicted that age should yield smaller differences in familiar as opposed to unfamiliar tasks. However, as Salthouse (1990) points out, assessments of familiar tasks generally measure participants' wealth of accumulated knowledge about the task (e.g. stored vocabulary), which does not usually exhibit age-related declines, rather than assessing performance on the component processes that underlie the task. Conversely, unfamiliar tasks tend to measure the efficiency of current or *online* processing which reliably shows age-related declines (e.g. Salthouse, 1982). An important question raised by Salthouse (1990) pertaining to the association between age and experience is whether the amount of experience that an individual has with a particular activity eliminates or reduces the negative effects of age. He further inquires as to whether experience reduces rather than eliminates the negative effects of age, and if so, are the effects of experience fixed, or is the reduction in age-related decline directly related to the amount of experience a person has?

A number of studies have been conducted in an attempt to answer this question by varying the amount or type of training that a participant receives on a particular task. Unfortunately, a large proportion of them have used only one age group, thus rendering it impossible to determine whether added experience affects age-cognition relations (see Baltes & Lindenberger, 1988, for a review). Furthermore, many of the studies that have used at least two age groups for comparison gave relatively small amounts of practice to participants in order to evaluate the effects of added experience on age-cognition relations (Salthouse, 1991). For instance, Hertzog, Williams, and Walsh (1976), in a test of the effects of practice on perceptual discrimination gave participants only five sessions of training comprising sixty trials each. Further, in a test of the effects of practice on mean reaction time, McDowd (1986) gave participants only four sessions comprising thirty trials per session.

Another concern, levelled at may studies within the domain of ageing and experience is that often extremely small sample sizes are used, sometimes as few as six participants per age group (e.g. McDowd, 1986). Therefore, although most studies within the area of human performance psychology use fairly low numbers of participants per group, such restrictive sampling must place limits on the generalisation of findings (Matthews et al., 2000).

A final concern outlined by Salthouse (2001) is that nearly all of the existing research that has investigated the relationship between age and experience has concentrated on a single dependent variable from a single task. This, as Salthouse argues limits inferences to the variable that has been measured.

The research presented in this thesis has therefore attempted to address these criticisms.

Age-sensitive component processes underlying Bingo

The first task was to ensure that the component processes underlying the game of Bingo are sensitive to age, given that according to Salthouse (1990) most studies that have claimed to measure the relationship between age and experience have instead measured the product of accumulated knowledge, which does not tend to decline in older adulthood (Salthouse, 2000). Indeed, this type of knowledge has been known to increase with advancing years (Horn & Cattell, 1967). Bingo, in contrast to most of the activities that have been studied within this domain relies upon a relatively minor crystallised component to play the game, in comparison to the online or fluid processes that are essential for successful performance at Bingo. Thus, although the skill of Bingo cannot be considered complex in comparison to chess or bridge, for instance, it is very likely that any measure taken to assess the effects of experience on performance will be measuring participants' current processing rather than their recall of previously stored knowledge (particularly as participants are issued with a new Bingo card for each game). Further, because the game of Bingo is not a highly complex skill it is perhaps more easily broken down into its component parts, thus making the game highly conducive to experimental investigation.

Visual search

A fundamental component process underlying the game of Bingo is that of visual search. The term visual search refers to the process of searching for a target within a visual scene, an operation carried out repeatedly as we view the world around us. Each time we look for a particular book, CD, video, tin of beans, jar of spice etc. on a shelf or check to make sure there are no vehicles approaching before we cross the road, we are performing a visual search. Detection of potential targets is critical, for instance, in radiology laboratories or at airports. Thus, devising ways of improving search accuracy and efficiency within these domains is a primary focus of applied visual search research. It is, therefore, not surprising to find a whole literature dedicated to this topic. Suffice to say, a number of theories seeking to explain the mechanisms underlying visual search have been put forward, the main contributors of which will now be discussed.

Visual search, first formally investigated by Neisser in the 1960s, is usually investigated in the laboratory by asking participants to locate or identify a target item among a number of non-target items (distractors). One of the most important findings from such experiments is that participants find some types of searches more difficult than others (Wolfe, 2003).

The Feature Integration Theory (FIT) was a pivotal attempt to model visual search (Treisman, 1988; Treisman & Gelade, 1980). FIT proposes a dichotomy of visual search processing; *preattentive* vs. *attentive*. Preattentive processing, according to FIT, occurs in parallel such that all items within a search array are processed at the same time. A search can rely on preattentive processing, according to FIT when a target is defined by a unique feature such as colour, orientation, size, or motion in a single dimension (feature search). Thus, a red target item amongst green distractor items will be detected immediately. Treisman and Gelade referred to this particular phenomenon as visual *'pop out'*. In operational terms, the reaction times produced from this type of search will be independent of the number of items in the search array (set size). However, when the visual search task is for a target that is defined by two or more basic features (conjunction search), e.g. a small green circle among big green and small red circles, attentive processing is required. Attentive processing, according to FIT, occurs serially such that all items within a search array are processed one-by-one until the target is found or the search array is exhausted. In operational terms, the reaction times produced from this type of search will be dependent on the number of items in the search array (response times will be slower as set size increases). Treisman has since modified the original theory in light of evidence suggesting that many conjunction searches are more efficient than would be predicted by a purely serial search and sometimes as efficient as preattentive search (e.g., Cohen, 1993; Cohen & Ivry, 1991; Dehane, 1989; Egeth, Virzi, & Garbart, 1984, cited in Wolfe, 1998). Other researchers have proposed alternative models of visual search in an attempt to explain these results.

The Guided Search model (Cave & Wolfe, 1990; Wolfe, Cave & Franzel, 1989; Wolfe, 1994), for example, was put forward in direct response to the problems identified with the original FIT. The Guided Search (GS) model, like FIT, is also a two-stage model of visual search and retains the preattentive/attentive composition. However, unlike the strict dichotomy between preattentive and attentive processing proposed by FIT, the GS model views these two types of search as a continuum with preattentive processes helping to guide the deployment of attention (Yang, Dempere-Marco, Hu & Rowe, 2002). In the first, preattentive stage, an activation map is created based on both bottom-up (stimulus driven) and top-down (expectancy driven) sources of activation. This map contains probable target locations and is used by the second, attentive, stage of processing to guide the deployment of attention first to the item with the highest level of activation, then to the item with the second highest level of activation, and so on and so forth until the target is located or the activation falls below a certain level (Chun & Wolfe, 1996). The GS model of visual search asserts that attention may also be implicitly guided based on the prior presentation of targets. This is referred to as *'priming of pop-out'* (Wolfe, 2003).

Another model of visual search that has explored this continuum between easy to difficult search is that of Duncan and Humphreys (1989). Duncan and Humphreys' model proposes that there are two critical factors determining search performance. The first is the difference between the target and the distractor items, or *target-distractor* *difference*. The model predicts that a target will be easy to locate, and even 'pop-out' if it is substantially different from all other items in the array. However, search performance will decline and the target will become more difficult to locate as it becomes increasingly similar to the distractors items. The second factor affecting search performance is the heterogeneity of the distractors, or *distractor-distractor difference*. The model predicts that the more dissimilar the distractors are to each other the more difficult search will be. Conversely, as the distractors are made increasingly similar to each other, search will become easier and performance will improve. Wolfe (1998) argues that it is difficult to criticise the basic tenet of Duncan and Humphrey's model, but stresses that the issue of similarity as it applies within the context of visual search needs to be explicitly and fully determined. Thus, there are a number of factors that contribute to visual search efficiency. The important question of whether age affects any or all of these factors will now be addressed.

The effects of ageing on visual search performance have been quite broadly researched and a number of consistent findings have emerged. For instance, the response times of both younger and older adults for searches comprising single features appear to be unaffected by set size (D'Aloisio & Klein, 1990; Plude and Doussard-Roosevelt, 1989). Humphrey and Kramer (1997) for instance, examined visual search performance differences between younger and older adults for feature and conjunction targets. They found that older adults showed comparable performance with younger adults in searches for targets that were defined by a single feature. In other words, both younger and older adults exhibited the flat (parallel) search slopes typically associated with feature search suggesting that this type of search is age invariant. In contrast, Humphrey and Kramer (1979) and Plude & Doussard-Roosevelt (1989), found that older adults generated slower search rates for targets that were defined by two or more features. In other words, older adults displayed steeper search slopes for conjunction targets as compared with younger adults. This result suggests that serial or effortful search is negatively affected by age. This finding is important for the present research as the game of Bingo requires rapid serial search for digits that comprise conjunctions of features that cannot be processed in parallel. Earlier support for age differences in visual search was also provided by Oken, Kishiyama, and Kaye (1992). They too found that visual search tasks that required serial or effortful processing were more sensitive to age than those requiring parallel or pre-attentive processing.

Madden (1983) tested the hypothesis that increased age is associated with a decrease in the ability to ignore irrelevant information by examining age differences in disruption of visual search performance by highly familiar distractor stimuli. In other words, Madden investigated whether stimuli that were used as targets in a prior search task would disrupt the search performance of older adults if they were used as distractors in a subsequent search task. Indeed, this was found to be the case as search performance in this condition was reduced for older participants in comparison to the performance of younger participants and in comparison to their own performance when only new stimuli were used. Importantly, participants of the game of Bingo are subject to the same disruption as those in Madden's experiment since a target on one Bingo trial becomes a distractor on the next. More recently, Maylor and Lavie (1998) have examined the effects of perceptual load on selective attention ability in older and younger adults. Participants were required to make a speeded response indicating which of two target letters was present in a visual (relevant) array displayed at the centre of a screen while at the same time ignoring a distractor (irrelevant) item presented in the periphery. They found that when the relevant visual array was small, older participants were negatively affected by the presence of the distractor compared with younger participants. However, when the relevant visual array was large, older participants were not differentially affected by the irrelevant item in comparison with younger participants. Maylor and Lavie (1998) concluded that older participants are not always likely to be more easily distracted by irrelevant information than younger participants and that factors such as perceptual load should be taken into consideration.

Automatic versus controlled processing

As discussed in Chapter 1, the rate at which an individual is able to search for a target does not only depend on whether a parallel or serial search is required, but also on the consistency of stimulus-response mapping. Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) found that if a fixed set of targets does not overlap with the set of distractors effortful search is facilitated by a reduction in the rate of the serial comparison process. Conversely, serial search is impeded if a set of distractors have previously appeared as targets. In an examination of the effects of age on consistent- versus varied-mapping visual search Plude and Hoyer (1981), and subsequently, Plude, Kaye, Hoyer, Post, Saynisch, and Post (1983) demonstrated that varied-mapping visual search is negatively affected by age but consistent-mapping visual search remains relatively unaffected. Importantly, Bingo comprises varied-mapping visual search. The response to a target digit varies from trial-to-trial. On one trial a digit forms part of the target set (digits to be crossed off) and on the next it forms part of the distractor set (targets to be ignored).

Perceptual speed

As previously stated, the game of Bingo is played under speeded conditions; therefore it is reasonable to assume that psychomotor speed is one of the factors governing performance. Evidence for a reduction in psychomotor speed with age is plentiful (e.g. Birren, 1965; Cerella, 1985; Salthouse, 1985; for reviews see Birren & Fisher, 1995; Craik & Salthouse, 1992, & Salthouse, 1991). Research into the effects of age on psychomotor performance can be traced back to Galton's (1994) lifespan reaction time experiment (Koga & Morandt, 1923). Importantly, in a subsequent analysis of Galton's data, Koga and Morandt (1923) determined that the behavioural slowing evident in older persons is located primarily within the central nervous system (CNS) as opposed to the peripheral nervous system (PNS). Further evidence that age-related slowing in speed of response is not correlated with peripheral nerve conductance velocity was provided by Birren and Botwinick (1995) in an assessment of the effects of age on finger, jaw, and foot reaction time. They predicted that if decreases in the efficiency of nerve conduction were responsible for age-related slowing in speed of response then foot reaction time should be proportionately slower than either finger or jaw reaction time. However, this was found not to be the case. Importantly, the finding that behavioural slowing with increased age is related to changes in central rather than peripheral processes laid the foundation for decades of cognitive research into the phenomenon (e.g., Era, 1988; Grant, Storandt, & Botwinick, 1978: Jordan & Rabbitt, 1977; Salthouse, 1993, 1996; Salthouse & Somberg, 1982; Smith & Brewer, 1985).

Working memory

As previously discussed in Chapter 2, a reduction in working memory capacity has been put forward as a theory of cognitive ageing. For example, tests of short-term memory span in which the participant repeats a list of digits read by the experimenter have produced small but reliable declines in older adulthood (Craik & Jennings, 1992; Craik, Anderson, Kerr, & Li, 1995). However, age differences increase signficiantly when extra demands are placed on the participant (Cohen, 1996; Craik, 1986). For instance, if the participant is required to repeat the items read by the experimenter in *reverse* order of presentation, the participant must hold in memory the items in their forward sequence so that the reverse order can be worked out. Thus, the backward digit span task becomes a test of working memory. Hence, differences in performance occur because the participant becomes unable to store and manipulate information in memory simultaneously. Bromley (1958) demonstrated that older adults perform significantly worse than younger adults on this task.

A number of explanations have been put forward to account for the age-related deficits in performance on working memory tasks. Morris, Craik, and Grick (1990), for instance, suggest that when younger participants are simultaneously given a list of words to remember and asked to decide whether a simple sentence is true or false, they not only encode the information in working memory but send a copy of the memory trace to long-term memory (LTM). Thus, if the information is lost from working memory they can retrieve the backup copy from LTM. However, Morris et al. argue that older participants are unable to perform this *copy>save* function, either because of a decline in the capacity of their working memory, or because of some deficit in LTM.

Baddeley (1986) advocates the central executive component of working memory as the mechanism responsible for age-related differences in working memory tasks. In Baddeley and Hitch's (1974) working memory model, the central executive performs the crucial function of both mediating attention and regulating processes in working memory. Baddeley argues that older adults perform worse than younger adults on tests of working memory because they are unable to combine memory and concurrent processing (Stuart-Hamilton, 2000).

In addition, Belmont, Freeseman and Mitchell (1988) suggest that older adults are also impaired in their ability to encode information in STM because they develop inefficient strategies that limit their ability to chunk information such as long lists of digits. Moreover, Perlmutter and Mitchell (1982) propose that older adults also have difficulties with retrieving information from memory.

Consistency and amount of practice

Another of Salthouse's (1990) criticisms concerned the problem of determining the amount of experience an individual has with a particular activity. One of the difficulties in evaluating laboratory-based training studies is that no matter how extensive the training, be it administered over a period of days, weeks, or even months, it cannot compare to the years or possibly decades of practice that an individual may have with a particular activity. Importantly, Salthouse (2001) argues that studies reporting positive effects of short periods of practice or training on measures of cognitive abilities may not be directly comparable to the effect of long-term practice on age-cognition relations (e.g. Baltes, & Lindenberger1988; Schaie & Willis1986). Further, it may also be the case that intensive laboratory practice does not affect cognitive function in the same way as real-life practice. Thus, experiments employing intensive laboratory-based practice may be measuring a different set of processes.

One of the main advantages with laboratory-based training studies however, is that the experimenter is able to tightly control the conditions under which training is given. Yet, in real life, the conditions of practice may vary widely both within and between individuals. For example, pianists may play in a variety of different genres, for example, blues, jazz, rock, country and western or classical. These different musical styles each have there own nuances with regard to finger movements, rhythm, complexity etc. In addition, some expert musicians may read music whereas others may play by ear. Thus, it is reasonable to suggest that a different set of processes are required for these two methods. With regard to determining the amount of experience that an expert pianist has it is relatively easy to establish when the skill was originally acquired and the number of times per week it is practiced. However, it may not be easy to determine the nature of each practice session. For instance, a pianist may spend varying amounts of time practicing scales, intricate bimanual sequences, or playing full musical pieces, each of which requires different cognitive processes. Moreover, equating the content of practice sessions for different pianists is even more problematic for researchers.

As discussed in Chapter 3, equating the amount of experience accrued by different age groups for a particular activity is particularly problematic as the processes underlying performance of the activity may have changed over the years. Indeed, this was one of the criticisms of the study carried out by Salthouse and Mitchell (1990); older architects in the study may not use the same skills as their younger counterparts. The nature of an activity may also change over time for other reasons. For instance, a project designer often has to construct detailed technical drawings of particular objects or structures to specified scales. A decade or so ago this process would have been carried out manually. The project designer would first accurately measure the dimensions of an object then carry out the appropriate mathematical calculations so that it could be converted to the desired scale. Finally, the object would then be drawn manually to the required specification. Today, a project designer can achieve this in one easy step by entering the key information into a computer aided design (CAD) program. Thus, the end product is the same but the mental processes required to achieve it are not. Changes over time in the nature of the processes underlying a skill may therefore threaten the validity of any experiment aiming to assess the effects of experience with the skill on age-cognition relations. Thus, it is understandable that laboratory-based training studies are often chosen over studies of real life training.

One possible solution to the problem of trying to equate the amount and type of experience different individuals have with a particular activity is to find an activity for which the conditions of practice do not vary either between or within individuals. The game of Bingo fits these criteria for a number of reasons. For instance, the UK game of Bingo has well-defined rules that must be adhered to by all who play it. Such rules equate to the standardised instructions issued to participants before they commence a laboratory experiment. Further, because the rules are the same for all sessions and for all clubs there is very little room for intraindividual variability in the way that the game is played, unlike in many of the other activities that have so far been studied (e.g. Hambrick, Salthouse, & Meinz, 1999; Krampe & Ericsson, 1996; Meinz, 2000; Salthouse

& Mitchell, 1990). Further, Salthouse (2001) argues that one of the greatest challenges faced by researchers exploring the disuse hypothesis is attaining objective measures of cognitive stimulation. It is proposed that persons who play the game of Bingo are able to provide an objective and detailed assessment of their experience with the activity; for example, the length of time that they have been playing, the number of times per week they play, the number of games they play in each session, the age at which they started to play, and the number of Bingo cards they play with. These quasi-independent variables can be used to explore effects of various amounts of experience on age-cognition relations. The negative aspect to this type of research is the fact that unlike in a controlled laboratory experiment, participants have not been randomly assigned to the experimental conditions. Moreover, age is also a quasi-independent variable, and therefore threats to both internal and external validity must be considered when employing this experimental design (Campbell & Stanley, 1963).

A partial solution to the methodological concerns surrounding quasi-experimental research is to have more than one dependent variable. As noted by Salthouse (1990), much of the research that has examined the effects of experience on age-cognition relations has concentrated on a single dependent variable from a single task. The research presented in this thesis aims to address this criticism by examining a number of dependent variables taken from a variety of cognitive tasks. Some of these variables will be domain-specific, that is, directly related to the game of Bingo, and others will be more general in nature.

Finally, it is important to consider the wider implications and applications of this research. For instance, as Matthews, Davies, Westerman and Stammers (2000) point out, increasing age is associated with a decrease in the willingness of older persons to participate in activities that they perceive as irrelevant or meaningless. Therefore, even if it can be determined that regular practice at a particular activity helps maintain the function of certain cognitive processes, it is important that the activity in question appeals to the section of the population who are most likely to benefit from its effects. Clark et al. (1987) for example, examined the effects of repeated video game playing on the response speed of older adults. Practice sessions lasted two hours per week over a period of seven weeks. Results demonstrated a significant increase in response speed both on simple and choice reaction-time tests. This experiment clearly demonstrates that practice at a particular activity can lead to improvement in the elementary cognitive processes underlying the activity. However, video game playing is not likely to be performed by a significant percentage of the older adult population as a social-recreational activity (of course this may be different for future generations). Thus, it is important to consider those activities that do appeal to a large proportion of the population. Furthermore, a study by Christensen and Mackinnon (1993) which examined the relationship between mental, social and physical activity and age-cognition relations found that mental activity was associated with higher performance on measures of fluid ability for participants with low levels of education but not for participants with high levels of education. Bingo, as already stated, is most likely to be played by persons within social class V (British Gambling Prevalence Survey, 2000), and research by Wilmott and Hutchinson (1992) found strong links between social class and level of educational achievement. It might be possible, for instance, that persons with higher levels of education have access to a more cognitively stimulating environment. Thus, if increased mental activity improves cognitive functioning, particularly in persons with low education levels, then it is important to consider the cognitive benefits of the social-recreational activities that persons within this category enjoy.

Finally, the most common reasons given by people questioned in the 1991 Gallup Survey for playing Bingo were enjoyment, socialisation, and companionship. Socialisation is a well known preventive measure of depression in older adulthood (Birren, 1990). Depression can lead to a marked decline in cognitive functioning and an increase in psychomotor slowing (Kitwood, 1997). Moreover, as pointed out by Rabbitt and Goward (1994), people need to be motivated to push themselves to the limits of their potential, which means taking part in something that they are both interested in, and enjoy doing.

Previous Bingo research

To date, there has been no published research into the effects of experience of Bingo on age-cognition relations using the UK variation of the game, although a small-scale US Bingo study comprising a sample of 48 Bingo players aged between 18 and 72 years with varying levels of experience was carried out by Smith et al. (1994). Smith and colleagues examined the relationship between Bingo playing experience and various measures of cognitive ability, including recall and recognition memory (for numbers called on an experimentally manipulated game of Bingo), and perceptual speed. The results showed no significant correlation between age and any of the measures taken, leading Smith et al. to suggest that Bingo playing experience had a positive benefit on age-cognition relations. However, Smith et al. were not able to examine possible interactions between age and Bingo experience as cells for each factor comprised too few data points.

Furthermore, as already discussed, the US game of Bingo is very different to the UK variation of the game. Smith et al. reported for instance, that the participants in their study played with the same Bingo cards every week. This enabled players to memorise the location and identity of each number on their card so that performance relied largely on previously stored knowledge (i.e. crystallised abilities). Conversely, in the UK version of Bingo, players purchase a new set of Bingo cards for each game that is played. These cards are then destroyed once the session has finished. Also, when observing participants playing a game of Bingo at their local club, Smith et al. noted that a period of 18 seconds lapsed in between each Bingo call. This is extremely slow in comparison with the UK game of Bingo in which a number is called every 2-3 seconds.

Thus, although the results of Smith et al's study suggest that the cognitive abilities underlying the skill of Bingo are maintained, the lack of interaction data prevents such a conclusion being drawn. Smith et al's research does, however, provide a basis for further research.

Rationale for the Research Presented in This Thesis

A number of studies have investigated the effects of experience on age-cognition relations. Most of these studies have explored complex cognitive skills such as the games of chess and bridge, which require extensive practice in order to achieve a high level of performance. According to Frensch and Sternberg (1991), games comprise several features that make them amenable for experiments in cognitive psychology. Firstly, the sequences of observable moves that make up a game are relatively easy to decompose. Secondly, games are non-deterministic because a player's goals and intentions determine the next move they make (Johnson-Laird, 1988). Thirdly, and perhaps more importantly, most games comprise well-defined rules that constrain performance. However, as discussed in Chapter 3, activities such as chess and bridge rely heavily on the products of accumulated knowledge. Thus, it is difficult to separate out the effects of experience on fluid abilities (which are particularly susceptible to the processes of ageing) from its effects on crystallised abilities (which have been found to remain relatively stable throughout the adult lifespan). In addition, findings from such studies are further complicated by the fact that a variety of compensatory strategies may be employed by older adults in order to maintain the skill. The study of psychological compensation is essential to the understanding of cognitive ageing. However, it is also important to examine the effects of experience on performance of activities for which compensatory mechanisms are not so easily employed because the activity comprises mainly elementary, fluid, cognitive processes.

Another problem with studying complex cognitive skills is that the more complex they are, the more difficult it is to decompose them into their molecular components. The complex cognitive skills that have been examined so far also require extensive practice to achieve high levels of performance. There may be no limit on the level of performance that it is possible to achieve. Thus, it becomes difficult to investigate age differences in performance as older adults rather than just maintaining the skill have the potential to continue to improve upon the skill. This makes interpretation of findings difficult.

Bingo presents an opportunity for studying a fairly simple cognitive skill. The game does not require years of intensive study in order to achieve a high level of performance. Further, it is likely that once the skill has been acquired, additional practice serves only to maintain the current level of performance. There is no doubt however, that Bingo is a skill, as persons learning to play the game progress through the various stages of skill acquisition outlined in Chapter 1. In the early stages of practice with Bingo, players tend to play with only a limited number of cards, perhaps one or two. Novice players are also provided with the declarative knowledge required to play the game and often watch a more experienced friend play a game or two before taking part themselves. Performance during this early stage of skill acquisition is often slow and error prone and sometimes results in false calls being made or numbers being missed. As practice continues (and the player becomes more confident), the number of cards played with is increased, usually to six (although it is not unusual for experienced players to play with twelve or eighteen cards). Performance becomes more fluent during this stage and the player is able to attend to the information displayed on the television screens placed around the Bingo hall as well as to the numbers that are read out by the Bingo caller. With further practice, the player acquires the ability to rapidly and carefully scan each card in between Bingo calls, looking for the required pattern and holding the numbers required in memory. This implies that certain of the processes underlying the game become automated resulting in the freeing-up of attentional resources so that additional tasks can be carried out concurrently.

Importantly, the molar skill appears to be maintained into older adulthood as players do not decrease the number of cards played with as they get older. Yet, the pace of the game remains the same. Indeed, many older adults become impatient because they feel the pace of the game is too slow and so look for ways to make the process a little bit more challenging such as turning the Bingo cards upside down.

Moreover, as the game of Bingo is a relatively simple activity, it makes the task of decomposing the molar skill into its molecular components a relatively straightforward task. This makes the game of Bingo highly conducive to experimental investigation.

The aims of this thesis are to examine closely the effects of extended practice at Bingo on various measures of cognitive function thought to underlie the skill and to then investigate whether these abilities are maintained in older adulthood. This thesis will also explore whether extended practice at domain-specific cognitive tasks transfers to other stimulus conditions, and if so, whether the ability to transfer the skill is maintained for older adults.

Methodology considerations in age-comparative research

The research presented in this thesis uses the age comparative cross-sectional design whereby the performance of groups of participants differing in age and Bingo playing experience is compared at one point in time. This design differs from the longitudinal approach, which compares the performance of the same group of participants at different points in their development. Further, groups of participants recruited into cross-sectional research often differ extremely in the variable of interest. For instance, cross-sectional ageing research usually includes a group of younger (e.g. 18-30 years) and older (e.g. 65+ years) adults. Old age tends to be defined in relation to the retirement age of 65 years (Kausler, 1991). However, these age boundaries are not fixed and much research has been carried out using participants outside of these age groups. The research reported in this thesis assigned participants to two age groups: younger (18-40 years) and older (60+ years).

The cross-sectional design is the most popular experimental design employed in cognitive ageing research as it is a quicker and less expensive means of collecting data than research using the longitudinal design (Salthouse, 2000, as cited in Craik & Salthouse, 2000). However, certain biases are reported to be inherent in this design. For instance, individuals who differ in age at a certain point in time are also likely to differ in other important respects (e.g. education, nutrition, access to health services). Further, as noted by La Rue and Markee (1995), individuals born in the 1920s and 1930s are also likely to have experienced a different kind of cognitive environment during development than individuals born in the 1960s and 1970s (e.g. reading books versus television versus computer games). These differences in experience result in what is referred to as *cohort* (generational) *effects* and act to confound the effect of age on the cognitive abilities measured. In light of these problems, researchers often view cross-sectional research as being inferior to longitudinal research. Schaie (1965) for instance, argues that individual differences in age changes can only be investigated with longitudinal research. However, as discussed previously in Chapter 2, longitudinal research also has its own inherent biases, such as selective attrition and practice effects. Further, although longitudinal research controls for cohort effects by repeatedly testing one generation of participants, it then becomes difficult to separate out age effects from time of measurement or cultural changes (Matthews et al., 2000). Furthermore, Salthouse (2000) argues that although cross-sectional studies cannot be used to infer age-related *changes* in abilities, as the processes of change can only be examined longitudinally, the cross-sectional design does present a valuable opportunity to investigate whether age *differences* exist in a given variable at a particular point in time. The methodological limitations of conducting cross-sectional research will therefore be taken into account when attempting to draw inferences from results of the experiments presented in this thesis.

CHAPTER FIVE

EXPERIMENT 1: SKILLED VERSUS UNSKILLED BINGO SEARCH

Introduction

The most important cognitive ability involved in playing the game of Bingo is the perceptual skill of visual search. The purpose of this first experiment therefore, is to (a) examine differences in Bingo search performance at searching for digits between experienced and novice Bingo players (b) to determine whether search performance declines with age, and (c) to test for a relationship between that decline and experience at playing Bingo.

The defining principle of a perceptual skill is the enhanced ability to "discriminate between and to classify stimuli based on perceivable properties" (Proctor & Dutta, 1995. p.33). Perhaps the most famous demonstration of perceptual skill was reported by Lunn (1948). Lunn investigated the effects of training and experience on the ability to identify the sex of day-old chicks. Such a task is extremely difficult as even poultry farmers cannot discriminate between the sexual organs of male and female chicks of this age. However, Lunn found that after a period of intensive and prolonged training an individual is able to sex around a thousand chicks per hour with near 100% accuracy. Various tasks have been used to investigate perceptual skill, using either accuracy or response time as a measure of performance. For example, detection tasks require participants to judge whether a stimulus event occurred during a designated period of time, discrimination tasks require participants to make a same-different judgement between two or more stimuli presented simultaneously or sequentially, recognition tasks require participants to make an old-new judgement between previously presented and newly presented items, and identification tasks require participants to make a judgement between stimuli using a particular response that has been pre-assigned to each possible stimulus. Further, visual search tasks have also been used to examine perceptual learning and require either the detection or identification of designated targets. In summary, then, the fundamental component of perceptual skill is the acquired ability to determine features that are both specific to a particular stimulus and discriminate it from other stimuli. Indeed, improvements in perceptual performance are often found to occur as a reduction in the processing of irrelevant features (Haider & Frensch, 1996). Importantly, as already outlined in Chapter 4, there are number of influential factors that can affect the ease with which perceptual stimuli can be detected and discriminated. These factors will now be discussed within the context of the present experiment.

The game of Bingo is played in the UK under severe time constraints whereby a number is called approximately every 2 to 3 seconds. A Bingo player elects either to listen to the Bingo caller read out each target number or to view the target number as it is presented on a television screen. Novice players tend to favour the auditory mode of presentation while experienced players prefer to identify the visually presented targets. Thus, the Bingo player has around two seconds to identify the target number presented on a television screen, and locate it in the visual array (Bingo card) where it is surrounded by distractor items, and cross it out with a marker pen. This type of visual search in which players make a present/absent judgement within a limited amount of time is not unlike search tasks that have been investigated in the laboratory.

The visual search required in the game of Bingo is difficult for a number of reasons. Firstly, digits comprise conjunctions of features, that is, each digit is made up of a collection of lines and curves at different orientations. Research has demonstrated that the time required to search a visual array for a conjunction of these types of features increases with the number of items in the array (e.g. Treisman and Gelade, 1980). Thus, the time required to search a visual array for a conjunction target is dependent upon the number of items in the array. A Bingo player who plays with six cards has a visual array comprising ninety items and conjunction searches through arrays of this size are often time-consuming.

Secondly, search performance has been found to be affected by both target-distractor difference and distractor-distractor difference. In other words a target will be easy to locate if (a) it is very different from the other items in the array and, (b) the non-target items in the array are very similar to each other (Duncan & Humphreys, 1989). A number of features are shared across the digits 0 – 9. Thus, a target digit is not usually easily detected if it is placed among other digits, unless the distractor digits are all the same. The full range of digits 0 – 9 is used in various combinations in Bingo making for difficult searches.

Thirdly, as previously discussed, the efficiency of visual search is also affected by the consistency of stimulus-response mapping such that stimuli that elicit a consistent response across trials become automatically detected with practice However, search for stimuli that elicit a varied response remains slow and effortful (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The stimuli used in the game of Bingo produce a varied response, namely, a target on one trial becomes part of the distractor set on the next. Thus, regardless of the amount of practice undertaken by Bingo players, visual search in this game remains effortful and controlled.

Nevertheless, people who play Bingo on a regular basis demonstrate clear improvements in performance as, for example, they are able to increase the number of cards they play with and carry out additional tasks while searching for target digits. The principle of the Guided Search (GS) model of visual search put forward by Cave and Wolfe (1990) provides a possible explanation for the improvements in search performance found in regular Bingo players such that visual attention in Bingo search is guided by both stimulus driven and top-down sources of activation. During the initial stage of Bingo skill acquisition a player is provided with declarative knowledge about the game. Importantly, the player is informed that the numbers displayed on a six card Bingo grid ascend in columns (e.g. column 1 comprises digits 1 to 9; column 2 comprises digits 10 – 19 etc.) but that within a given column a particular number can appear in any of the 18 rows. However, although the novice Bingo player has knowledge of this rule it has not yet become proceduralised; thus the novice player's search is not automatically directed to the correct column when locating a target digit. As practice with Bingo search continues, the rules of Bingo become proceduralised such that the game can be played without the active maintenance of declarative knowledge (e.g. Anderson, 1982). Thus, a target presented during this stage acts also as a cue to automatically guide attention to the correct subset of the stimulus array. Indeed, it has been proposed that the efficient visual search performance demonstrated by experts over novices on domain-specific tasks results not from a superior ability to search and detect designated targets but from the contextual cuing of learned regularities within a visual array (Hoyer & Ingolfsdottir, 2003). Hoyer & Ingolfsdottir's proposal echoes an assertion made by Biederman (1972) that in the real world there is a predictable relationship between objects and their context and that target detection becomes easier as this relationship is learned. Empirical tests of this theory using the experimental technique of contextual cuing have confirmed that visual search for targets is facilitated by the provision of contextual information (e.g. Chun & Jiang, 1998). Furthermore, eye movement studies carried out by Henderson & Hollingworth (1999) have provided evidence to suggest that contextual cuing acts to guide attention to the portion of a visual scene deemed most important. Additionally, within the research area of expert performance, Reingold, Charness, Pomplun, and Stampe (2001) reported that expert chess players make fewer eye fixations for structured chess configurations than chess players who possess lower levels of skill.

The present experiment was designed to measure performance on the type of search carried out when playing the game of Bingo, that is, it is domain-specific. In other words the experimental task utilised here has been designed to mimic as closely as possible the routines executed by skilled Bingo players when they are playing a real game. It is important to establish if superior performance on the domain-specific tasks underlying molar performance occurs for Bingo players as this provides evidence that skill acquisition has taken place (for a review see Proctor & Dutta, 1995). This experiment also provides an opportunity to examine age differences in performance between younger and older adults given that age differences in visual search have been reported (e.g. Kramer, 1979; Madden, 1983; and Oken et al., 1992; Plude et al., 1983).

Also, the important finding in cognitive ageing research that behavioural slowing occurs for older adults on a wide range of cognitive tasks (for a review see Birren & Fisher, 1995) implies that older adults will take longer to process visual search information. However, it is important to separate out the effects of peripheral slowing from central slowing. Peripheral slowing refers to a decrease in the speed of sensory-motor processes such as stimulus detection and motor speed and is evident in the performance of older adults on many cognitive tasks (Welford, 1977). Central slowing, on the other hand, refers to the slowing down of central nervous system functioning and is evident on tasks that manipulate the complexity of conditions (e.g. Birren, 1965; Birren et al., 1980).

One technique that has been adopted recently by cognitive ageing researchers to remove the peripheral processing component from cognitive tasks is the time-accuracy method. The time-accuracy technique has been utilised in perceptual and cognitive psychological research for many years as it eliminates confounding issues such as motor speed on performance and allows us to look specifically at perceptual ability. Thus, in employing this method we are able to examine the relationship between central processing time and accuracy on a wide variety of cognitive tasks by manipulating the processing time available to participants (Verhaeghen, 2000). Verhaeghen notes that only a limited number of age-comparative studies have utilised this method so far (e.g. Kliegl 1995; Kliegl et al., 1993; Kliegl et al., 1994; Mayr et al., 1996; Verhaeghen et al., 1997; Verhaeghen et al., 1998, as cited in Perfect & Maylor, 2000). The time-accuracy method often uses a psychophysical staircase to plot accuracy as a function of time available. In the present experiment however, six pre-determined stimulus presentation times are used to examine time-accuracy relations between younger and older adults performance at Bingo search.

It is predicted that Bingo players will demonstrate superior performance to non-Bingo players on this domain-specific task. Further, it is expected that there will be no difference in the performance of Young and Old Bingo players on this task; they will possess comparable levels of molar performance (Salthouse, 1984) even though age-related declines have been reported in other experiments for this type of visual search.

Method

Design

This experiment employed a mixed design in which Age Group (younger/older), and Bingo (player/non-player) were between-subject factors and Presentation Time (600 ms, 1040 ms, 1480 ms, 1920 ms, 2360 ms and 2800 ms) was a within-subject factor. The measure of performance was percentage of trials for which the presence or absence of the target number was correctly reported (accuracy rate) for each stimulus presentation time.

Additional measures of performance were taken using indicators of sensitivity (*d'*) and bias (*c*).

Participants

Eighty participants volunteered to take part in this experiment. Twenty participants were younger non-Bingo players (17 female, 3 male) recruited from the Southampton area and were each given a box of chocolates on completion of the experiment. They were aged between 21 and 39 years (mean age = 28 years, *SD* = 5.31) and had a mean number of 11.75 years education. Twenty participants were younger Bingo players (18 female, 2 male) recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 24 and 39 years (mean age = 29.85 years, *SD* = 5.62) and had a mean number of 10.9 years education. Twenty participants were older non-Bingo players (18 female, 2 male) aged between 65 and 74 years (mean age = 68.50 years, *SD* = 4.14) and had a mean number of 10.4 years of education. They were recruited from the community via local press, radio, and TV advertising and were given a box of chocolates on completion of the experiment. Finally, 20 participants were older Bingo players (17 female, 3 male) who were recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 65 and 77 years (mean age = 68.85 years, *SD* = 5.2) and had a mean number of 9.95 years of education. To test whether the older and younger Bingo and non-Bingo players were matched for education a 2 (Age Group) x 2 (Bingo) between subjects ANOVA was performed on the data. The ANOVA revealed a significant main effect of Bingo, $F(1, 76) = 10.83$, $p < .01$, and it can be seen from looking at the descriptive data that the Bingo players have accrued fewer years of education overall than non-Bingo players. There was also a significant effect of Age Group, $F(1, 76) = 33.90$, $p < .01$, with older adults averaging fewer years of education than younger adults. There was, however, no significant interaction between Age Group and Bingo, $F < 1$. All participants had normal or corrected-to-normal vision and reported to be in good to excellent health.

Materials

The stimuli used in this experiment comprised 252 six-card Bingo grids (see Figure 5.1). A computer program written in Visual Basic (Microsoft Corporation, 1998) was used to generate the Bingo grids according to UK Bingo rules with the proviso that for half of the grids, one number was removed, thus creating 126 target-present trials and 126 target-absent trials.

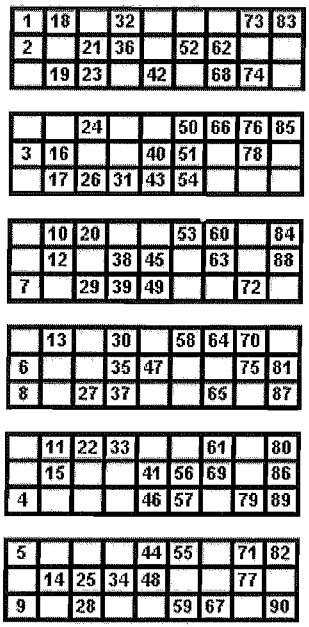

Figure 5.1. *An example of a target present six-card Bingo grid presented to participants.*

The digits within each six-card Bingo grid were drawn in black 18-point Arial font, with a row height of 3 and a column width of 4.3. The grid was drawn with a black 2 ¼ point border. The fill colour of the grid was pale yellow (R = 255, G = 255, G = 153). The stimuli were presented on a white background using an 850 MHz Pentium III IBM Laptop computer with an external 15" Sony TFT screen (running at 1024 x 768 resolution). Responses were made via a RB-610 six-button response box (Cedrus Corporation, 1991). The experiment was designed and administered with the commercial software Superlab Pro version 2.0 (Cedrus Corporation, 1991).

Procedure

Participants were tested individually. A variation of the time-accuracy method (e.g. Verhaeghen, 2000) was used to collect data. Firstly, participants were asked to familiarise themselves with the layout of a six-card UK Bingo grid. The rules for distributing the numbers 1 to 90 across the six cards were outlined, and participants were told to press the *Red* button to continue once they had read and understood the rules. A screen describing the experimental procedure was then presented to participants. Participants pressed the *Red* button to continue once they had read and understood the experimental procedure. Prior to performing the experimental task, participants completed a set of twelve practice trials (one of each stimulus presentation time and response type). Practice trials were included to ensure that each participant fully understood the procedure before continuing onwards with the experimental trials. The data from these trials were excluded from any subsequent analyses.

The sequence of displays for one trial is shown in Figure 5.2 below. At the start of each trial the word *Ready* was presented on the screen for 1000 ms. A 500 ms inter-stimulus interval (ISI) was given before the target number was presented for 1000 ms. Another 500 ms ISI was given and then a six-card Bingo grid was presented for 600 ms, 1040 ms, 1480 ms, 1920 ms, 2360 ms or 2800 ms. The target number was present somewhere in the appropriate column of the grid on half the trials, and absent on the other half. Following the presentation of the Bingo grid, a mask comprising a grid filled with hash marks (#) was displayed for 250 m/s. A further 500 m/s ISI was given before a question mark (?) was presented in the centre of the screen. This was the point at which the participant was required to make a response, by pressing the button marked *Y* if the target number was present on the six-card Bingo grid, or pressing the button marked *N* if the target number was absent. Following the participant's response, a 1000 m/s ISI was given and then a new trial began. The *Y* and *N* buttons were counterbalanced across participants so that for 50% of participants the *Y* button appeared on the left-hand side of the response box. Participants were instructed to make their responses using the index fingers of both hands and were informed that accuracy and *not* speed was important for this task.

The experiment comprised 240 experimental trials (twenty present and twenty absent trials for each stimulus presentation time). The experimental trials were presented randomly in 4 blocks of 60 trials, thus, providing opportunity for 3 breaks. The experimental procedure lasted approximately 40 minutes.

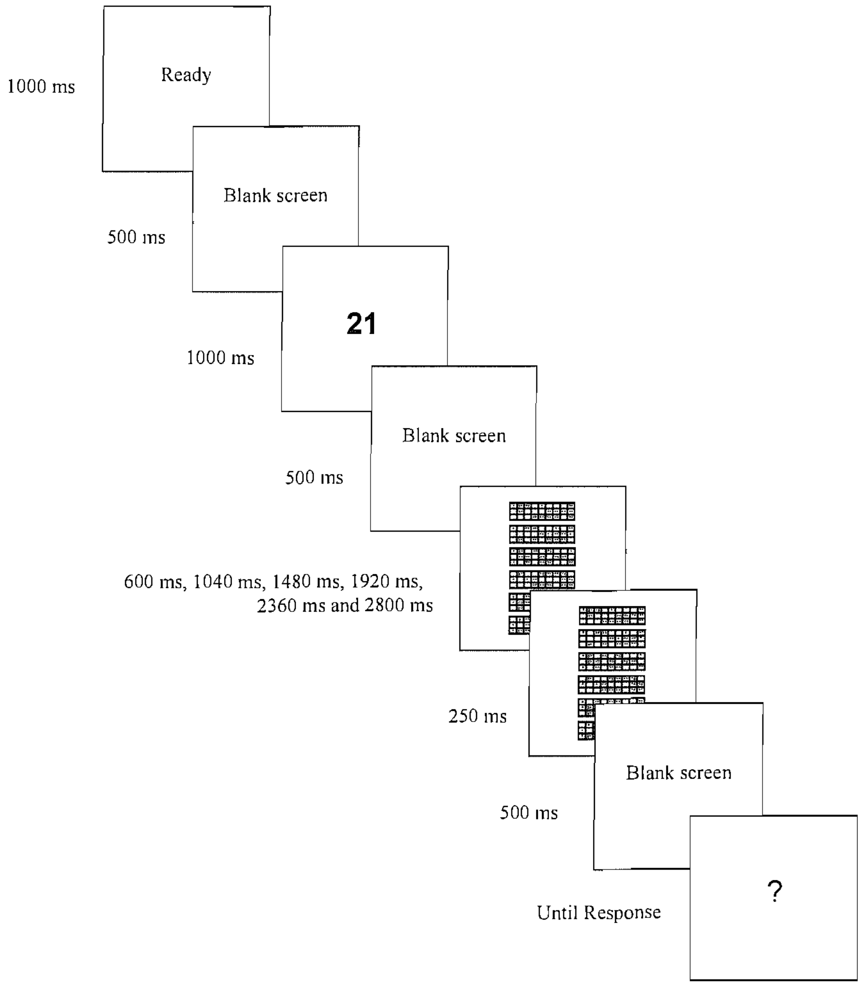

Figure 5.2. Sequence of events for one trial of the Bingo-search experiment.

Results and Discussion

The design of the present study allowed several analyses to be conducted. First, accuracy rate was examined by combining the number of correctly reported targets from the 20 target-present and 20 target-absent trials at each stimulus presentation time. The percentage of correct responses was collated for all participants so that a 2(Age) x 2(Bingo) x 6(Presentation Time) mixed design ANOVA could be performed on the data. The between-subject factors were Age and Bingo and the within subject factor was Presentation Time. Following this, signal detection theory was applied to the accuracy data in order to generate measures of sensitivity (*d'*) and bias (*c*). These measures were also examined to ascertain the effect of Age Group, Bingo and Presentation Time on participants' decision-making. Further, for all analyses the Alpha value was set at 0.05.

Accuracy Data

Table 5.1. Mean percentage accuracy rates for target-present and target-absent trials combined as a function of Presentation Time, Bingo, and Age-Group.

	Non-Bingo Players			Bingo Players		
Presentation Time (ms)	Mean %	(SD)	N	Mean %	(SD)	N
Younger						
600	48.38	(6.45)	20	49.00	(5.53)	20
1040	63.38	(1.86)	20	73.63	(5.99)	20
1480	75.50	(2.64)	20	88.25	(4.60)	20
1920	87.38	(2.98)	20	96.88	(2.42)	20
2360	96.25	(3.19)	20	99.75	(0.77)	20
2800	98.50	(2.35)	20	99.75	(0.77)	20
Older						
600	48.25	(3.73)	20	47.63	(8.41)	20
1040	55.25	(4.36)	20	71.50	(4.32)	20
1480	65.88	(3.06)	20	84.88	(2.86)	20
1920	76.75	(3.25)	20	96.75	(3.15)	20
2360	87.38	(3.58)	20	99.63	(1.22)	20
2800	94.75	(4.58)	20	99.88	(0.56)	20

The accuracy data, presented as percentage of correct responses, are summarised across experimental condition in Table 5.1. From this it appears that accuracy rate was differently affected by the variables manipulated in this experiment. Indeed, the results of the mixed 2 x 2 x 6 ANOVA produced a three-way interaction between the factors of Presentation Time, Bingo, and Age Group, $F(5, 380) = 6.488, p < .01$. In other words, the change in accuracy rate across the six different presentation times is differently affecting older and younger Bingo and non-Bingo players. For the purpose of clarity, however, this three-way interaction will now be broken down so that the separate effects of Age Group and Bingo on Presentation Time can be explored.

Firstly, it can be seen from looking at Figure 5.3 that as presentation time increased, the mean percentage of present targets correctly identified also increased. This resulted in a highly significant main effect of Presentation Time, $F(5, 380) = 2301.38, p < .01$.

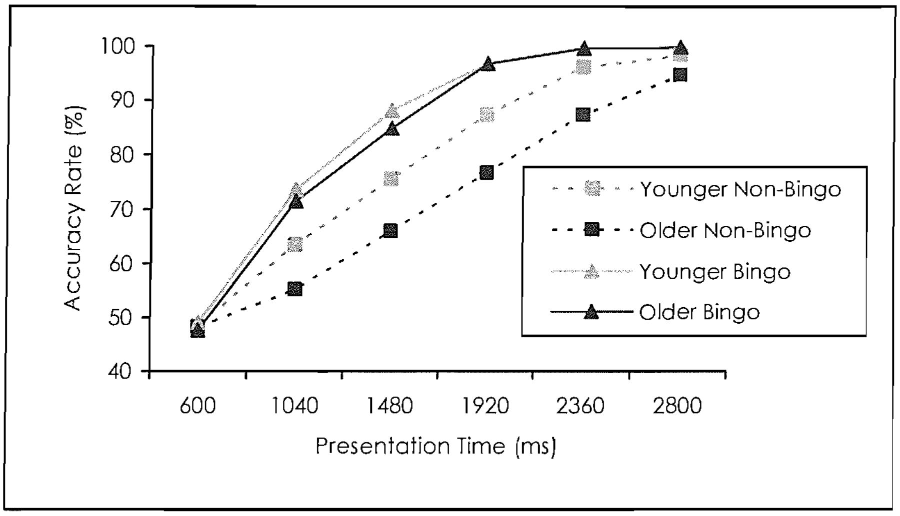

Figure 5.3. Overall accuracy rates for Bingo and non-Bingo players as a function of presentation time and age.

A primary interest of this experiment was whether or not Bingo players demonstrate superior performance on a domain-specific visual search task. Figure 5.3 illustrates that, overall, participants with Bingo experience achieved higher accuracy rates than those with no Bingo experience on this task. Moreover, this was confirmed by a significant main effect of Bingo, $F(1, 76) = 375.73$, $p < .01$. Such a result suggests that the Bingo players have indeed acquired a high level of proficiency for this type of skilled visual search. Furthermore, this result was predicted as all of the Bingo players recruited for this experiment had been playing the game for at least two years, and reported playing at least three times per week. Moreover, in the case of the older Bingo players most have been playing for several decades. This amounts to hundreds of hours of practice at searching the type of visual array used in this experiment. Importantly, although older participants identified fewer targets than younger participants overall, $F(1, 76) = 72.08, p < .001$, age appears to be having a different effect on the performance of Bingo and non-Bingo players. Indeed, this was confirmed by a significant Age Group x Bingo interaction, $F(1, 76) = 36.24, p < .001$. In light of the predictions made earlier, it is perhaps not surprising then that further examination of the simple-main effects of the Age Group x Bingo interaction by means of three independent t-tests, with a Bonferonni correction for multiple tests, found that older Bingo players identified more present targets overall than both older non-Bingo players ($t(38) = 16.64, p < .01$) and younger non-Bingo Players ($t(38) = 8.81, p <.01$). Importantly, however, there was no significant difference in performance between younger and older Bingo players, $t(38) = 1.77, p >.05$. This implies that both younger and older Bingo players are achieving the same level of performance at the molar skill of Bingo search (see Figure 5.4).

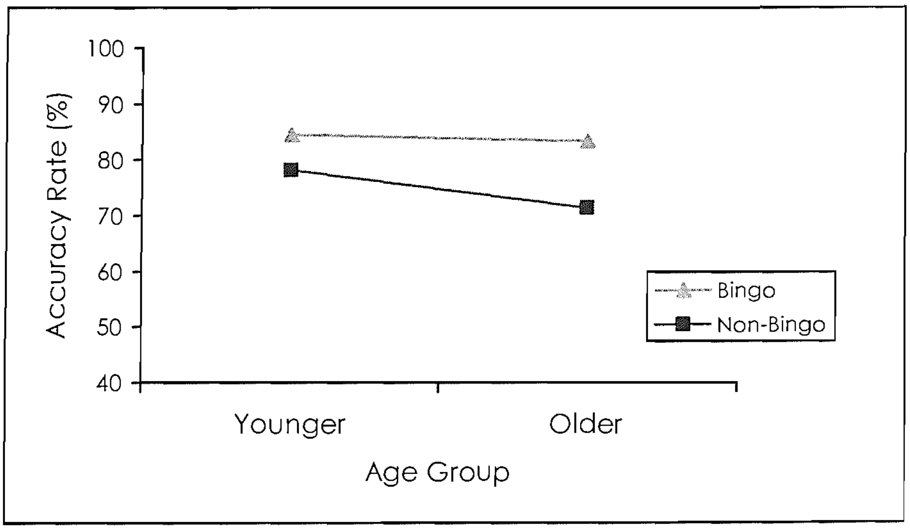

Figure 5.4. Overall accuracy rates for Bingo and non-Bingo players as a function of age group.

These results suggest that the skills underlying this visual search task normally show age-related deterioration, but are being maintained through practice into older adulthood in those who play Bingo. However, it should be noted that the older Bingo players recruited for this experiment have had significantly more practice over their lifetimes than the younger Bingo players. Yet, it could also be argued that as Bingo is not a highly complex cognitive skill, maximum performance might be reached quite quickly in comparison to more complex skills such playing chess or bridge. Therefore, the older Bingo players are not likely developing increasingly higher levels of skill but are rather maintaining their performance.

The descriptive data in Table 5.1 also indicate that Bingo players taken as a group elicited a different pattern of accuracy across the six presentation times than non-Bingo players. Further, this was confirmed by a significant interaction between Presentation Time and Bingo, $F(5, 380) = 65.92, p < .001$.

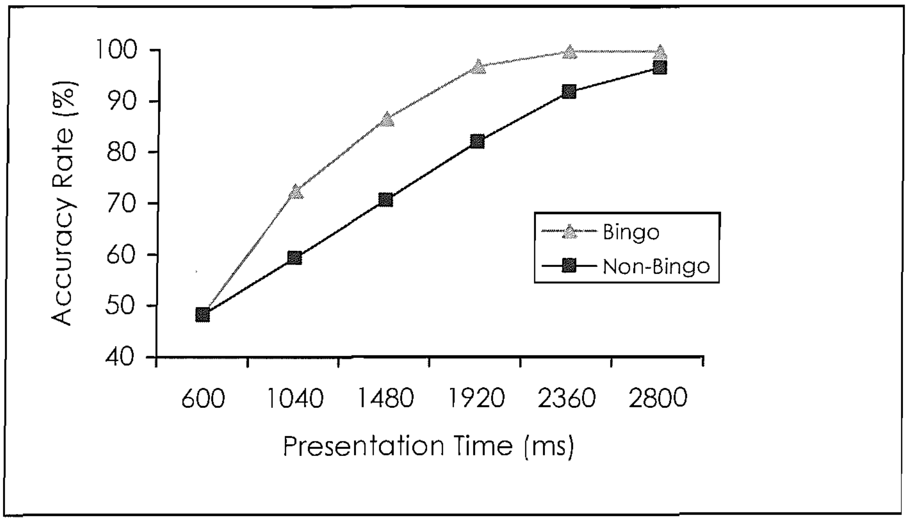

Figure 5.5. Overall accuracy rates for Bingo and non-Bingo players as a function of presentation time.

Figure 5.5 illustrates that Bingo players' performance increased more steeply from 600 ms to 1040 ms than non-Bingo players'. Further, by presentation time 1929 ms, the Bingo players were nearing asymptote performance whereas the performance of non-Bingo players was still increasing quite steeply.

Sensitivity and Bias

It is generally accepted that virtually all decision-making is carried out in the presence of some degree of uncertainty, for example, on any given experimental trial a participant maybe unsure as to whether a target is present or not. However, in a two-alternative forced-choice experiment a judgement must be made and a response given. Thus, it is proposed that a participant adopts a particular strategy for response-selection on these particular trials. In light of this argument it is important to determine whether the factors of Bingo and Age Group are differently affecting the response-selection strategy of participants in the present experiment. Signal detection theory (SDT) provides a means of determining both the sensitivity of perceptual discrimination and detecting the presence of response bias (i.e. a tendency to adopt a particular response strategy). The data in the present study were therefore subjected to analysis by application of signal detection theory, the results of which will now be presented.

Sensitivity

Sensitivity or discrimination ability refers to the ability of an individual to correctly distinguish a target stimulus from a number of distractor stimuli. To obtain the measures of sensitivity known as *d'* (the difference between the noise and signal-to-noise means in *z*-score units), and response bias referred to as *c* (where response criterion values are transformed to z-score units), the hit rate (the proportion of correctly identified present targets) and false alarm rate (the proportion of mistakenly identified targets in absent trials) must be calculated. However, as the present experiment was designed to ascertain asymptote performance, perfect performance accuracy is not only possible but very likely to occur at the longest presentation times particularly for Bingo players. Perfect accuracy, implies an infinite *d'*, therefore, as recommended by Snodgrass and Corwin (1988) a frequency of 0.5 will be added to all data cells before participants hit rate and false alarm rate are calculated.

The mean *d'* scores for the six presentation times across all participant groups were calculated and are presented in Table 5.2. A mixed 2 (Age Group) x 2 (Bingo) x 6 (Presentation Time) ANOVA was then performed on the data.

Table 5.2. Sensitivity of response (d') and standard deviations as a function of Presentation Time, Bingo, and Age-Group.

	Non-Bingo			Bingo		
Presentation Time (ms)	Mean	(SD)	N	Mean	(SD)	N
Younger						
600	-0.08	(0.33)	20	-0.05	(0.28)	20
1040	0.65	(0.09)	20	1.23	(0.35)	20
1480	1.33	(0.16)	20	2.29	(0.52)	20
1920	2.14	(0.27)	20	3.45	(0.48)	20
2360	3.38	(0.59)	20	4.05	(0.18)	20
2800	3.77	(0.51)	20	4.05	(0.18)	20
Older						
600	-0.09	(0.18)	20	-0.12	(0.42)	20
1040	0.26	(0.22)	20	1.09	(0.25)	20
1480	0.78	(0.15)	20	1.94	(0.22)	20
1920	1.40	(0.20)	20	3.43	(0.61)	20
2360	2.15	(0.32)	20	4.02	(0.28)	20
2800	3.17	(0.76)	20	4.08	(0.13)	20

The results of the mixed 2 x 2 x 6 ANOVA found that *d*' scores were indeed significantly affected by an interaction between Age Group, Bingo, and Presentation Time, $F(5, 380) = 9.19$, $p < .01$, suggesting that the pattern of proficiency of performance across the six different presentation times is differently affected by younger and older non-Bingo and Bingo players. For the purpose of clarity this three-way interaction between the factors of Presentation Time, Bingo, and Age Group will be broken down so that the separate effects of Age Group and Bingo on Presentation Time can be explored.

Firstly, as expected the results of the mixed ANOVA found that *d*' scores increased significantly with presentation time, $F(5, 380) = 1620.84$, $p < .01$, suggesting that all participants demonstrated an increased ability to distinguish between target and non-target stimuli as the available time to search the array was extended. Indeed, it can be seen from looking at Table 5.2 and at Figure 5.6 that as presentation time increased, the sensitivity of performance also increased, which is not surprising.

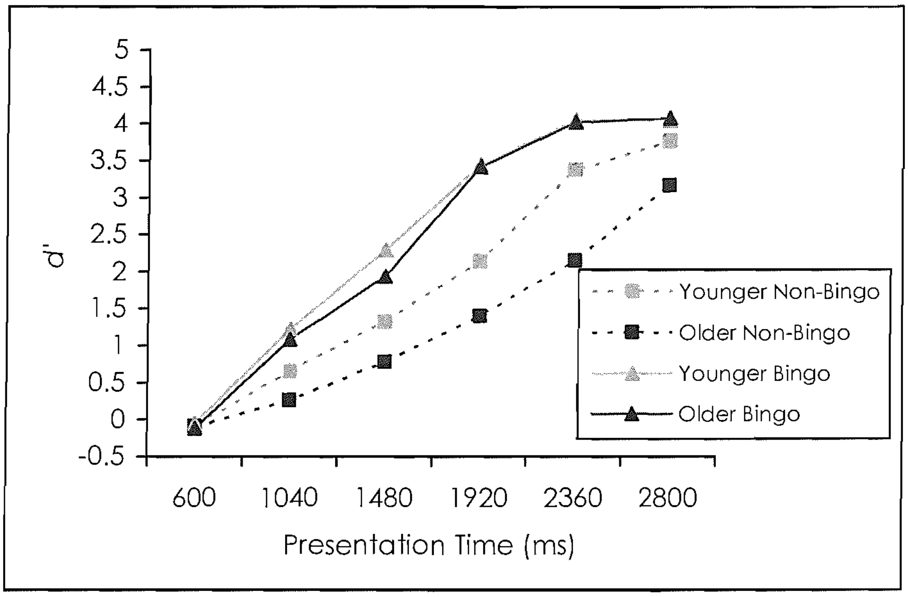

Figure 5.6. Sensitivity of response (d') for Bingo and non-Bingo players as a function of presentation time and age.

The results also revealed that Bingo players demonstrated superior response sensitivity than non-Bingo players, $F(1, 76) = 409.87, p < .001$ on this task. This supports the earlier analysis of accuracy rates and supports the suggestion that the Bingo players have acquired a high level of proficiency for this type of skilled visual search.

Further, although older participants demonstrated a lower response sensitivity than younger participants overall, $F(1, 76) = 61.81, p < .001$, Age Group appears to be differently affecting Bingo and non-Bingo players (see Figure 5.7 below). Indeed, this was confirmed by a significant Age Group x Bingo interaction, $F(1, 76) = 31.36, p < .01$.

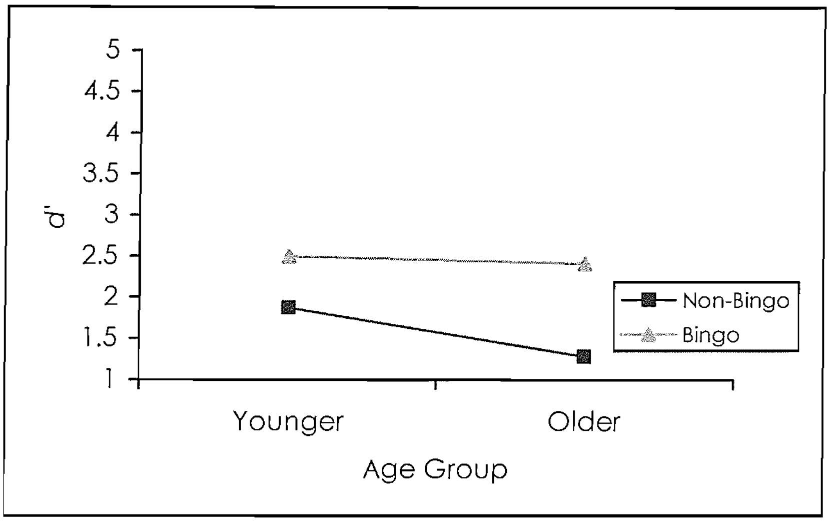

Figure 5.7. Sensitivity of response (d') for Bingo and non-Bingo players as a function of age.

The data displayed in Figure 5.7 illustrate that the sensitivity of response of the older non-Bingo players is much lower than that of the younger non-Bingo players while the difference in response sensitivity for younger and older Bingo players is very slight. This supports the results of the accuracy data and supports the assertion that both younger and older Bingo players are achieving the same level of performance at the molar skill of Bingo search.

The descriptive data presented in Table 5.2 and in Figure 5.8 also indicate that Bingo players differed in their sensitivity of response across the six presentation times to non-Bingo players. Again, this was confirmed by a significant interaction between Presentation Time and Bingo, $F(5, 380) = 60.33, p < .01$.

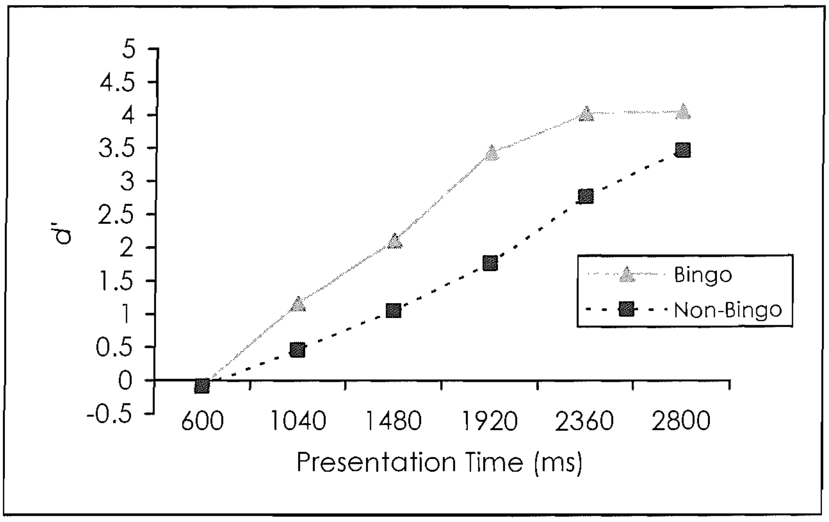

Figure 5.8. Sensitivity of response (d') for Bingo and non-Bingo players as a function of presentation time.

Figure 5.8 illustrates that Bingo players exhibited steeper increases in response sensitivity across the six presentation times than did non-Bingo players. This suggests that the Bingo players were able search more proficiently as presentation time increased in comparison to their non-Bingo playing counterparts. Further, it can be seen from looking at the data presented in Figure 5.9 that the response sensitivity exhibited by participants across the six presentation times was differently affected by age. This was confirmed by a significant two-way interaction between the factors of Age Group and Presentation Time, $F(5, 380) = 7.17$, $p < .01$. From looking at Figure 5.9, it seems possible that this interaction reflects the fact that the two age groups are achieving approximately the same level of performance for the shortest and longest exposures, but the younger participants are consistently better than the older participants for the presentation times in between. It is possible that the floor and ceiling effects are occurring here with all participants guessing at the shortest exposure and getting most everything right at the longest exposure.

However, the three-way interaction between Presentation Time, Age, and Bingo reported earlier suggests that the pattern of response sensitivity for younger and older adults across the six presentation times is differently affected for Bingo and non-Bingo players. Figure 5.6 suggests that Bingo players generally perform well regardless of age, while non-Bingo players perform less well, especially if they are older.

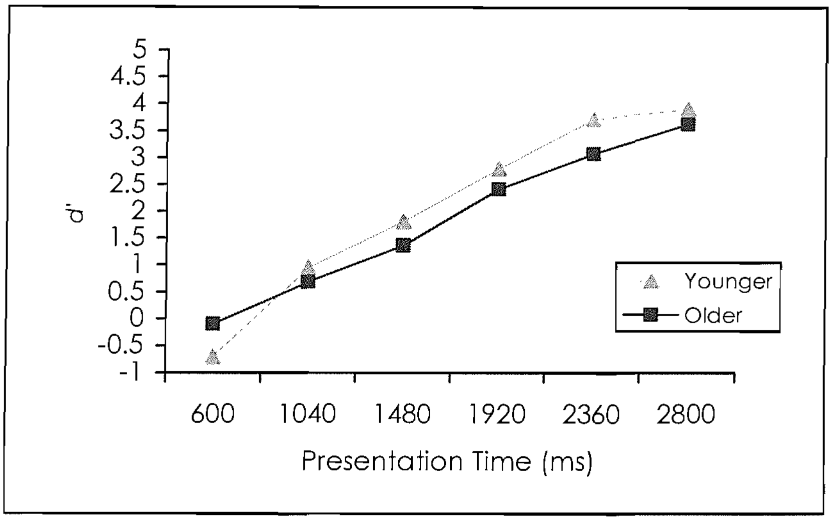

Figure 5.9. Sensitivity of response (d') for younger and older participants as a function of presentation time.

Bias

Finally, the accuracy data were manipulated to generate a measure of response bias (*c*). This measure allows any bias to respond 'present' or 'absent' across each of the conditions to become apparent. The scale over which response bias (*c*) is measured ranges from a value of -1 to +1. A negative value of *c* indicates the adoption of a liberal response strategy, that is, a greater tendency to say 'yes', whereas, a positive value of *c* signifies the presence of a conservative response strategy, that is, a greater tendency to say 'no'. It is important to note that a number of different response bias statistics are utilised in signal detection research (for a review see MacMillan & Creelman, 1991). However, the *c* statistic has been used in the present experiment to avoid the statistical errors that can occur in the calculation of the β statistic when hit rates and false alarm rates are equivalent (MacMillan & Creelman, 1990). Thus, the mean *c* scores for the six presentation times across all participant groups were calculated and are presented below in Table 5.3. A mixed 2 (Age Group) x 2 (Bingo) x 6 (Presentation Time) ANOVA was then performed on the data.

Table 5.3. Response bias (c) and standard deviations as a function of Presentation Time Age Group and Bingo.

Presentation Time (ms)	Non-Bingo Mean	Non-Bingo (SD)	Non-Bingo N	Bingo Mean	Bingo (SD)	Bingo N
Younger						
600	-0.122	(0.27)	20	-0.096	(0.21)	20
1040	0.016	(0.07)	20	0.062	(0.11)	20
1480	0.023	(0.06)	20	0.044	(0.18)	20
1920	-0.040	(0.10)	20	0.125	(0.19)	20
2360	-0.032	(0.10)	20	0.000	(0.08)	20
2800	-0.020	(0.07)	20	0.000	(0.08)	20
Older						
600	-0.091	(0.28)	20	-0.107	(0.32)	20
1040	-0.055	(0.16)	20	0.071	(0.06)	20
1480	-0.003	(0.05)	20	0.045	(0.08)	20
1920	0.008	(0.05)	20	0.034	(0.14)	20
2360	-0.007	(0.19)	20	0.129	(0.06)	20
2800	-0.018	(0.07)	20	0.129	(0.06)	20

The results of the mixed ANOVA produced a significant main effect of Presentation Time, $F(5, 380) = 9.30$, $p < .01$. Further, it can be seen from looking at the descriptive data presented in Table 5.3 and in Figure 5.10 that, overall; participants are adopting a more conservative response strategy as presentation time increases. This appears to be particularly true for the Bingo players; however, the interaction between Presentation Time and Bingo did not quite attain significance, $F(5, 380) = 2.03$, $p = .07$. Moreover, there was also no significant three-way interaction between Presentation Time, Bingo and Age Group, $F(5, 380) = 1.17$, $p > .05$.

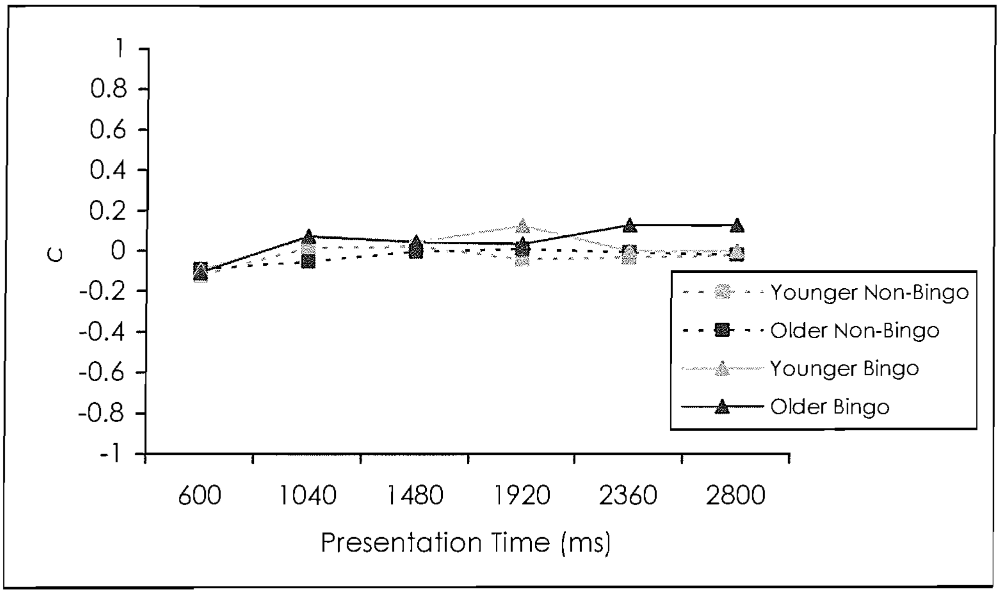

Figure 5.10. Mean response bias (c) scores as a function of presentation time, age group and Bingo.

The results however, did produce a significant main effect of Bingo, $F(1, 76) = 5.53$, $p < .05$, with Bingo players choosing to adopt a more conservative response strategy in general (Mean = 0.17, SD = 0.065), in contrast to non-Bingo players who tended towards a more liberal overall response strategy (Mean = -0.019, SD = 0.069).

Summary of Results

Analysis of accuracy rates and sensitivity of response (*d'*) revealed differences in performance of older and younger Bingo and non-Bingo players. In particular, Bingo players demonstrated superior performance to non-Bingo players on this task. Moreover, there were no significant differences in the performance of younger and older Bingo players suggesting that the skill involved in playing the game of Bingo is not negatively affected by the process of ageing.

General Discussion

The superior performance demonstrated by the Bingo players in the present experiment suggests that the task of Bingo Search utilised here does indeed tap into the cognitive processes underlying the skill of Bingo. The results of the present experiment also provide evidence to support the suggestion that skilled performance can be maintained with regular practice even when the processes underlying the skill are known to be sensitive to the ageing process (e.g. Bosman, 1993; Charness, 1981; Charness & Bosman, 1990; Rybash, Hoyer & Roodin, 1986; Salthouse, 1987, 1989, 1990).

Performance was analysed in terms of both accuracy rate and sensitivity (*d'*) of target detection. The time-accuracy technique was employed to control for possible age-differences in response execution by removing the motor component of the task. In addition, task difficulty was manipulated by measuring accuracy at six different presentation times, thus, setting limits on the amount of information processing time available to participants. The accuracy rate search slopes produced by participants along with the *d'* results suggest that Bingo players require considerably less time to search the six-card array than non-Bingo players and are able to perform this task more proficiently (as evidenced by the significantly higher response sensitivity of Bingo players). In contrast with the non-Bingo players, the six-card Bingo players recruited for this experiment have experienced hundreds of hours of practice at searching for target digits. Thus, it is likely that they have developed highly efficient and possibly automatic search strategies. All participants were provided with declarative knowledge of the task before the experiment commenced so that the non-Bingo players were familiarised with the simple rules regarding the layout of the six-card Bingo grid. Thus, the only perceived difference between the non-Bingo and Bingo players was the number of times they had previously carried out this type of search. The lower accuracy rates and *d'* scores found for non-Bingo players are characteristic of performance during the early stages of skill acquisition (e.g. Fitts and Posner, 1962, 64; Anderson, 1982, 1983; Rasmussen, 1979). Thus, even though the game of Bingo is a fairly simple cognitive skill as compared with chess or bridge, significant improvements in performance with practice are found despite the fact that Bingo search is a varied-mapping task. The rapid and accurate searching ability demonstrated by the younger and older Bingo players, is likely due to the transition of declarative Bingo knowledge to procedural Bingo knowledge (e.g. Anderson, 1982, 1983). In other words, the Bingo players do not only know how to execute the task, but know how to execute more efficiency. It is also possible that the performance of the Bingo players is being facilitated by the contextual cues provided by the target digits, thus resulting in the efficient guiding of attention to the important part of the array (Chun & Jiang, 1998).

In addition to efficient strategy development, a further possible explanation exists for the superior performance demonstrated by Bingo players, namely that of *unitisation.* Unitisation is a perceptual learning mechanism which involves the construction of single functional units from separate parts (Goldstone, 1998; for a review see Proctor & Dutta, 1995). For instance, Czerwinski, Lightfoot and Shiffrin (1992) described the *chunking* together of stimulus features with practice so that they are eventually perceived as a single unit. Additional evidence for the process of unitisation has been provided by studies investigating the mechanisms underlying word perception (O'Hara, 1980; Smith & Havilland, 1972). Such studies argue that words are perceived as single units because of the extensive experience people have with them, e.g. reading, writing etc. The computer modelling of neural networks has also contributed to our understanding of unitisation (e.g. Grossberg, 1984, 1991). Mozer, Zemel, Behrmann, and Williams (1992) for example, developed a neural network that demonstrates how unitisation, via the synchronisation of neurones, occurs for often repeated stimuli. In other words, visual features that repeatedly occur in a set of patterns will be synchronously bound together. Moreover, neuroscience research has demonstrated that experience causes the development of configuration units within the inferior temporal areas and the superior colliculus (Stein & Wallace, 1996). In light of the supporting evidence for the concept of unitisation, it is suggested that the superior performance demonstrated by Bingo players on the Bingo Search task may be partly due to the possible unitisation of the double-digit numbers used in the game of Bingo so that Bingo players move from searching for the two digits separately to searching for them as a single unit. Unitisation of the double-digits numbers would reduce the time required to identify the presence or absence of a target. Moreover this reduction in processing time, added to the time already saved as a result efficient strategy development would lead to enhanced performance at Bingo

Search. Unfortunately, however, it is not possible to test this hypothesis in the current experiment.

Importantly, the execution of efficient search strategies and possible unitisation following extensive practice at the game of Bingo appear to be maintained for the older Bingo players. Post hoc analyses revealed no significant difference between the performance of older and younger Bingo players. Moreover, older Bingo players performed significantly better than both younger and older non-Bingo players, with the performance of older non-Bingo players lagging somewhat behind that of the younger non-Bingo players. Furthermore, the performance of the older non-Bingo players appeared to be disadvantaged for all presentation times. In other words, their performance was particularly poor in comparison to the other three groups during those conditions which placed high constraints on the time available to process the visual search information. This finding is consistent with the idea that performance declines in older adults in this task because of a reduction in information processing resources. It is possible, for instance, that the older non-Bingo players are no longer proficient in their ability to make speeded perceptual judgements and therefore cannot compare as many target-non-target items in the allotted time as their younger non-Bingo playing counterparts (e.g. Salthouse1991, 1996). It is also possible that the older non-Bingo players have a reduced capability for inhibiting distracting information and are thus diffusing their attentional pool across both target and distractors (e.g. Hasher & Zacks, 1979). On the other hand, these results argue against an account based on a reduction in working memory capacity in this instance (e.g. Craik & Byrd, 1982) as the Bingo Search task required only one target item to be held in memory. Unfortunately, this experiment is not able to determine which if any of these mechanisms are responsible for the poor performance of older non-Bingo players.

In addition, the present experiment cannot determine the mechanism by which older Bingo players are able to achieve the same level of performance as younger Bingo players. It is, however, highly unlikely that accommodation is the mechanism responsible for maintained performance as the older Bingo players were subject to the same task constraints as the younger Bingo players. It is possible, though, that older Bingo players have sub-consciously developed a compensatory strategy in order to achieve comparable performance to younger players. For instance, older Bingo players may be able to utilise the contextual information contained within the visual array to the extent that any age differences in the speeded perceptual processes underlying the task are circumvented. Indeed, Hoyer and Ingolfsdottir (2003) reported that middle-aged medical laboratory technologists were able to use contextual cues provided in images of bacterial morphology to achieve comparable levels of visual search performance with their younger counterparts. However, the Bingo Search task does not enable the nature of any compensatory strategy used by the older Bingo players in the present experiment to be determined. Remediation or maintenance of the cognitive processes underlying the skill is also a potential candidate to explain the maintenance of performance of the older Bingo players as it is possible that regular practice is serving to eliminate or reduce age deficits in the elementary cognitive processes underlying Bingo search. This can be tested by assessing performance on more general elementary cognitive processes. Finally, the encapsulation hypothesis also provides a possible explanation for maintained performance with age as skilled Bingo search may no longer depend on the elementary cognitive processes that underlie it. Tests of both the remediation and encapsulation hypothesis will be presented later in this thesis.

Further, the experimental design employed in the present experiment prevents conclusions being drawn about the direction of causation. There is some possibility that practice at Bingo does not improve visual search, but that the people who are better searchers play more Bingo.

In addition, this experiment does also not reveal anything about whether the cognitive skills practiced by Bingo player are transferable to other stimulus domains. In other words, does practice at searching for digits foster a general ability of visual search as predicted by the doctrine of formal discipline (Locke, 1700, as cited in Higginson, 1931), or does practice at searching for digits just improve the ability to search for digits as proposed by the theory of identical elements (Thorndyke & Woodworth, 1901)? This question will be addressed in the next experimental chapter.

Conclusion

In summary, this first experiment has provided initial support for the maintenance of skilled performance in older adulthood. It has also established the Bingo Search task as a measure of domain-specific performance of the skill of Bingo. Further research will be conducted in attempt to (a) elucidate the mechanism responsible for the maintenance of Bingo skill in older adults, and (b) establish whether practice at the type of visual search involved in Bingo transfers to other types of search.

CHAPTER SIX

EXPERIMENT 2: A TEST OF THE TRANSFERABILITY OF BINGO SEARCH

Introduction

The experimental task utilised in the previous study provides an opportunity for investigating the transfer of skill in visual search. The purpose of the present experiment, therefore, is to determine if Bingo players are able to apply the skill they have learned to a new situation. The literature on perceptual and cognitive skill transfer leads to certain predictions about the transfer of Bingo search to another stimulus domain.

Transfer of learning can either be positive, negative, or neutral. Positive transfer occurs when a previous skill *facilitates* the learning of a new skill; negative transfer occurs when a previous skill *impairs* the learning of a new skill; and neutral (or zero) transfer occurs when a previous skill has *no effect* on the learning of a new skill. Various theories postulating the conditions under which the different types of transfer occur have been put forward. Firstly, the *doctrine of formal discipline* (Locke, 1700, as cited in Higginson, 1931) proposes that performance on all tasks is facilitated if fundamental cognitive abilities like reasoning and problem solving are practiced. In other words, the mind is like a muscle which if exercised results in an increase in fitness of the general cognitive abilities which underlie all tasks. Conversely, the *theory of identical limits* put forward by Thorndyke and Woodworth (1901) argues that transfer is much more specific such that positive transfer only occurs for new activities which comprise the same stimulus-response elements as previously learned activities. In their classic transfer studies participants received training on the skill of judging the area of various rectangles. Following a significant amount of practice on the rectangle task for which all participants showed improvement, participants were then given a related but different task of estimating the areas of circles and triangles. Thorndyke and Woodward found very little evidence of transfer from the rectangle task to the triangle and circle task and concluded that the ability to estimate area was not a general skill. It is important when considering Thorndyke and Woodworth's findings, however, to take into account that the rules for estimating surface area for rectangles are different from that of triangles and circles, that is, additional declarative knowledge is required to carry out the task.

Subsequent research has suggested that transfer is neither as general as that proposed by the doctrine of formal discipline (e.g. Logan & Klapp, 1992), nor as specific as that purported by the theory of identical elements (e.g. MacKay, 1992). Singley and Anderson (1989) and Bovair, Kieras and Polson, (1990) have developed theories that specify the elements of a task that need to be kept constant across new learning situations for positive transfer to occur. These elements are also similar to those proposed by Anderson's (1983) Adaptive Control of Thought Model (ACT). The fundamental principle underlying each of these three theories is that positive transfer occurs when the *cognitive abstractions*, for example, rules or chunks of knowledge, that are formed in the original learning context, can be used in another. Thus, the sharing of *identical elements* between the original and transfer task remains an important principal of transfer for these theories; however, the nature of the specified elements is what distinguishes them from that of Thorndyke and Woodworth. Importantly, theories such as ACT propose a number of different means by which experience on one task can influence another. In light of these more recent theories, it would appear that transfer is not difficult to achieve. Yet, there is a plethora of research that demonstrates both the problems of achieving transfer and the failure of learners to identify and take advantage of the shared elements between prior and subsequently learned tasks (for a review see Patrick, 1992). Importantly, theories based on the production of rules argue that failure to transfer from one situation to another occur because the elements contained within the rules are too specific and therefore, learners do not realise that an old rule can be applied in a new situation. Further, Druckman and Bjork (1994) propose that generalisations between tasks have to be explicitly encoded, for instance, by the learner becoming consciously aware of the similarities in the rules underlying the tasks.

Failure to positively transfer from one situation to another also occurs when the original task is dramatically different from the to-be-acquired task. For example, Knerr, Morrison, Mumaw, Stein, Sticha, Hoffman, Buede, and Holding (1987) found that although participants trained in the ability of flight path recognition demonstrated superior flight path recognition performance to controls, they performed no better than controls on a test of flight path generation.

The findings reported from the evidence outlined above provide a rationale for using the Symbol Search task presented in the current experiment to examine the effects of Bingo experience on the ability to perform a new task which on the one hand, comprises the same production rules as the original task but on the other, introduces a different stimulus set.

In a typical laboratory experiment of cognitive transfer, an Experimental Group is given both the original and the transfer task, and a Control Group is given only the transfer task. Performance on the transfer task is then compared for both groups, with higher levels of performance by the experimental group indicating positive transfer, lower levels of performance indicating negative transfer, and equivalent levels of performance for both groups indicating no transfer. Such laboratory experiments provide a valuable insight into the effects of training on cognitive skill transfer. However, they do not mimic the acquisition of everyday skill. That is, laboratory training studies although very well controlled cannot emulate the amount and regularity of practice undertaken by a person with, for instance, thirty or forty years of experience at Bingo.

The present experiment adopts a similar design to that used in laboratory studies in that skilled Bingo players will be given a transfer task having already acquired the original skill, namely, that of Bingo search, whereas non-Bingo players will be given only the transfer task. Thus, the difference between the present experiment and many laboratory transfer studies is that the original skill has already been acquired. The present experiment will therefore provide an opportunity to determine whether the type of search involved in playing the real life activity of Bingo is transferable to other stimulus search domains. Aside from providing knowledge of the conditions under which practice on a particular task affects the performance of another, studies of the transfer of cognitive skill have important practical implications. For instance, if it is found that practice at one activity (e.g. visual search for digits) improves performance on other related activities (e.g. visual search for symbols) then practice on such a task might improve performance on everyday tasks involving visual search such as shopping or driving. Such knowledge also has important implications for education which is based on the principle that academic learning activities extend beyond the exact conditions of initial learning to different tasks, other subjects, and eventually to the workplace.

Further, the present experiment provides the additional opportunity to study the effect of age on the transferability of Bingo skill. Cognitive ageing research has suggested that a possible reason for the reduced performance of older adults on many cognitive tasks is the loss of the ability to develop efficient strategies (for a review see Salthouse, 1991). In light of this evidence it is possible that older Bingo players will experience difficulty in transferring the strategies they use for Bingo search to a new situation.

Method

Design

This experiment employed a mixed design identical to the previous experiment. Age Group (younger/older) and Bingo (player/non-player) were between-subject factors and Presentation time (1350 ms, 1700 ms, 2050 ms, 2400 ms, 2750 ms and 3300 ms) was a within-subject factor. The measure of performance was percentage of trials for which the presence or absence of the target number was correctly reported (accuracy rate) for each stimulus presentation time. Additional measures of performance were taken using indicators of sensitivity (*d'*) and bias (*c*).

Participants

Eighty participants volunteered to take part in this experiment. Twenty participants were younger non-Bingo players (19 female, 1 male) recruited from the Southampton area and were each given a box of chocolates on completion of the experiment. They were aged between 22 and 39 years (mean age = 28.9 years, *SD* = 5.03) and had a mean number of 11.5 years education. Twenty participants were younger Bingo players (18 female, 2 male) recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 24 and 39 years (mean age = 30.05 years, *SD* = 4.55) and had a mean number of 10.8 years education. They were recruited from the community via local press, radio, and TV advertising and were given a box of chocolates on completion of the experiment. Twenty participants were older non-Bingo players (17 female, 3 male) aged between 61 and 74 years (mean age = 67.4 years, *SD* = 3.35) and had a mean number of 10.3 years of education. Finally, 20 participants were older Bingo players (18 female, 2 male) who were recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 62 and 71 years (mean age = 66.4 years, *SD* = 2.85) and had a mean number of 9.7 years of education. To test whether the older and younger Bingo and non-Bingo players were matched for education a 2 (Age Group) x 2 (Bingo) between subjects ANOVA was performed on the data. The ANOVA revealed a significant main effect of Bingo, $F(1, 76) = 13.45$, $p < .01$, and it can be seen from looking at the descriptive data that the Bingo players have attained fewer years of education overall than non-Bingo players. There was also a significant effect of Age Group, $F(1, 76) = 47.53$, $p < .01$, with older adults averaging fewer years of education than younger adults. There was, however, no significant interaction between Age Group and Bingo, $F < 1$. All participants had normal or corrected-to-normal vision and self-reported to be in good to excellent health. None of the participants used in the present experiment took part in the previous experiment.

Materials

The stimuli used in this experiment comprised 252 six-card symbol grids. A computer program written in Visual Basic (Microsoft Corporation, date) was used to generate the symbol grids. As in the Bingo-Search experiment, the symbol grids were generated according to UK Bingo rules. However, before a grid was exported to a bitmap (.bmp) file, each digit was substituted by a symbol. Each digit was always replaced by the same symbol, and there was a different symbol to replace each digit. The symbols were selected from the SPSS marker set. However, because some of the symbols had different baseline co-ordinates (i.e. subscript/superscript), adjustments were made using the commercial font-editing software Fontlab 3.0 (FontLab Developers Group, 1996).

0	1	2	3	4	5	6	7	8	9
⧗	□	◈	✢	▯	▽	⬠	○	✳	⬆

Figure 6.1. The digits 0 - 9 and their corresponding symbols.

As in the Bingo-Search experiment, the symbol grids were generated with the proviso that for half of the grids, one symbol-number was removed, thus, creating 126 target-present trials and 126 target-absent trials. Except for the missing targets and the substitution of symbols for digits, the cards were generated according to the rules for Bingo in the U.K. The symbols within each six-card symbol grid were drawn in black 18-point SPSS Marker Set font. The grid was drawn using a black 2 ¼ point border. The fill colour of the grid was pale yellow (R = 255, G = 255, B = 153). The stimuli were presented using an 850 MHz Pentium III IBM Laptop computer with an external 15" Sony TFT screen (running at 1024 x 768 resolution). Responses were made via a RB-610 six-button response box (Cedrus Corporation, 1991). The experiment was designed and administered with the commercial software Superlab Pro version 2.0 (Cedrus Corporation, 1991).

Procedure

Participants were tested individually. Firstly, participants were asked to familiarise themselves with the layout of the six-card symbol grid. Participants were shown the symbols to be used and the equivalent digit for each (see Figure 6.1). The rules for distributing the number-symbols 1 to 90 across the six cards were outlined, and participants were told to press the *Red* button to continue once they had read and understood the rules. A screen describing the experimental procedure was then presented to participants. Participants pressed the *Red* button to continue once they had read and understood the experimental procedure. Prior to performing the experimental task, participants completed a set of twelve practice trials (one of each stimulus presentation time and response type). The data from these trials were excluded from any subsequent analyses.

At the start of each trial the word *Ready* was presented on the screen for 1000 ms. A 500 ms inter-stimulus interval (ISI) was given before the target number was presented for 2000 ms. Unlike in the Bingo-Search experiment, the number of the column that the target would appear was indicated above the target symbol or symbol-pair (see Figure 6.2). This was done to provide the same cuing information for participants as in the Bingo search experiment.

Another 500 ms ISI was given and then a six-card symbol grid was presented for 1350 ms, 1700 ms, 2050 ms, 2400 ms, 2750 ms or 3300 ms (half of trials comprised target-present Bingo grids). The task was expected to be more difficult than the number search in the previous experiment, and thus the exposure times were increased. Following the presentation of the Bingo grid, a mask comprising a grid filled with hash marks (#) was displayed for 250 ms. A further 500 ms ISI was given before a question mark (?) was presented in the centre of the screen. This was the point at which the participant was required to make a response, by pressing the button marked *Y* if the target symbols were present on the six-card symbol grid, or pressing the button marked *N* if the target symbols were absent. Following the participant's response, a 1000 m/s ISI was given and then a new trial began. The *Y* and *N* button positions were counterbalanced across participants so that for 50% of participants the *Y* button appeared on the left-hand side of the response box. Participants were instructed to make their responses using the index fingers of both hands and were informed that accuracy *not* speed was important for this task.

The experiment comprised 240 experimental trials (twenty present and twenty absent trials for each stimulus presentation time). The experimental trials were presented randomly in 4 blocks of 60 trials, thus, providing opportunity for 3 breaks. The experimental procedure lasted approximately 40 minutes.

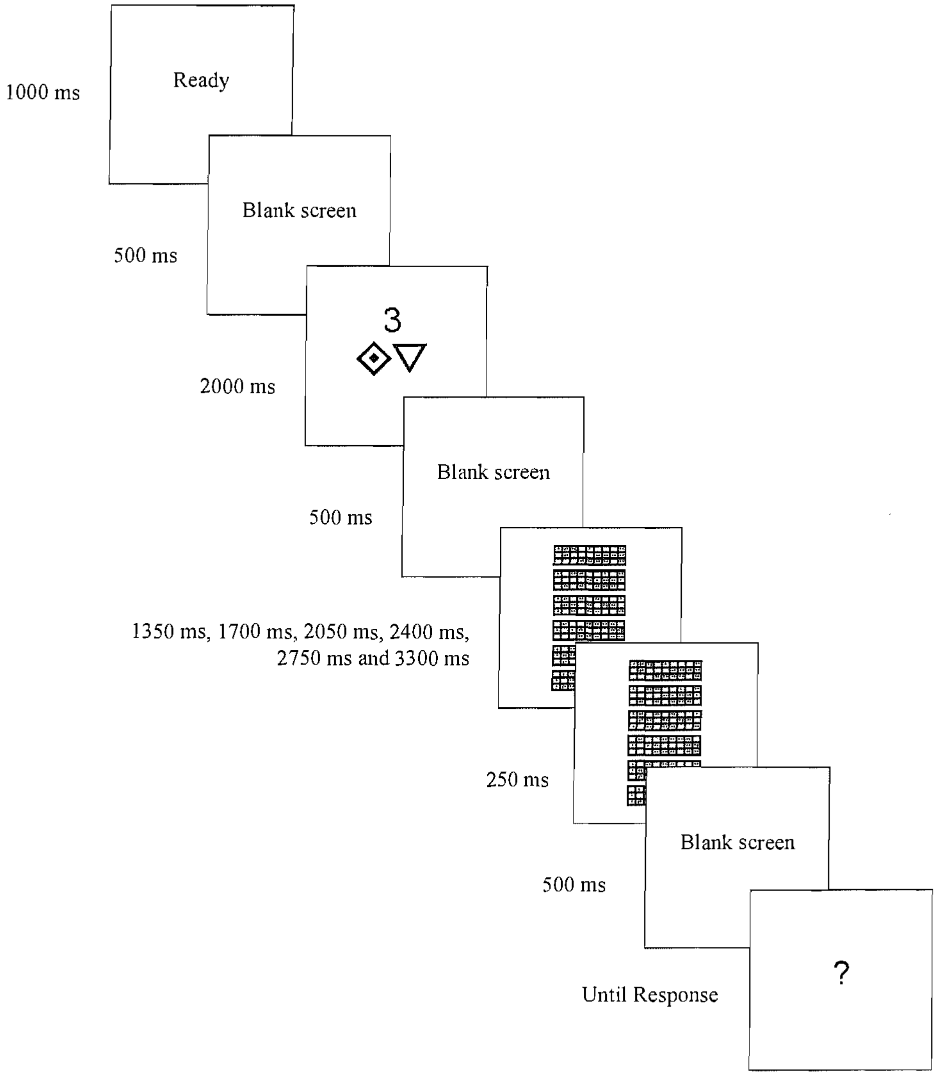

Figure 6.2. Sequence of events for one trial of the symbol-search experiment.

Results and Discussion

The design of the present study allowed several analyses to be conducted. First, accuracy rate was examined by combining the number of correctly reported targets from the 20 target-present and 20 target-absent trials at each presentation time and a 2 (Age) x 2 (Bingo) x 6 (Presentation Time) mixed design ANOVA was performed on the data. The between-subject factors were Age Group and Bingo and the within subject factor was Presentation Time. Following this, measures of sensitivity (*d'*) and bias (*c*) were calculated. These measures were also examined to ascertain the effect of Age Group, Bingo and Presentation Time on participants' decision-making. For all analyses the Alpha value was set at 0.05.

Accuracy Data

Table 6.1. Mean percentage accuracy rates for target-present and target-absent trials combined as a function of Presentation Time, Bingo, and Age-Group.

	Non-Bingo			Bingo		
Presentation Time (ms)	Mean	(SD)	N	Mean	(SD)	N
Younger						
1350	53.25	(9.39)	20	57.00	(11.11)	20
1700	61.00	(3.92)	20	67.75	(5.06)	20
2050	69.75	(4.28)	20	74.13	(4.39)	20
2400	76.75	(2.82)	20	81.00	(4.47)	20
2750	83.25	(2.58)	20	88.38	(4.16)	20
3300	86.88	(2.80)	20	91.88	(3.62)	20
Older						
1350	51.25	(7.97)	20	52.25	(8.66)	20
1700	58.38	(5.46)	20	59.69	(4.88)	20
2050	65.00	(4.59)	20	67.38	(5.00)	20
2400	71.75	(4.06)	20	74.25	(4.28)	20
2750	76.75	(4.67)	20	80.00	(4.97)	20
3300	81.88	(4.28)	20	84.38	(4.38)	20

The accuracy data, presented as percentage of correct responses, are summarised across experimental conditions in Table 6.1. Firstly, it can be seen from looking at the descriptive data displayed in Table 6.1 and in Figure 6.3 that as presentation time increased the mean percentage of present and absent targets correctly identified by participants also increased. This resulted in a highly significant main effect of Presentation Time, $F(5, 380) = 559.48$, $p < .01$.

A primary interest of this experiment was whether or not Bingo players would demonstrate superior performance on this test of the transferability of Bingo search. Figure 6.3 below illustrates that overall participants with Bingo experience achieved higher accuracy rates than those with no Bingo experience on this task. Moreover, this was confirmed by a significant main effect of Bingo, $F(1, 76) = 56.51$, $p < .01$, implying that Bingo experience somehow facilitated performance on this task. However, unlike in the previous experiment, the factor of Bingo did not interact significantly with that of Age Group, $F < 1$; moreover, older participants identified fewer targets overall than younger participants, producing a main effect for the factor of Age Group, $F(1, 76) = 41.11$, $p < .01$ (see Figure 6.4).

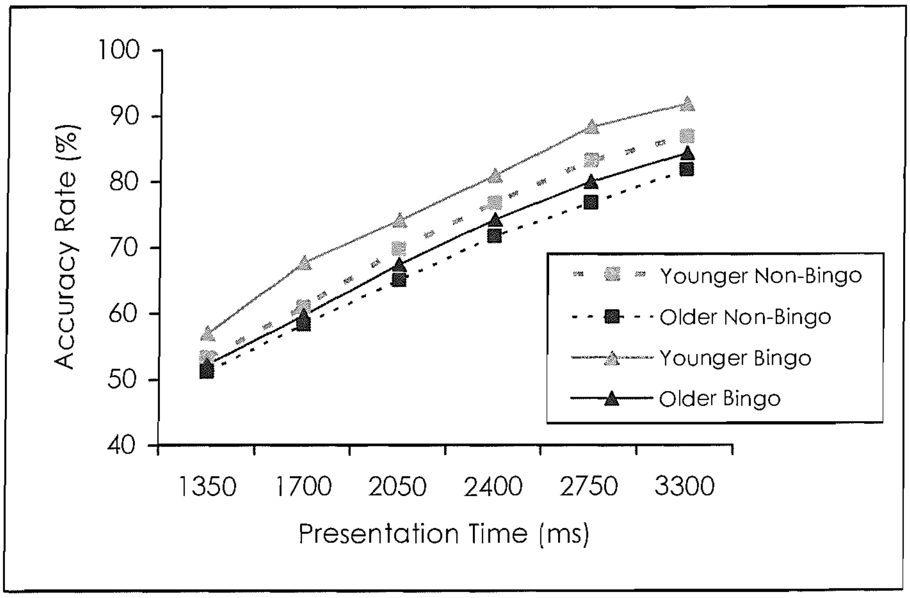

Figure 6.3. Overall accuracy rates for Bingo and non-Bingo players as a function of presentation time and age.

The lack of a significant interaction between Age Group and Bingo suggests that the ageing process negatively affects the processes underlying performance of both Bingo players and non-Bingo players on this task in a similar way (see Figure 6.4). Thus, although Bingo players demonstrated superior performance overall, the component processes underlying the task are negatively affected by age in spite of the continued practice of the older Bingo-players.

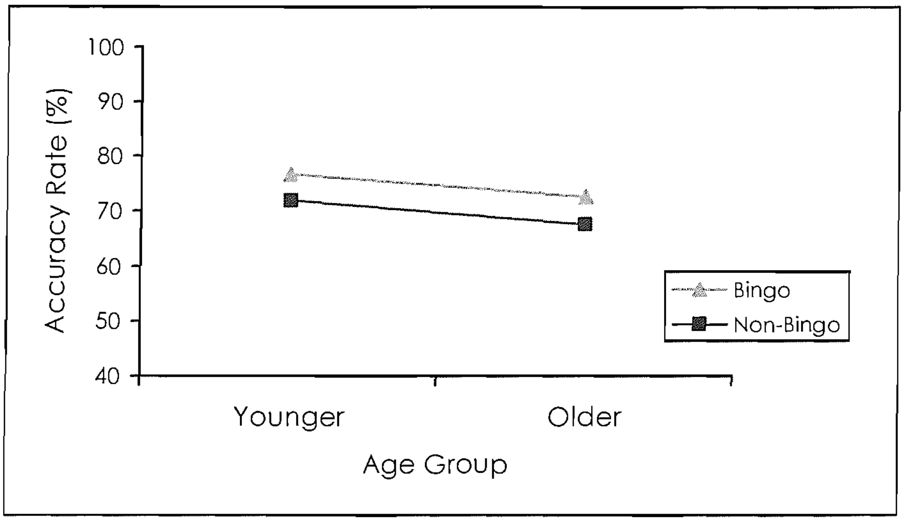

Figure 6.4. Overall accuracy rates for Bingo and non-Bingo players as a function of age.

The results also revealed no significant interaction between Presentation Time and Bingo, $F < 1$. This suggests that although Bingo players demonstrated superior performance over non-Bingo players for this visual search task; this advantage remains stable across the six presentation times (see Figure 6.5).

It is possible, for instance, that Bingo players have acquired certain general skills for searching an array laid out according to familiar rules and that these have transferred to a different class of stimulus items. Further, this transference may be knowledge-based, i.e. how to search most efficiently by utilising effective and well-rehearsed search strategies. Although the symbol search task is designed to exclude factors of response speed and motor control, it does assess performance of more than one cognitive process. Firstly, there is the process of speeded visual-search (searching for and locating a target symbol(s) amongst distracters, and secondly, there is the process of encoding and holding in memory one or two symbols. Further, there is probably a process of assigning each symbol a verbal label in order for it to be encoded. It is possible that age may differentially affect these processes. However, the present experiment is unable to tease apart the processes responsible for a participant's performance. Further research could assess participant's recall of the symbols.

Finally, the results of the mixed ANOVA produced no significant three-way interaction between the factors of Presentation Time, Bingo, and Age $F < 1$. In other words, the pattern of accuracy rates across the six different presentation times for younger and older adults was not affected by Bingo experience.

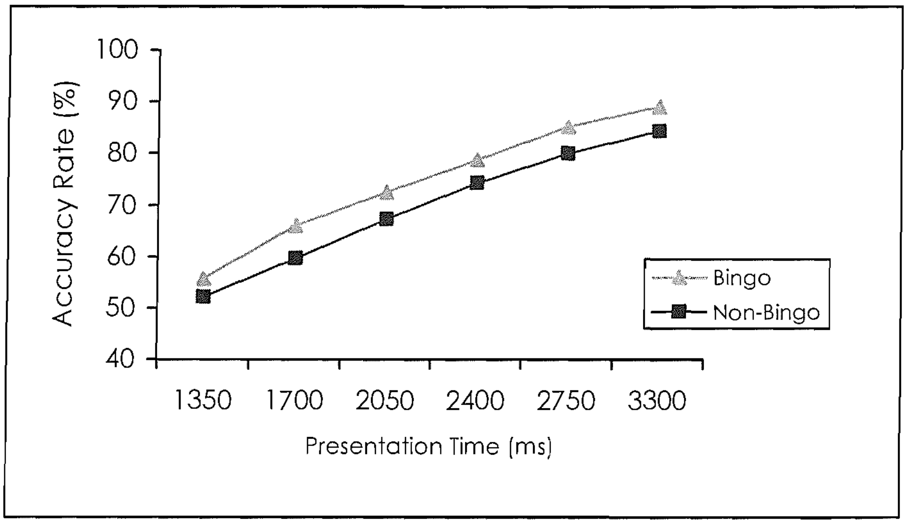

Figure 6.5. Overall accuracy rates for Bingo and non-Bingo players as a function of presentation time.

Sensitivity and Bias

As with the previous experiment it is important to determine whether the factors of Bingo and Age Group are differently affecting the sensitivity and the response-selection strategy of participants in the present experiment. The data were therefore subjected to analysis by application of signal detection theory.

Sensitivity

In accordance with the first experiment, *d'* was calculated from the hit rate and false alarm data. A frequency of 0.5 was added to all data cells before participants' hit rate and false alarm rate were calculated to avoid an infinite *d'*. The mean *d'* scores along with their standard deviations for the six presentation times across all participant groups were then calculated and are presented below in Table 6.2. A mixed 2(Age Group) x 2(Bingo) x 6(Presentation Time) ANOVA was then performed on the data.

Table 6.2. Sensitivity of response (d') and standard deviations as a function of Presentation Time, Bingo, and Age-Group.

	Non-Bingo			Bingo		
Presentation Time (ms)	Mean	(SD)	N	Mean	(SD)	N
Younger						
1350	0.16	(0.47)	20	0.36	(0.59)	20
1700	0.54	(0.20)	20	0.90	(0.32)	20
2050	1.00	(0.23)	20	1.24	(0.27)	20
2400	1.39	(0.17)	20	1.67	(0.33)	20
2750	1.85	(0.20)	20	2.28	(0.37)	20
3300	2.13	(0.29)	20	2.68	(0.48)	20
Older						
1350	0.06	(0.41)	20	0.23	(0.33)	20
1700	0.41	(0.27)	20	0.71	(0.26)	20
2050	0.74	(0.23)	20	1.06	(0.22)	20
2400	1.10	(0.23)	20	1.38	(0.16)	20
2750	1.40	(0.29)	20	1.76	(0.22)	20
3300	1.74	(0.32)	20	2.11	(0.33)	20

The descriptive data presented in Table 6.2 and in Figure 6.6 suggest that as expected, presentation time increased participants' response sensitivity also increased. Indeed, this was confirmed by the results of the mixed 2 x 2 x 6 ANOVA which found that *d'* scores were significantly affected by presentation time, $F(5, 380) = 532.96$, $p < .01$.

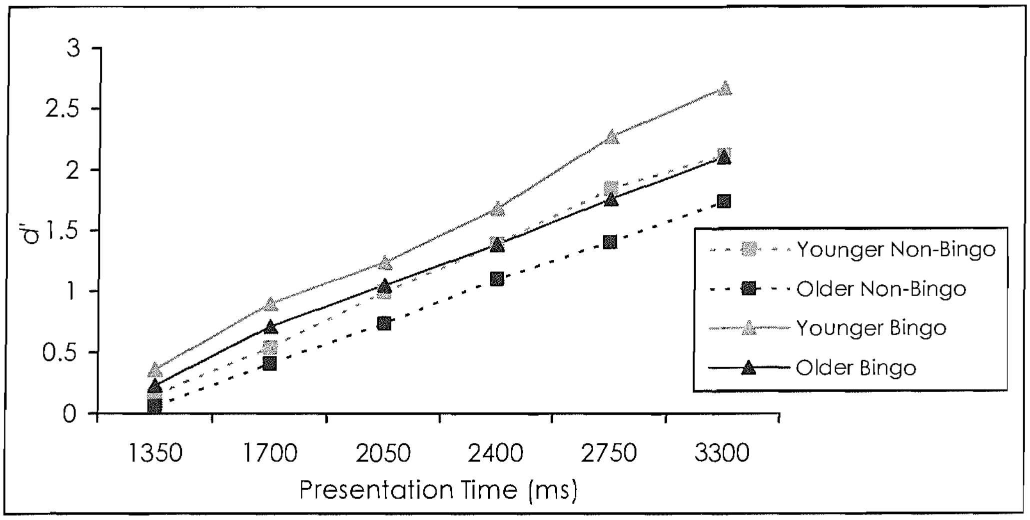

Figure 6.6. Sensitivity of response (d') for Bingo and non-Bingo players as a function of presentation time and age.

The results also revealed that overall participants with Bingo experience demonstrated higher response sensitivity on this task than those with no Bingo experience. This was confirmed by a significant main effect of Bingo, $F(1, 76) = 63.27$, $p < .01$. In addition, older participants demonstrated a lower response sensitivity than younger participants overall, $F(1, 76) = 50.86$, $p < .01$. Moreover, unlike in the Bingo search experiment this main effect of Age Group did not interact significantly with the factor of Bingo, $F < 1$, suggesting that the negative effects of age on response sensitivity is affecting both Bingo and non-Bingo players in a similar way (see Figure 6.7).

The results further revealed that the Bingo players differed in their sensitivity of response across the six presentation times relative to non-Bingo players. Indeed, this was confirmed by a significant interaction between Presentation Time and Bingo, $F(5, 380) = 2.25$, $p < .05$.

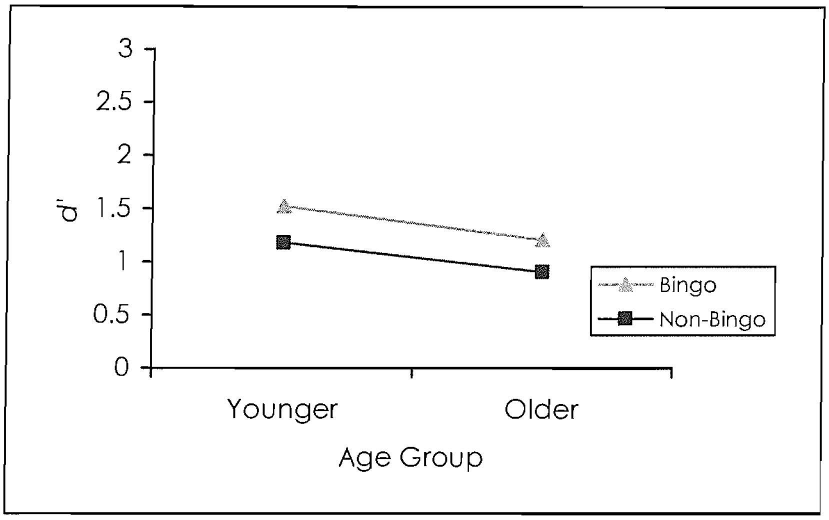

Figure 6.7. *Sensitivity of response (d') for Bingo and non-Bingo players as a function of age.*

Figure 6.8 illustrates that the sensitivity of Bingo players' responses exhibited steeper increases with presentation time than that of non-Bingo players. However, the interaction between Age Group and Presentation Time did not quite attain significance, $F(5, 380) = 2.05$, $p = .071$.

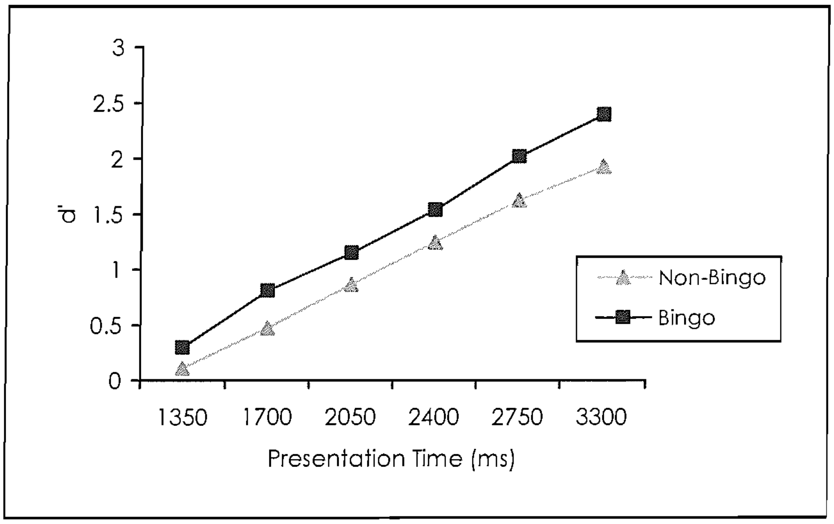

Figure 6.8. *Sensitivity of response (d') for Bingo and non-Bingo players as a function of presentation time.*

However, unlike in the Bingo search experiment there was no significant three-way interaction between the factors of Age Group, Bingo and Presentation Time, $F < 1$, suggesting that the pattern of response sensitivity for Bingo and non-Bingo players across the six presentation times was similarly affected by age.

Bias

Finally, the measure of response bias (c) was calculated. The scale over which response bias (c) is measured ranges from a value of -1 to +1. A negative value of c indicates the adoption of a liberal response strategy, that is, a greater tendency to say 'yes', whereas a positive value of c signifies the presence of a more conservative response strategy, in other words the tendency to say 'no'. As in the previous experiment, the c statistic was used as a measure of bias to avoid the statistical errors that can occur in the calculation of the β statistic when hit rates and false alarm rates are equivalent (MacMillan & Creelman, 1990).

Thus, the mean c scores of participants along with their standard deviations were calculated for the conditions of Presentation Time, Bingo and Age Group and are presented below in Table 6.3. A mixed 2 (Age Group) x 2 (Bingo) x 6 (Presentation Time) ANOVA was then performed on the data.

Table 6.3. Response bias (c) and standard deviations as a function of Presentation Time, Age Group and Bingo.

	Non-Bingo			Bingo		
Presentation Time (ms)	Mean	(SD)	N	Mean	(SD)	N
Younger						
1350	-0.093	(0.28)	20	0.040	(0.26)	20
1700	0.177	(0.13)	20	0.021	(0.16)	20
2050	-0.014	(0.14)	20	0.034	(0.11)	20
2400	-0.001	(0.11)	20	0.022	(0.14)	20
2750	0.025	(0.19)	20	0.009	(0.16)	20
3300	0.090	(0.13)	20	0.162	(0.17)	20
Older						
1350	-0.158	(0.28)	20	0.093	(0.23)	20
1700	-0.030	(0.16)	20	0.014	(0.17)	20
2050	-0.026	(0.84)	20	0.037	(0.13)	20
2400	0.022	(0.10)	20	0.059	(0.09)	20
2750	0.041	(0.11)	20	0.090	(0.10)	20
3300	0.061	(0.90)	20	0.122	(0.14)	20

The results of the mixed ANOVA produced a significant main effect of Presentation Time $F(5, 380) = 7.140$, $p < .01$. Further, it can be seen from looking at the descriptive data presented above in Table 6.3 and in Figure 6.9 below that overall, participants are adopting a more conservative response strategy as presentation time increases.

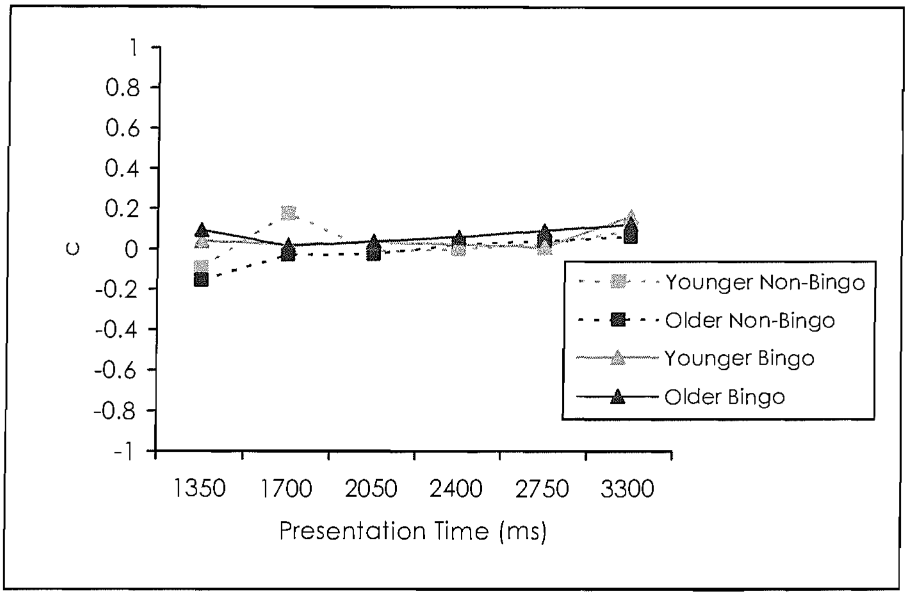

Figure 6.9. Mean response bias (c) scores as a function of presentation time, age group and Bingo.

The results also revealed that this main effect of Presentation Time interacted significantly with Bingo, $F(5, 380) = 3.49$, $p > .05$. It can be seen from looking at Figure 6.10 that for the shortest presentation time non-Bingo players adopted a more liberal response strategy than Bingo players while Bingo players adopted a more conservative strategy across the six presentation times. This conservatism may be rooted in experience at playing the game. If in a regular Bingo game a player makes a false call, claiming to have won a game when they haven't, there is no financial penalty. However, attention is drawn to the fact that a false call has been made and the other Bingo players will be aware of the identity of the person who has made the false call. Thus, there is a degree of embarrassment attached to making a false claim. Further, in certain clubs a Bingo card will be removed from a player if they make more than two false calls, thus negating their chances of winning a prize.

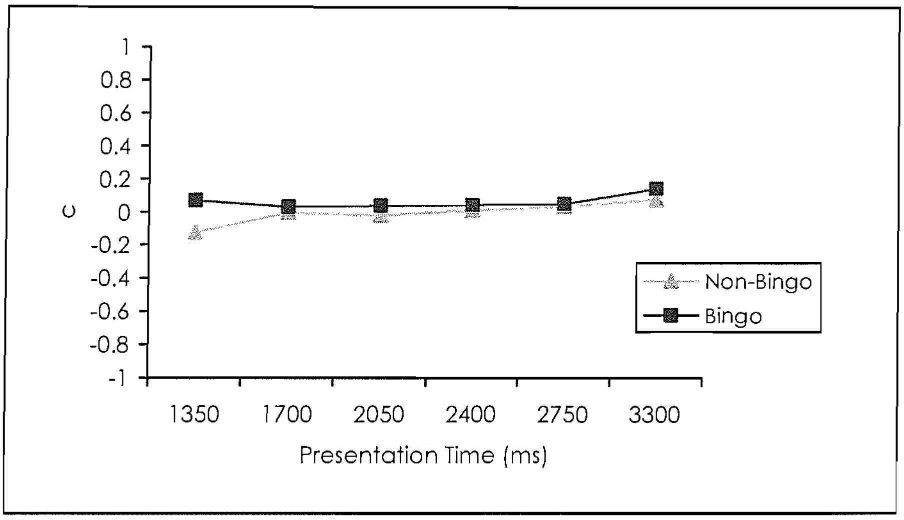

Figure 6.10. Mean response bias (c) scores as a function of Bingo and presentation time.

The factor of Presentation Time did not interact significantly, however, with Age Group, $F < 1$. Further, there was also no significant main effect of Age Group, $F < 1$, suggesting that overall, age had no effect on the response strategies adopted by participants on this task. Finally, there was no significant three-way interaction between the factors of Age Group, Bingo and Presentation Time, $F < 1$.

Summary of Results

Analysis of accuracy rates and sensitivity of response (*d'*) revealed that Bingo players demonstrated superior performance overall to non-Bingo players for this type of visual search, suggesting that the previously acquired skill of Bingo facilitated performance on this task. The sensitivity (*d'*) data reported provides supporting evidence for the proficient searching of the symbol grids by Bingo players in comparison to non-Bingo players. However, unlike in the previous experiment utilising Bingo search the older Bingo player's performance on this task was negatively affected by age.

Combined Data Analysis for Bingo and Symbol Search

In order to determine whether the advantage of playing Bingo is bigger for digits than for symbols, one more statistical analysis combining the data from experiment 1 (Bingo search) with the data from the present experiment (Symbol search) was done. To limit the number of factors entered for analysis the target-present and target-absent data for the different presentation times were averaged for both Bingo search and Symbol search, thus, providing a general accuracy percentage for each condition. A full factorial 2 (Age) x 2 (Bingo) x 2 (Search Type) between-subjects ANOVA was then performed on the data. Further, to avoid repetition of previously reported analyses only those effects involving the new factor of Search Type will be examined

Table 6.4. Mean percentage accuracy rates and standard deviations (SD) for Bingo Search and Symbol Search as a function of Bingo and Age-Group.

		Non-Bingo		Bingo	
		Mean	(SD)	Mean	(SD)
Bingo Search					
	Younger	78.23	(1.67)	84.54	(2.16)
	Older	71.37	(2.52)	83.38	(2.01)
Symbol Search					
	Younger	71.81	(2.25)	76.69	(3.80)
	Older	67.50	(3.01)	72.54	(2.50)

It can be seen from looking at the descriptive data presented in Table 6.4 and in Figure 6.11 that accuracy rates were higher for Bingo search (M = 79.38, SD = 5.625) than for Symbol Search (M = 72.14, SD = 4.373) in spite of the fact that the presentation times for Symbol Search were considerably longer than those for Bingo Search. This difference in search accuracy was confirmed by the results of the between-subjects ANOVA which produced a significant main effect of Search Type, $F(1, 152) = 318.963$, $p < .01$.

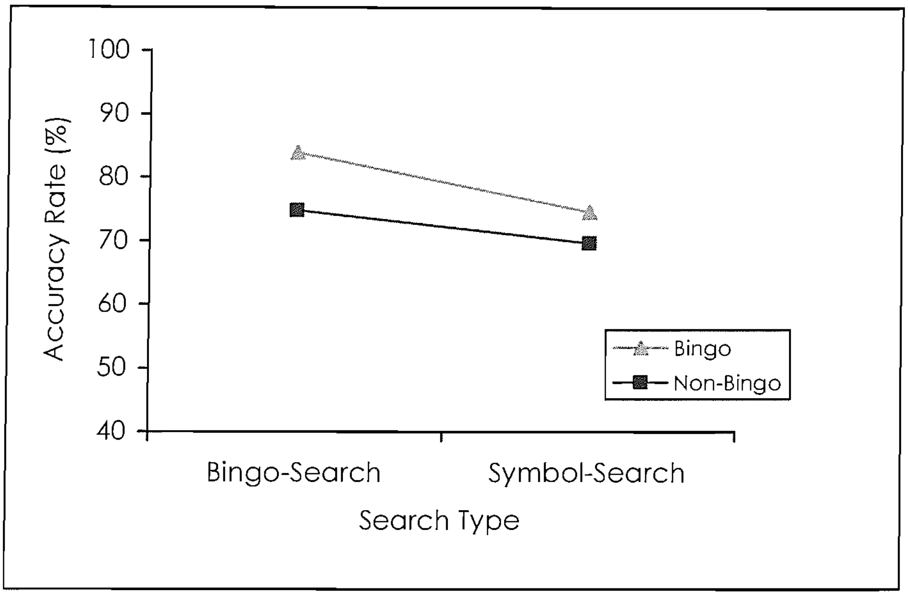

Figure 6.11. Overall target accuracy rates for Bingo and non-Bingo players as a function of search type.

Perhaps most importantly, the factor of Search Type interacted significantly with that of Bingo, $F(1, 152) = 26.77$, $p < .01$. As Figure 6.11 shows, the advantage of playing Bingo is greater for digits than for symbols. No significant interaction was found between Age-Group and Search Type, $F < 1$, but there was a significant three-way interaction between the factors of Age-Group, Search Type, and Bingo $F(1, 52) = 13.017$, $p < .01$, suggests that this is not the case for those participants with Bingo experience. The data displayed in Figure 6.12 suggest that the advantage Bingo players' exhibit over non-Bingo players for Bingo search is especially great for older Bingo players as their performance in the Symbol Search condition is considerably reduced in comparison with the younger Bingo players. Older Bingo players are able to keep their number search performance up to the same level as younger Bingo players, but the older players cannot match the younger players at all search tasks.

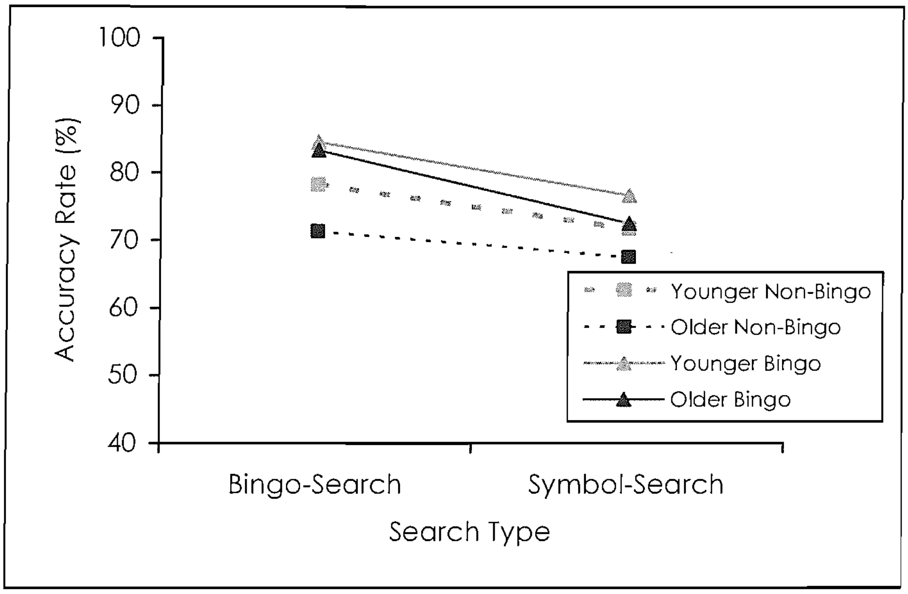

Figure 6.12. Overall target accuracy rates for older and younger Bingo and non- Bingo players as a function of search type.

General Discussion

The purpose of the present experiment was to determine whether practice at searching for digit targets in the game of Bingo facilitates performance on another type of visual search, namely that of search for symbol stimuli. Importantly, the rules that underlie Bingo search were held constant for the transfer task.

Participant performance was analysed in terms of both accuracy rate and sensitivity (*d'*) of target detection. As in the previous experiment the time-accuracy technique was employed to control for possible age-differences in response execution by removing the motor component of the task. In addition, task difficulty was manipulated by measuring accuracy at six different presentation times, thus setting limits on the amount of information processing time available to participants. The accuracy rates produced by participants along with the *d'* results suggest that Bingo players require less time to search the ninety symbol array than non-Bingo players and are able to perform this task more proficiently (as evidenced by the significantly higher response sensitivity scores of Bingo players). Further, in accordance with the results reported in the Bingo search experiment, the performance of older participants was negatively affected by age on this task. However, unlike in the Bingo search experiment; this decline in accuracy with age was not modified by the factor of Bingo.

The superior performance demonstrated by the younger Bingo players on this task once again demonstrates the ability of Bingo Players to search for visual targets. Importantly, the significant main effect of Bingo provides evidence for positive transfer of the visual search skills utilised in Bingo search to the new task of symbol search. Such a result suggests that Bingo Players are able to implement the search strategies they have developed over 1,000s of trials in order to carry out a visual search task for an unfamiliar target more efficiently than non-Bingo Players. It must be noted, however, that the results of the combined Bingo Search/ Symbol Search ANOVA revealed that performance on the symbol search task was generally lower than that for the Bingo-Search task even though the presentation times were extended in comparison with those used in the Bingo Search experiment. This finding, therefore, suggests that the unfamiliarity of the symbol stimuli did somewhat impair the search performance of the Bingo players relative to their search performance for familiar target digits. This finding would not be predicted, for instance, by the doctrine of formal discipline (see Higginson, 1931, for a review). An alternative explanation is that performance was impaired on the Symbol search task in comparison with Bingo search because the symbols were less easy to discriminate than the digits used in Bingo search, although this seems less likely. However, the finding that Bingo players found the new stimulus array easier to search than non-Bingo players challenges the notion of stimulus-response specificity put forward by the theory of identical limits (Thorndyke and Woodworth, 1901). However, it is important to take into account the fact that Search-Type was a between-subjects factor in this analysis; thus, it is possible that the difference in performance found between the two search tasks was due to group differences and not task differences. This is not likely to be the case in this instance though, as each participant group possessed similar characteristics such as education and health status.

A further possibility which may account for the lower performance elicited by Bingo players and, in particular, older Bingo players on this task in comparison with their performance on the Bingo Search task exists. It is possible that the Bingo players may have been misled by the number cues appearing above the target symbol(s) as in the game of Bingo the number 3 would appear in column 4. An alternative method of indicating the relevevant column (e.g. an arrow) should be considered when designing future experiments.

Upon consideration of the skill literature reviewed in the introduction of this chapter, it is probable that the Bingo players in this study identified the shared features underlying the rules of search between the two tasks and were able to apply them to the new symbol search task. If this is indeed the case it would offer support to the argument that positive transfer occurs when the cognitive abstractions formed in the original learning context can be used in another (Bovair, Kieras, & Polson, 1990; Singley & Anderson, 1989). Furthermore, it is likely that the task similarities were explicitly encoded by the Bingo players such that they were consciously aware of the generalities in the rules underlying both tasks. It has already been noted that conscious awareness of task generalities is an essential requirement for positive transfer (Druckman and Bjork, 1994). Importantly, the fact that the symbol search task was not dramatically different to the original task was also conducive to positive transfer. For instance, unlike the experiment conducted by Knerr et al. (1987) that examined the transfer of flight path recognition ability to flight path generation ability, the goals of both the original (Bingo) task and the transfer (symbol) task were kept constant. Hence, the only thing that differed between the two tasks was the nature of the stimulus set.

It is therefore possible that the Bingo players in this experiment used the contextual information in Bingo search to perform the symbol search task. For instance, as mentioned earlier, a digit was located above the target symbol(s) indicating the column in which the symbol(s) would appear. It is thus likely that although both non-Bingo players and Bingo players would have used this information to direct their attention to the important subset of the array, Bingo players who are already familiar with this type of cue might have performed this action more efficiently (e.g. Chun & Jiang, 1988). However, it would appear that the older Bingo players were not able to utilise this contextual information with the same efficiency as their younger counterparts, hence, their significantly lower accuracy rates in comparison with younger Bingo players on this task. As noted earlier, it has been suggested that differences in performance between younger and older adults on certain tasks occur because older adults are not able to develop new efficient task strategies (for a review see Salthouse, 1991). The results of the present study further suggest that older adults are impaired in their ability to transfer existing strategies to new situations.

It is important to consider, however, the possibility that Symbol search draws on additional cognitive processes to those utilised in Bingo search. For instance, listening to participants' verbalisations during the experimental procedure suggests that they assigned each symbol a verbal label. If this was indeed the case, participants did not only have to search for the target symbol(s) but also maintain in memory the verbal labels of the 10 different symbols used in this experiment. Moreover, anecdotally some participants reported difficulty in remembering the symbol pairs and admitted to occasionally forgetting the symbols they were supposed to be searching for. It is therefore possible that the difference in performance between younger and older Bingo players was due to an age-related deficit in working memory rather than in search performance per se. Further research could perhaps explore participants' ability to encode and recall the symbol pairs.

Conclusion

In summary, it may be argued that the present experiment provides supporting evidence for positive transfer that occurs when the transfer task comprises the same production rules and contextual information as the original task. It would appear that younger Bingo players at least, are able to abstract the similarities between the two tasks and apply them to the new situation. Conversely, the results of the present experiment suggest that older Bingo players may not able to do this with the same efficiency as younger players. This may be, for instance, because they are not able to efficiently transfer existing strategies to a new situation. However, due to the nature of the stimuli used in the present experiment it is possible that the older Bingo players were not able to maintain the verbal labels assigned to the symbols in memory as well as their younger counterparts.

The two experiments presented so far have focussed on domain-specific performance and its transfer. However, in order to ascertain whether extended practice at Bingo facilitates performance on the elementary cognitive processes underlying the skill it is necessary to assess the more general perceptual and cognitive abilities of both non-Bingo and Bingo players. Moreover, in addition to the assessment of molar performance reported in chapter one measures of general cognitive abilities are also required if the remediation and encapsulation hypothesis of cognitive ageing and skilled performance are to be tested. Therefore, the following two experimental chapters will endeavour to address both of these issues.

CHAPTER SEVEN

EXPERIMENT 3: VISUAL MEMORY SCANNING FOR SINGLE AND DOUBLE-DIGIT NUMBERS

Introduction

It may be suggested that aside from rapid visual search another important requirement of the game of Bingo is the ability to scan and compare numbers quickly in memory. For instance, as a game of Bingo progresses, the player must be aware of the number of digits that remain on each card along with their identity. As previously discussed, Bingo players have only a short time window within which they can detect the called number on their card and announce its presence in order to win. Thus, to ensure that they can respond quickly, players will often keep the numbers they need to win in short term memory. If they follow this strategy, then they must perform a rapid scan of the numbers in short-term memory to see if any match the number called.

The type of memory search described above has been researched extensively by Saul Sternberg (1966, 1969, 1975). In tests using the standard Sternberg memory-scanning paradigm participants are presented with random sequences of digit strings (memory set) varying in length from one to six digits. Each digit is presented individually at the centre of a computer screen for 1.2 seconds. Then follows a delay of 2 seconds after which a warning signal is given closely followed by the probe digit. The participant's task is to decide whether or not the probe digit was among those presented in the memory set. Participants are required to make their response as quickly and accurately as possible by pressing one of two levers or buttons. Both response latency and accuracy are taken as measures of performance. Importantly, the results of the standard Sternberg task reveal that mean response time increases in a linear fashion with memory set size and that error rates are low. Sternberg proposes that the linearity of participant's response times is a result of the serial comparison of the probe-digit to the digits contained in the memory set. Moreover, Sternberg reported that this type of memory search is exhaustive as equivalent latency slopes (approximately 38 milliseconds per item) are found for both probe-present and probe-absent trials. Moreover, the equivalence of set size effects for both positive and negative trials holds for a wide diversity of stimulus classes. Thus, it appears that even when a positive match between probe and memory set has been made, search continues until the end of the sequence is reached. As an explanation for the exhaustive search of the memory set, Sternberg proposes a memory search mechanism comprising four stages. Firstly, the stimulus must be encoded, such that an internal representation is formed of the probe-digit. Secondly, the probe-digit is compared against the digits within the memory set in an exhaustive, item-by-item fashion. Thirdly, the participant has to make a 'yes-no' (binary) decision as to whether a probe-to-memory set match has occurred, and finally, this decision is translated so that the appropriate response can be executed (Greene, 1992). Sternberg thus suggests that if decision time is slow in relation to the probe-matching time, it may be a more efficient strategy to make one decision after all memory set items have been compared with the probe rather than to make a decision following each memory set item-probe comparison.

Subsequent variations of Sternberg's original experiment have demonstrated that variables other than set size affect response times for memory search. For instance, when the items within a memory set are kept constant, probes that appear more frequently produce quicker response times (e.g. Theios, Smith, Haviland, Traupman, & Moy, 1973). Further, Forrin and Cunningham (1973) in an experiment that manipulated the delay between the presentation of the memory set and probe found that response times are quicker for the most recently presented items in the memory set. In light of these findings researchers have suggested that amendments be made to Sternberg's original theory. However, the original paradigm continues to be used as a measure of short-term memory scanning in a wide variety of experimental situations.

Importantly, a number of experiments utilising the Sternberg memory scanning paradigm have produced evidence to suggest that the processes underlying this task are negatively affected by age. For instance, research carried out by Anders, Fozard and Lillyquist (1972), and by Eriksen, Hamlin and Daye (1973) revealed that older adults take longer to perform a memory scan than younger participants, although the equivalence between positive and negative slopes remain. More recently, Ferraro and

Balota (1999) have reported that in comparison to healthy younger adults, older adults display increases in both slopes and intercepts of the response time by set size function on the standard Sternberg memory-scanning task.

In addition, the effects of extended practice on performance of the Sternberg memory-scanning task have been investigated. Kristofferson (1972), for instance, reported that when experimental trials are given that comprise variedly mapped probe and memory set digits, that is, a probe-digit on one trial may become part of the memory set on the next trial, practice has little effect on response times. Kristofferson suggests that with practice participants become more skilled at stimulus encoding and response execution but do not demonstrate an increased ability to scan the memory set. Conversely, as previously stated in Chapter 1, when stimulus and response are consistently mapped such that a probe-digit always elicits the same response (either positive or negative) practice reduces set size effects substantially (e.g. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Further, Kristofferson (1972) reported that when a consistently mapped version of the Sternberg memory scanning task was given to participants, set size effects were minimal.

It is important to note, however, that a number of researchers have cast doubt upon Sternberg's proposal of an exhaustive memory search. For instance, Baddeley and Ecob (1973) conducted an experiment in which the items within a memory set were manipulated such that certain items were repeated more frequently than others and found that participants took less time to respond to those items. However, Greene (1992) argues that the reduction in response times for repeatedly presented items may be due to either improved stimulus encoding ability or response execution rather than an enhanced ability to scan the memory set. Still other theories have been proposed which argue that the type of search involved in the Sternberg memory task is not exhaustive but rather self-terminating (e.g. Reed, 1976; Theios, Smith, Haviland, Traupmann, & Moy, 1973). The central tenet for a self-terminating search in the memory scanning task is that the fastest reaction time for a probe-to-memory set item match should remain constant across set size: regardless of the size of the memory set, there will be an instance in which the probe-digit matches the first item in the memory set. However, research carried out by

Lively and Sanford (1972) and by Sternberg (1975) provide evidence that the fastest reaction time to positive and negative probes increases as a function of set size.

Still other theories have argued that parallel search is utilised in the Sternberg memory scanning task, so that probe-digit to memory set item comparisons are made simultaneously. The main contender promoting parallel search in memory scanning is the *diffusion model* put forward by Ratcliff (1978). Ratcliff provides a trace-model of memory retrieval suggesting that the process of memory retrieval becomes less effective as set size increases. Further, tests of the diffusion model have accounted for all of the results predicted by the Sternberg paradigm (Green, 1992).

In spite of the lack of agreement as to which theoretical explanation provides the best account of the results of the Sternberg paradigm, the standard Sternberg task presents an opportunity to test a number of hypotheses pertinent to this thesis. For instance, with regard to the evidence presented above relating to the effects of practice on the varied-mapping version of the Sternberg task, it will be possible to ascertain whether practice at rapidly searching short-term memory for digits in the game of Bingo facilitates performance on this task, either in terms of an improvement in stimulus encoding and/or response execution, or in terms of an enhanced ability to scan the memory set. Further, in light of the evidence indicating age differences in memory scanning ability, the Sternberg paradigm can be used to examine whether the ability to rapidly scan memory for digits is maintained in older Bingo players. Finally, the flexibility of the Sternberg memory scanning task provides a further means of testing the domain-specific abilities of Bingo players. In addition to the standard version of the Sternberg memory scanning task, the present experiment will include a condition that should favour the ability of Bingo players. Specifically, as Bingo players have considerable experience with double-digit numbers, memory-sets comprising double-digit numbers will be used in addition to the typical single-digit memory set. This manipulation obviously increases task difficulty, as participants will be required to memorize five double-digit numbers for the largest set-size. If, however, Bingo players are particularly skilled at searching and scanning for double-digit numbers their performance on this task might be expected to be superior to the performance of non-Bingo players. Furthermore, if superior performance is found for Bingo players on this task, it will also be possible to determine whether it is maintained across age.

Method

Design

This experiment employed a mixed design in which Age Group (younger/older) and Bingo (player/non-player) were between-subject factors, and Digit Type (single /double-digit numbers) and Set Size (1, 3, and 5) were within-subject factors. As equivalent latency slopes have been reported to occur for both positive-probe and negative-probe trials these will be combined in the present experiment. Thus, the measures of performance in this experiment comprise participant's response times and percentage of errors.

Participants

One hundred and twelve participants volunteered to take part in this experiment. These participants were also used in experiments 4-7 with the exception that only those participants who played Bingo took part in experiment seven. Furthermore, none of the participants who took part in experiments 4-7 took part in experiments 1 and 2. Experiments 3-7 were run over two sessions with experiment 3 taking place in session one and experiments 4-7 taking place in session two. Twenty-eight participants were younger female non-Bingo playing undergraduate psychology students at the University of Southampton and received course credit for taking part in the experiment. They were aged between 18 and 21 years (mean = 19.04, *SD* = .838) and had a mean number of 13.46 years education. Twenty-eight participants were younger female Bingo players recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 22 and 40 years (mean = 31.89, *SD* = 5.53) and had a mean number of 10.93 years education. Twenty-eight participants were older non-Bingo players (13 female, 1 male) aged between 60 and 78 years (mean = 68.54, *SD* = 5.26) and had a mean number of 10.71 years of education. They were recruited from the community via local press, radio, and TV advertising and were informed that their names would be entered into a prize draw with a first prize of £100 and second prize of £50. Finally, 28 participants were older Bingo players (25 female, 1 male) who were recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. They were aged between 60 and 81 years (mean = 70.32, *SD* = 6.53) and had a mean number of 9.93 years of education. To test whether the older and Younger Bingo and non-Bingo groups were matched on the variables of age and education two 2 (Age Group) x 2 (Bingo) between subjects ANOVAs were performed. The analysis of the age data revealed a significant main effect of Bingo, $F(1, 108) = 59.10$, $p < .01$, and a significant interaction between Bingo and Age Group, $F(1, 108) = 33.79$, $p < .01$. Indeed, it can be seen from looking at the descriptive data that the younger non-Bingo players have a significantly lower mean age than the young Bingo players in comparison with the older Bingo and non-Bingo players. The analysis of the education data revealed significant effects of both Age Group, $F(1, 108) = 132.24$, $p < .01$, with older adults averaging fewer years of education than younger adults, and Bingo, $F(1, 108) = 103.74$, $p < .01$, with Bingo players averaging fewer years of education than non-Bingo players. There was also a significant interaction between Age Group and Bingo, $F(1, 108) = 28.80$, $p < .01$, and it can be seen from looking at the descriptive data that younger non-Bingo players have attained a greater number years of education in comparison with the other three groups. All participants had normal or corrected-to-normal vision.

Materials

The memory sets used in this experiment were computer presented 36pt Arial font single- and double-digit numbers. Participants were asked to choose a comfortable viewing distance from the screen. Therefore the visual angle subtending the stimuli varied for each participant. Thirty-six memory sets comprising 12 each of set-sizes one, three, and five numbers were created for both the single-digit and double-digit number conditions. Thus, 72 sets of numbers were created in total for the experimental trials. The memory sets were created with the following provisos: (i) Items within each set occur in random rather than numerical order, and, (ii) each number within a set was unique. A mask was created for each memory set using the '#' character in place of each digit. Finally, seventy-two 'probe' numbers, one for each memory set, were created. Each probe number had the same number of digits as the numbers in its corresponding memory set. Half of the probe numbers matched one of the numbers in its corresponding memory set.

A further 12 sets of numbers were created (one of each permutation) to be used in the practice trials that preceded the experimental trials.

The stimuli were presented using a Time 266mmx Pentium II laptop computer with a 13.1-inch TFT screen (running at 800 x 600 resolution). Responses were made via a RB-610 six-button response box (Cedrus Corporation, 1991). The experiment was designed and administered with the commercial software Superlab Pro version 2.0 (Cedrus Corporation, 1991).

Procedure

Participants were individually tested. At the start of each trial, the word *Ready* was presented on the screen and remained until the participant pressed the red button on the response box with their non-dominant hand to commence the trial. Once the red button had been pressed, a blank screen was presented for 500 ms followed by one of the 72 randomly presented single-digit and double-digit memory sets, which remained on the screen for a variable amount of time according to set-size (single-digit and double-digit memory sets were mixed during presentation). A set-size of 1 number was presented for 1.2 seconds, a set-size of three numbers was presented for 3.6 seconds, and a set-size of five numbers was presented for 6 seconds (these times applied to both single and double-digit memory sets). Participants were informed that they were to use this time to try to memorize the displayed set of numbers. Following the presentation of a memory set, the mask appeared for 500 ms. A probe digit then appeared at the centre of the screen. This was the point at which the participant was required to make a response, pressing the button marked *Y* if the probe digit matched one of those in the previously presented memory set, or pressing the button marked *N* if the probe digit did not match. Following the response, a blank screen was presented for 1000 ms and then a new trial began. The *Y* and *N* buttons were counterbalanced across participants so that for 50% of participants the *Y* button appeared on the left-hand side of the response box. Participants were instructed to make their responses using the index fingers of both hands and were informed that speed and accuracy were equally important for this task.

Prior to performing the experimental task, participants completed a set of twelve practice trials (one of each stimulus and response type). Practice trials were included to ensure that each participant fully understood the procedure before continuing onwards with the experimental trials. The data from these trials were excluded from any subsequent analyses. The experimental procedure lasted approximately 20 minutes.

Results and Discussion

The mean response time (RT) for correct decisions was calculated for each participant within each condition, after outliers greater than or less than the mean + 2.5 standard deviations were removed. The resultant data are summarised in Table 7.1. For the purpose of clarity, the response times for the single- and double-digit conditions were first analyzed separately in two 3 (Set Size) x 2 (Bingo) x 2 (Age Group) mixed analyses of variance with between-subject factors of Bingo and Age Group and a within-subjects factor of Set Size. The results of these separate analyses will be presented first in order to provide a clear picture of the way in which the factors of Bingo and Age Group differentially influence performance on these two tasks. For all analyses the Alpha value was set at .05.

Response Time Data for Single-Digit Condition

Table 7.1. Mean response times (with standard deviations) for the single-digit condition set-sizes 1, 3, and 5 across all participants.

	Non-Bingo			Bingo		
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	681.20	(235.43)	28	668.65	(141.82)	28
3	847.83	(193.60)	28	807.08	(191.55)	28
5	934.46	(190.33)	28	913.20	(232.32)	28
Older						
1	1088.68	(282.11)	28	908.55	(188.26)	28
3	1278.82	(179.59)	28	1053.60	(209.98)	28
5	1449.30	(197.37)	28	1212.68	(253.43)	28

The descriptive data presented above in Table 7.1 and in Figure 7.1 illustrate that all participants generated slower response times as set size increased, suggesting they took longer to scan their memories for a target digit as the number of digits to-be-held in memory increased. The results of the mixed ANOVA confirmed this main effect of Set Size, $F(2, 216) = 202.54$, $p < .01$. In addition, older participants produced significantly slower response times overall in comparison with younger participants, $F(1,108) = 96.63$, $p < .01$. Furthermore, their pattern of responding was modified by Set Size, producing a significant two-way interaction between these two factors, $F(2, 216) = 4.40$, $p = .05$.

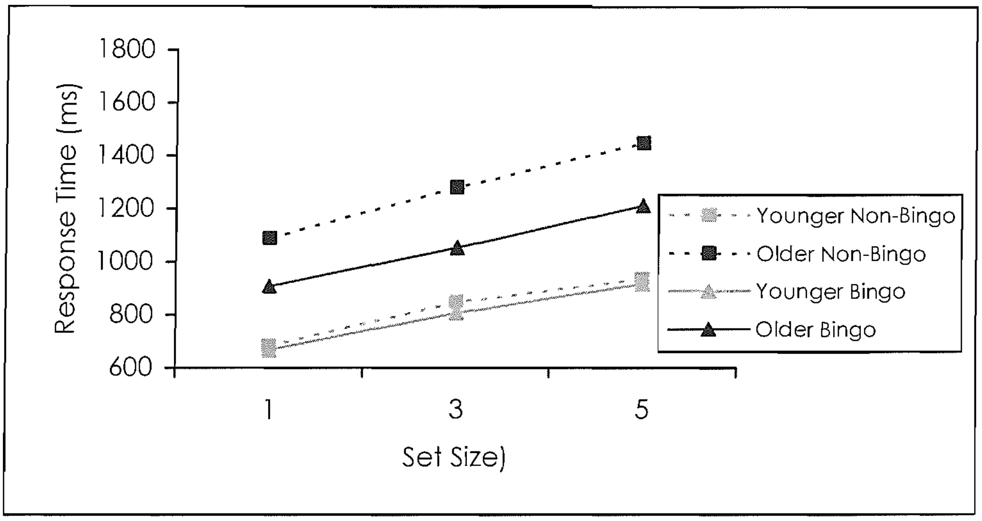

Figure 7.1. Mean single-digit response times for set sizes one, three, and five as a function of age and Bingo.

The results also revealed a significant main effect of Bingo, $F(1, 108) = 10.74$, p < .01, which was further modified by Age Group producing a significant two-way interaction between these two factors, $F(1, 108) = 6.95$, p < .05.

The data presented in Figure 7.2 illustrate that older participants' generated slower response times overall than younger participants implying that the components underlying this task are sensitive the process of ageing. Moreover, the steeper slope exhibited by older participants from set size three to five in comparison with younger participants suggests that this increase in digits to be scanned is maybe having a greater effect on older participant's response times than younger participant's. Thus, it appears that the performance of older participants is slightly impaired by an increase in task complexity. However, the factors of Bingo, Age Group and Set Size did not interact significantly, $F < 1$, suggesting that Bingo is not affecting the pattern of responses of older and younger participants.

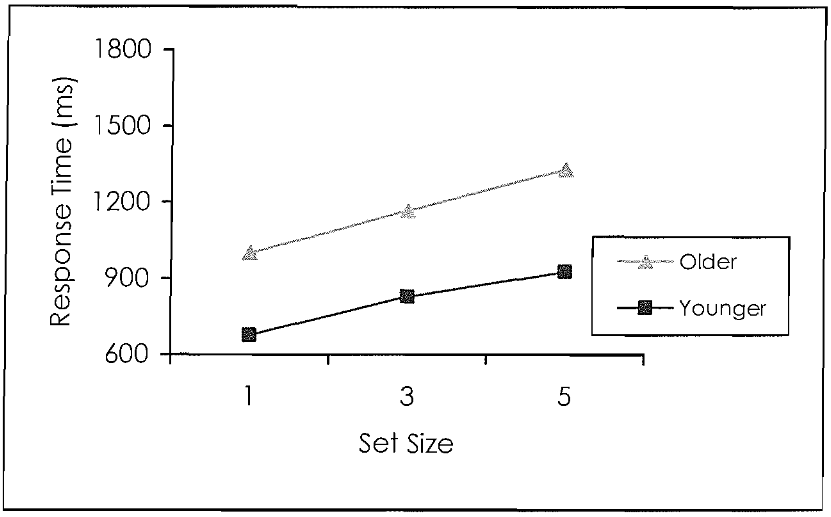

Figure 7.2. Mean response times for set sizes one, three and five for younger and older participants

Importantly, the data displayed in Figure 7.3 illustrate that Bingo players produced quicker response times overall than non-Bingo players. However, it is also apparent from looking at back at the data displayed in Figure 7.1 that this main effect results from the superior performance of older Bingo players in comparison with their non-Bingo playing counterparts as the graph indicates that there is little difference between the response times of younger non-Bingo players and younger Bingo players. Although older participants took longer to search their memories for the target digit overall, this disadvantage was especially great for the older non-Bingo players.

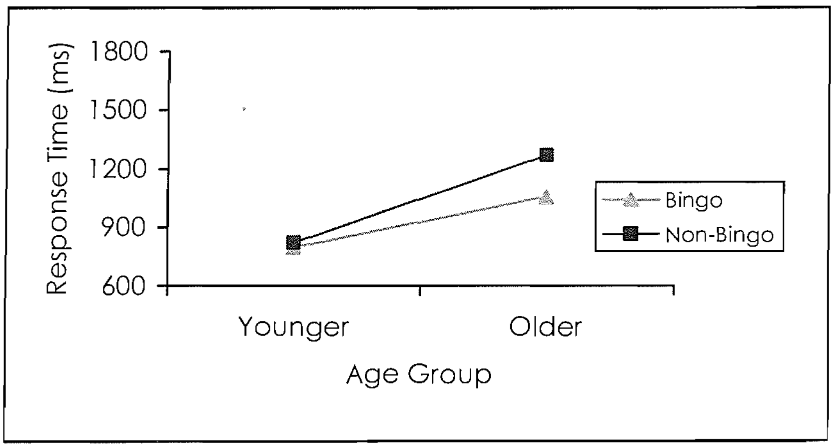

Figure 7.3. Mean response times for younger and older participants as a function of Bingo

To further examine the significant interaction between Age Group and Bingo, independent t-tests of the simple main effects using a Bonferonni correction for multiple tests revealed that the older Bingo players produced slower response times overall than both younger Bingo players, $t(54) = 5.074, p < .01$, and younger non-Bingo players, $t(54) = 4.656, p < .01$. This suggests that the processes underlying performance on this task are negatively affected by age. Importantly, however, the deficit in performance of older Bingo players appears to be reduced in comparison with older non-Bingo players.

Response Time Data for the Double-Digit Condition

Table 7.2. Mean response times (with standard deviations) for the double-digit condition for set sizes one, three, and five across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	SD	N	Mean	SD	N
Younger						
1	679.29	(159.67)	28	703.72	(163.70)	28
3	923.67	(169.14)	28	892.48	(207.94)	28
5	1073.59	(180.03)	28	1031.73	(255.49)	28
Older						
1	1175.46	(199.22)	28	1000.89	(244.53)	28
3	1433.43	(220.66)	28	1193.94	(216.73)	28
5	1660.81	(232.67)	28	1300.97	(232.31)	28

The descriptive data presented in Table 7.2 and in Figure 7.4 illustrate that as in the single-digit condition all participants generated slower response times as set size increased. Further, this was confirmed by the mixed ANOVA which produced a significant main effect of Set Size, $F(2, 216) = 397.096$, $p < .01$. The results of the

ANOVA also revealed significant main effects of Bingo, $F(1, 108) = 14.218$, $p < .01$, and Age Group, $F(1,108) = 127.281$, $p < .01$. Further, in accordance with the results of the single-digit condition there was also a significant two-way interaction between Bingo and Age Group, $F(1, 108) = 11.054$, $p < .05$. In addition, in contrast to the single digit condition, the double-digit condition also produced a significant two-way interaction between the factors of Set Size and Bingo, $F(2, 216) = 10.952$, $p < .01$. There was however, no two-way interaction between Set Size and Age Group, $F < 1$. Furthermore, the results from the double-digit condition, unlike those reported in the single-digit condition, revealed a significant three-way interaction between the factors of Set Size, Bingo and Age Group, $F(2, 216) = 3.029$, $p = .05$. These interactions and main effects will now be explored.

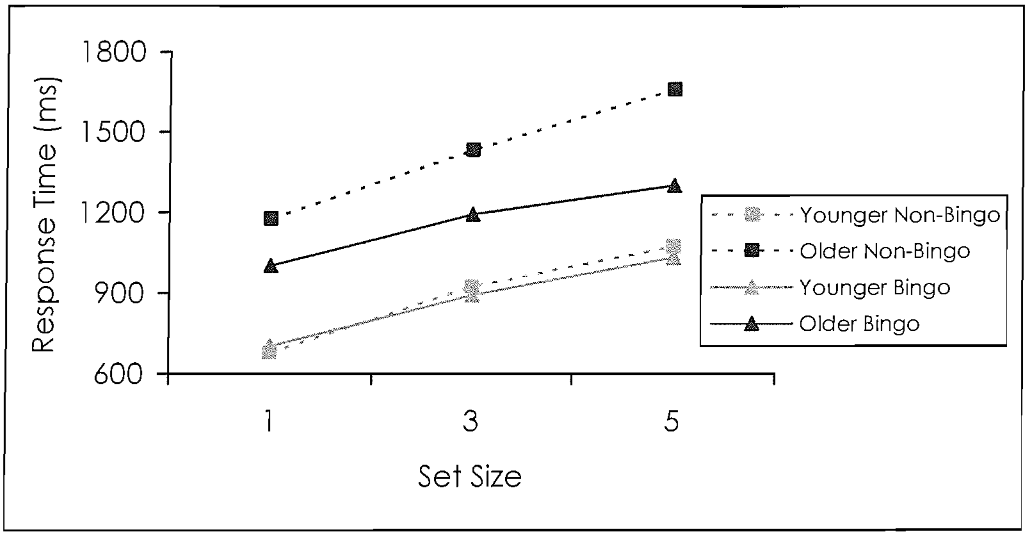

Figure 7.4. Mean Double-digit response times for set sizes one, three, and five as a function of age and Bingo.

It can also be seen from looking at Figure 7.5 that, in accordance with the results reported in the single-digit condition, older participants generated slower response times overall than younger participants. This provides further support for the argument that the processes underlying this task are sensitive to the effects of ageing. It is also apparent, however, that the older non-Bingo players are particularly disadvantaged in the double-digit condition in comparison with the older Bingo players; hence, the significant interaction reported between Bingo and Age Group.

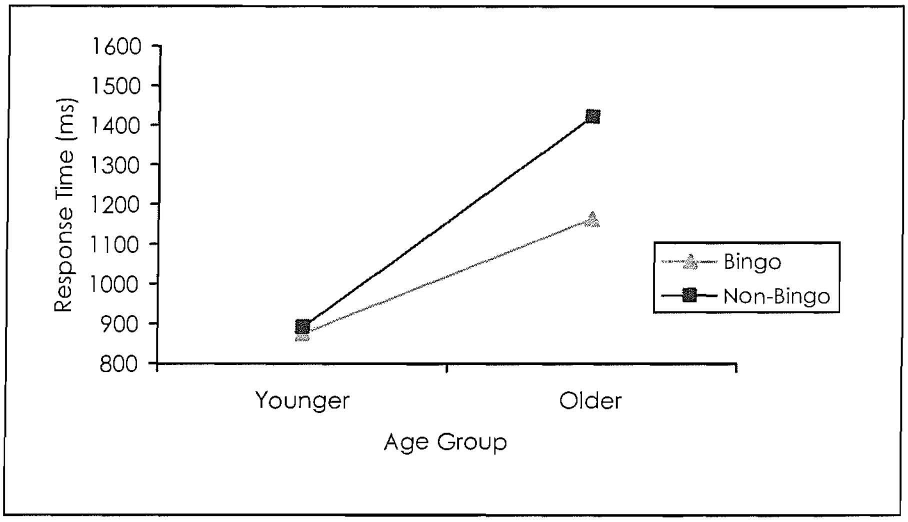

Figure 7.5. *Mean double-digit response times for Bingo and non-Bingo players as a function of age.*

Furthermore, it can be seen from looking at the response slopes displayed in Figure 7.6 that in contrast to the single-digit condition, non-Bingo players exhibited steeper latency slopes with increasing set size in comparison with Bingo players. To establish whether the increase in response time from both set sizes one to three and from three to five were significantly different for the non-Bingo players in comparison with the Bingo players, two separate 2 (Bingo) x 2 (set size) mixed ANOVAs were carried out on the data. Importantly, the results revealed a significant Set Size x Bingo interaction for both set sizes one to three, $F(1, 110) = 7.004$, $p < .01$, and for set sizes three to five, $F(1, 110) = 6.57$, $p < .05$, indicating that the increase in complexity is having a greater effect on the response times of non-Bingo players than on those of Bingo players.

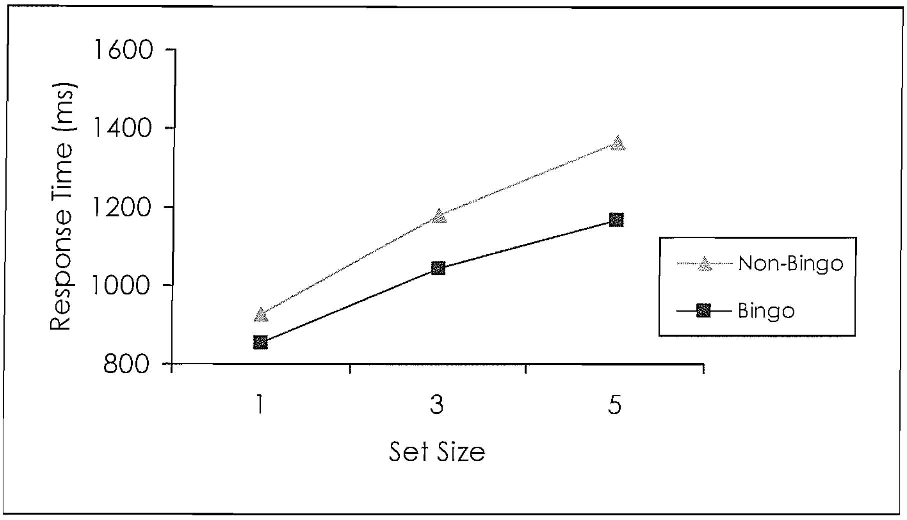

Figure 7.6. Mean double-digit response times for Bingo and non-Bingo players as a function of set size.

Finally, as was found in the single-digit condition, Bingo players demonstrated superior performance in this condition. However, as indicated by the significant Age Group x Bingo interaction, this positive effect on performance once again occurred only for the older Bingo players. It is possible that regular practice at scanning memory for digits by older Bingo players helps to offset the deficit in the processes underlying this task.

Combined Analysis for Single- and Double-Digit Data

One further analysis of variance was performed on the data incorporating the additional factor of Number-Type (single/double) so that any effects of number-type on the factors of Set Size, Age Group and Bingo would be made apparent.

The results of this additional mixed ANOVA revealed a significant main effect of Number-Type, $F(1, 216) = 111.46$, $p < .01$, confirming that slower responses were generated overall in the double-digit condition than in the single-digit condition. In addition, the factor of Number-Type also interacted significantly with that of age group, $F(1, 216) = 7.99$, $p < .01$, and it can be seen from Figure 7.7 that although response time increased for younger participants from the single- to the double-digit condition, this increase in response time was even greater for the older participants.

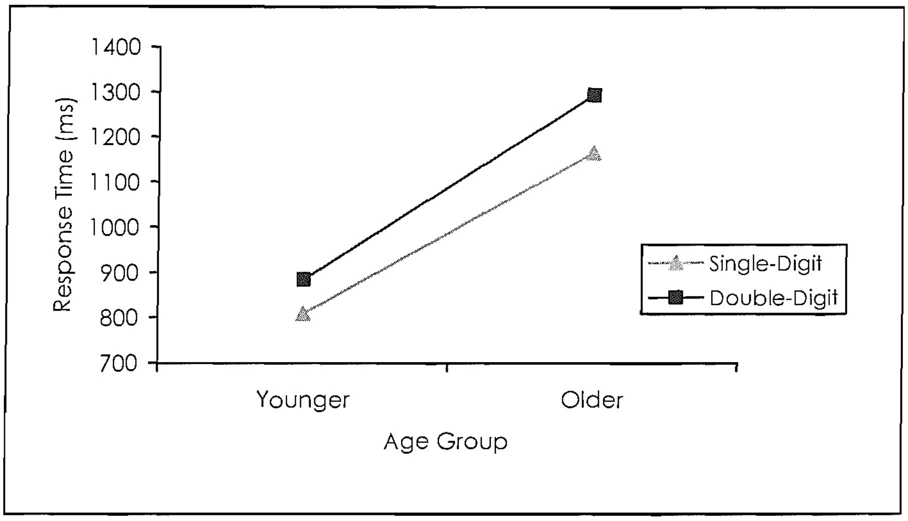

Figure 7.7. Mean response times for double-digit and single digit-condition as a function of age group.

The results of the combined ANOVA also revealed a significant two-way interaction between the factors of Number-Type and Set Size, $F(2, 216) = 13.60$, $p < .01$, and it can be seen from Figure 7.8 that the interaction appears to be occurring at set size three in the double-digit condition. Namely, response times are disproportionately slower from set size one to three in the double-digit condition as compared to the single-digit condition. To establish statistically whether the increase in response time from set sizes one to three and from three to five were significantly different for the Double-Digit condition in comparison with the Single-Digit condition, two separate 2 (Digit-Type) x 2 (Set Size) ANOVAs were carried out on the data. The results revealed a significant Number-Type x Set Size interaction for set sizes one to three, $F(1, 111) = 15.90$, $p < .01$, but not for set sizes three to five, $F(1, 111) = 2.20$, $p > .05$. The differences between these two ANOVAs confirm that there is clearly a difference in slope between Single-Digit and Double-Digit in the range between set-size 1 and set-size 3, but there may not be a difference in slope between set-size and set-size 5.

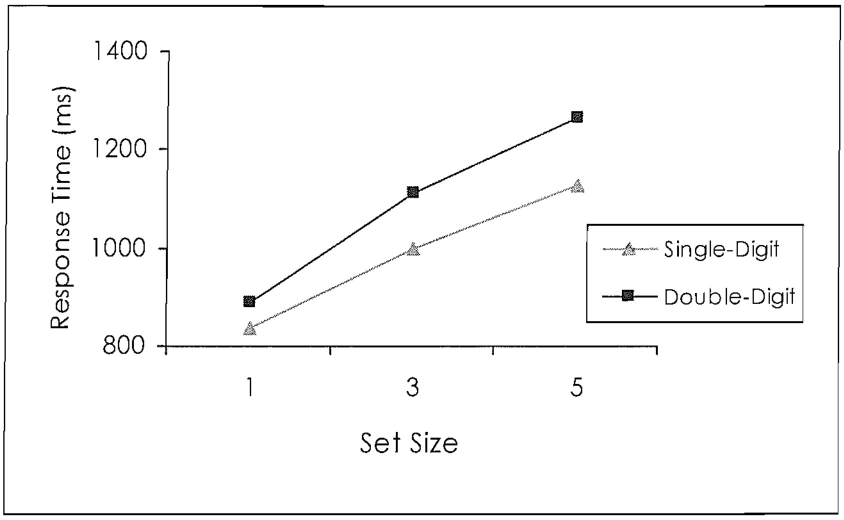

Figure 7.8. Mean response times for single-digit and double-digit conditions as a function of set size.

Furthermore, the interaction between Number-Type, Set-Size, and Bingo was also found to be significant, $F(1, 216) = 4.40$, $p < .05$, and it can be seen from looking at Figure 7.9 that the non-Bingo players appear to be particularly adversely affected in the double-digit condition as set size increased in comparison with the Bingo players.

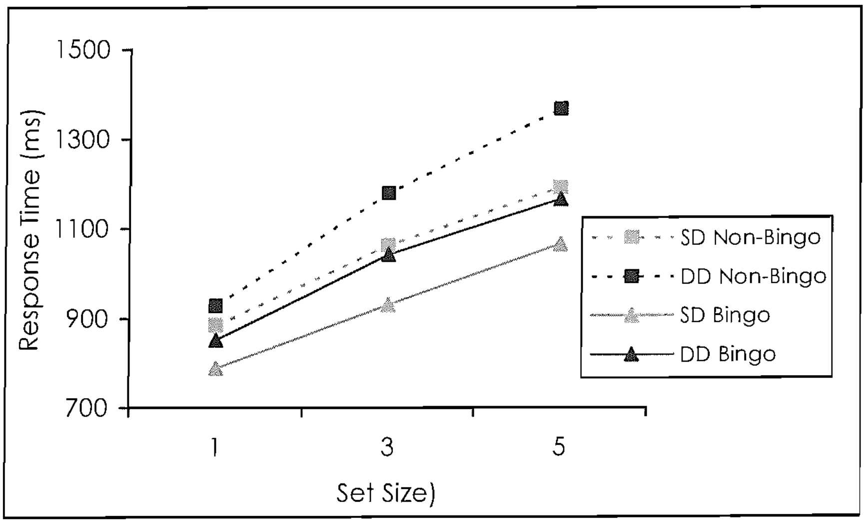

Figure 7.9. Mean response times for single-digit (SD) and double-digit (DD) conditions as a function of set size and Bingo.

Finally, the four-way interaction between Number-Type, Set Size, Age Group, and Bingo did not attain significance, $F < 1$.

Summary of Response Time Data

In summary, the Single-Digit and Double-Digit conditions produced different patterns of performance on the modified Sternberg Memory Scanning Task. It would appear from the response time data for younger participants that the modified Sternberg memory scanning task did not tap into the cognitive processes employed in the game of Bingo. However, it is possible that playing Bingo doesn't necessary facilitate performance when you are younger because short-term memory is good with or without Bingo. Bingo might, however, help to prevent the decline in short-term memory with age. On the other hand, it is possible that younger players don't try to remember the numbers needed to win. Perhaps this strategy only arises with age. Regardless of the reasons, the significant interaction between Bingo and Age suggests that Bingo is somehow facilitating the performance of older participants on this task, particularly as the task increases in complexity.

Error Rate Data for Single-Digit Condition

The mean percentage of errors made by participants was calculated for each condition. The resultant data are summarised below in Table 7.3. For the purpose of clarity, the error rates for the single- and double-digit conditions were first analysed separately in two 3 (Set Size) x 2 (Bingo) x 2 (Age Group) mixed analyses of variance with between-subject factors of Age Group and Bingo and a within-subjects factor of Set Size. The results of these separate analyses will be presented first in order to provide a clear picture of the way in which of the way in which the factors of Bingo and Age Group differentially influence performance on these two tasks. For all analyses the Alpha value was set at 0.5.

Table 7.3. Mean percentage errors (with standard deviations) for the single-digit condition set sizes one, three, and five across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	3.87	(5.31)	28	2.08	(4.32)	28
3	9.52	(10.32)	28	.30	(1.57)	28
5	4.76	(5.28)	28	.60	(2.19)	28
Older						
1	2.67	(4.57)	28	1.49	(3.25)	28
3	3.87	(4.80)	28	2.08	(3.67)	28
5	8.63	(9.48)	28	1.48	(3.25)	28

The descriptive data presented in Table 7.3 and in Figure 7.10 illustrate that Bingo positively affected the accuracy of performance, $F(1,108) = 44.86$, $p < .01$, with Bingo players making fewer errors overall (Mean = 1.34) than non-players (Mean = 5.56). Moreover, independent t-tests with a Bonferonni correction for multiple tests revealed that the older Bingo players made fewer errors overall than both the older non-Bingo players $t(54) = 3.58$, $p < .01$, and the younger non-Bingo players, $t(54) = 5.37$, $p < .01$. Importantly, there was no significant difference in the amount of errors made by the older and younger Bingo players in this condition, $t(54) = 1.50$, $p > .05$.

In addition, although there were no significant main effects of Set Size, $F(2, 216) = 2.53$, $p >.05$, or Age Group, $F< 1$, these two factors were significantly affected by Bingo, $F(2, 216) = 3.15$, = $P < .05$. Further exploration of the simple-main effects revealed that the younger non-Bingo players made significantly more errors at set size 2 than both the younger and older Bingo players and the older non-Bingo players, Tukey HSD, $p< .05$. However, it is not clear why this was the case; although erroneous information was ruled out as an explanation for this particular result as all data were screened for outliers.

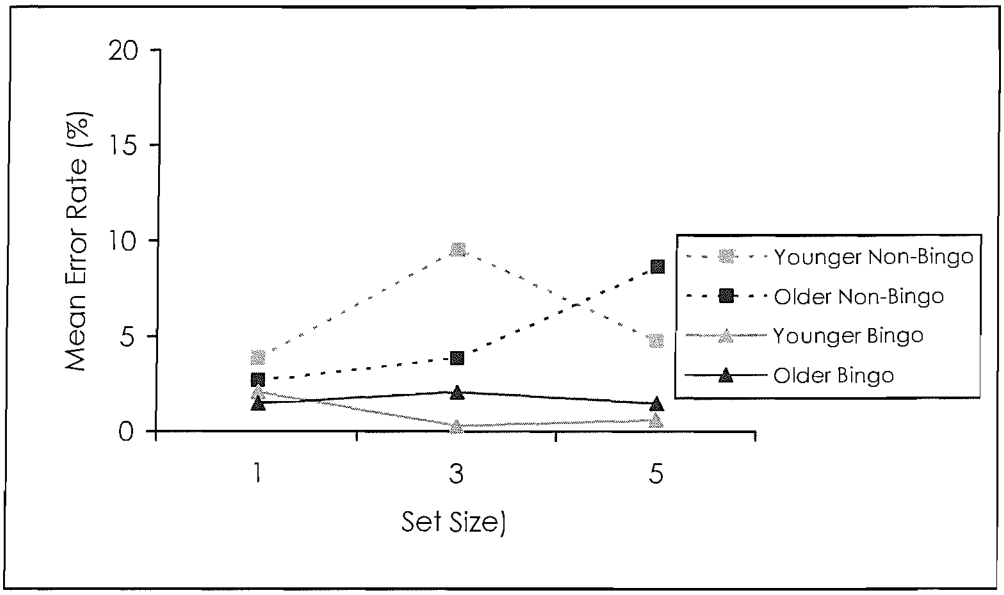

Figure 7.10. Mean percentage single-digit error rates for set sizes one, three, and five as a function of age and Bingo.

Thus, in accordance with the response time data for the single-digit condition, Bingo players made fewer errors overall than non-Bingo players did. As already discussed, accuracy is an essential ingredient of the skill required to play the game of Bingo and this could provide a possible explanation for the Bingo players' superior performance in this condition. However, in comparison with participants' response times, error rates were not significantly affected by set size, although the anomalous result that occurred at set size three for younger non-Bingo players may have masked a possible effect of set size.

Error Rate Data for Double-Digit Condition

Table 7.4. Mean percentage errors (with standard deviations) for the double-digit condition set sizes one, three, and five across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	2.08	(4.32)	28	.89	(2.62)	28
3	10.42	(10.30)	28	7.74	(4.50)	28
5	26.49	(11.80)	28	1.32	(6.98)	28
Older						
1	10.41	(4.88)	28	2.08	(3.67)	28
3	14.88	(9.45)	28	6.55	(5.72)	28
5	28.27	(11.64)	28	12.50	(11.45)	28

The descriptive data presented in Table 7.4 and in Figure 7.11 suggest that as in the Single-Digit condition Bingo positively affected the accuracy of performance. Namely, Bingo players made fewer Double-Digit errors overall (Mean = 7.79) than non-Bingo players (Mean = 15.43). Further, this was confirmed by a significant main effect of Bingo $F(1, 78) = 26.01$, $p < .01$. However, unlike in the Single-Digit condition there was also a significant main effect of Set Size, $F(2, 216) = 164.43$, $p < .01$, and it can be seen from looking at Figure 7.11 that the percentage of errors made by participants increased with set size. Perhaps most importantly, this factor of Set Size interacted with that of Bingo, $F(2, 216) = 10.25$, $p < .01$. To explore the modifying effect of Bingo on Set Size, two further 2 (Set Size) x 2 (Bingo) mixed ANOVAs were performed on the data for set sizes one and three and three and five respectively to confirm the location of the interaction. Results revealed a significant interaction between Bingo and Set Size for set sizes three and five, $F(1, 110) = 10.96$, $p < .01$, with non-Bingo players displaying a steeper slope from set sizes three to five than Bingo players. However, no significant interaction was found between Bingo and Set Size for set sizes one and three, $F < 1$.

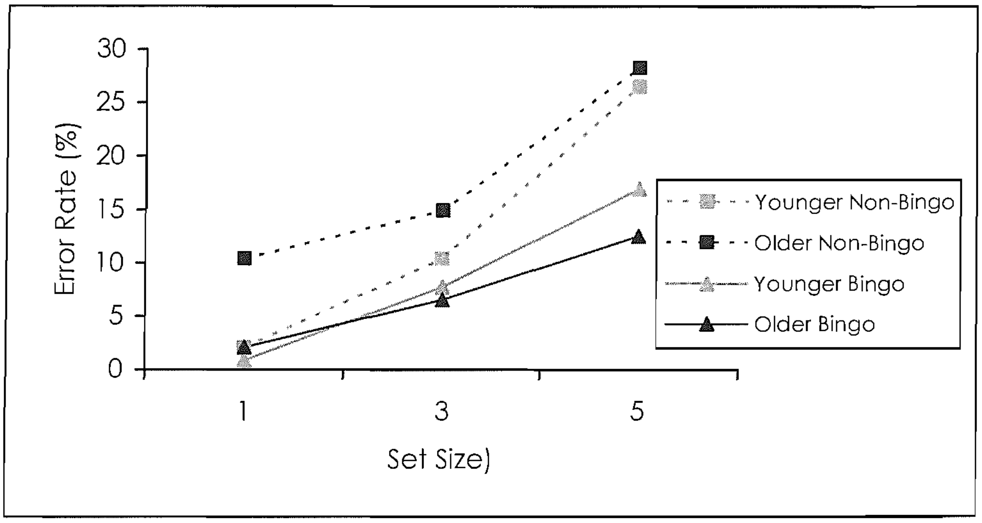

Figure 7.11. Mean percentage double-digit error rates for set sizes one, three, and five as a function of age and Bingo.

In accordance with the Single-Digit condition, there was no significant effect of Age Group, $F(1, 108) = 2.72$, $p > .05$. However, this factor was modified by Set Size, $F(2, 216) = 5.03$, $p < .01$, suggesting that the pattern of error rates as set size increased was different for the older and younger participants. Figure 7.12 indicates that younger participants exhibited a steeper increase in errors from set size 1 to 3 than older participants; although older participants made more errors at set size 1 than younger participants.

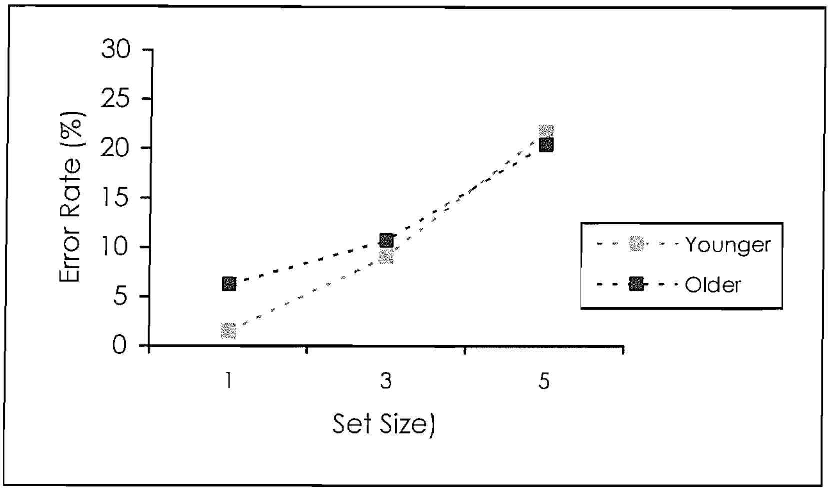

Figure 7.12. Mean percentage double-digit error rates for older and younger participants across set-size.

Importantly, though, in the Double-Digit condition, there was no significant three-way interaction between the factors of Set-Size, Age-Group and Bingo, $F < 1$.

A significant two-way interaction between Age Group and Bingo, $F(1, 108) = 9.64$, $p < .01$, however, suggests that age is differently affecting the overall accuracy performance of Bingo and non-Bingo players. Indeed, it can be seen from looking at the data displayed in Figure 7.13 that Bingo appears to particularly enhance the performance of older Bingo players as they made fewer errors than their younger counterparts. Conversely, the percentage of errors increased across age for the non-Bingo players. The simple main effects of the Bingo x Age Group interaction were tested by independent t-tests using a Bonferonni correction for multiple tests. Young non-Bingo players made fewer errors overall than older non-Bingo players, $t(54) = 2.77$, $p < .05$. Older Bingo players made fewer errors overall than older non-Bingo players, $t(54) = 6.86$, $p < .05$. Perhaps more importantly, Older Bingo players made fewer errors overall than younger non-Bingo players, $t(54) = 4.02$, $p < .05$. There was however, no significant difference in the overall percentage of errors made by younger and older Bingo players, $p > .05$.

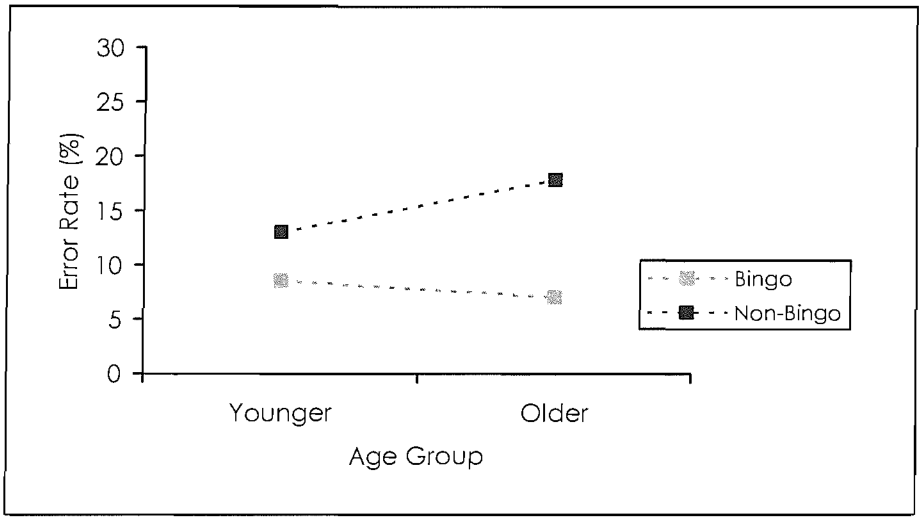

Figure 7.13. Mean percentage double-digit error rates for Bingo and non-Bingo players as a function of Age Group.

Combined Analysis for Single- and Double-Digit Error Rate Data

As with the response time data, one further analysis of variance was performed on the error rate data incorporating the additional factor of Number-Type producing a 3 (Set Size) x 2 (Bingo) x 2 (Age Group) x 2 (Number-Type) mixed analysis of variance so that any effects of Number-Type (single or double) on the factors of Set Size, Age Group and Bingo would be made apparent.

The results of this additional ANOVA revealed a significant main effect of Number-Type, $F(1, 216) = 322.89$, $p < .01$, with participants producing more errors overall in the Double-Digit condition than in the Single-Digit condition.

Further, the factor of Number-Type also interacted with Set Size, $F(2, 216) = 104.88$, $p< .01$, and it can be seen from looking at the data displayed in Figure 7.14 that participants generated more errors overall in the double-digit condition with increasing set size than in the single digit condition. Moreover, this increase in error rate with set size in the double-digit condition was especially apparent at the largest set size. To examine whether interaction between Number-Type and Set Size was significant for both set sizes one and three and for set sizes three and five, two further 2 (Number-Type) x 2 (Set Size) ANOVAs were performed on the data. The results confirmed a significant interaction between set sizes one and three, $F(1, 108) = 69.90$, $p < .01$, and for set sizes three and five, $F(1, 108) = 28.80$, $p < .01$.

Importantly, the interaction between Number-Type and Set-Size varied between Bingo and non-Bingo players, $F(2, 216) = 4.83$, $p < .01$, and also between older and younger participants, $F(2, 216) = 9.56$, $p < .01$. However, the four-way interaction between Number-Type, Set-Size, Bingo and Age Group did not attain significance, $F(2, 216) = 2.39$, > 0.05.

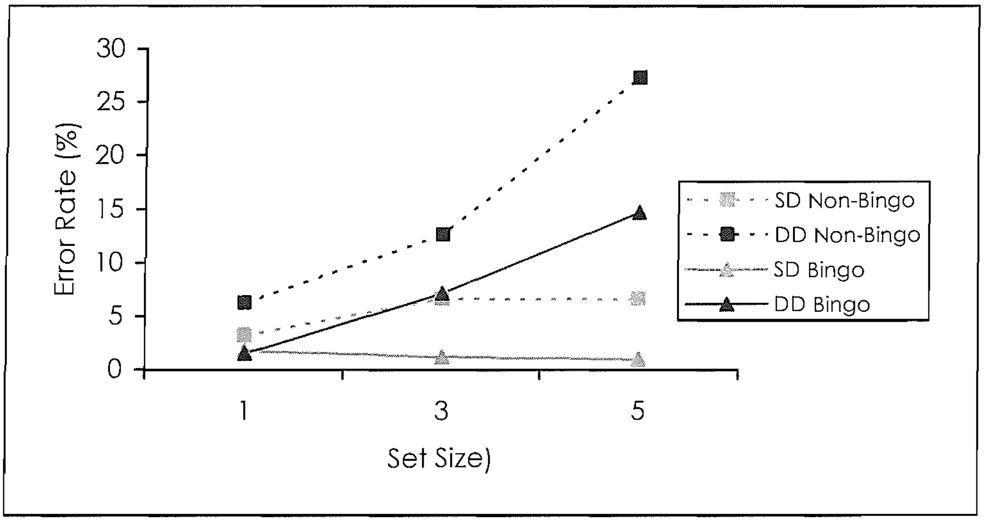

Figure 7.14. Mean error rates for single-digit (SD) and double-digit (DD) conditions for set sizes 1, 3, and 5 as a function of Bingo.

The data displayed in Figure 7.14 illustrate that errors increased with set size in the Double-Digit condition particularly for the non-Bingo players, suggesting that this participant group was most disadvantaged by an increase task complexity. In addition, the factor of Digit Type also interacted significantly with that of Age Group, $F(1, 216) = 4.08$, $p < .05$, and moreover, both of these factors were modified by the factor of Bingo, $F(1, 216) = 19.57$, $p < .01$.

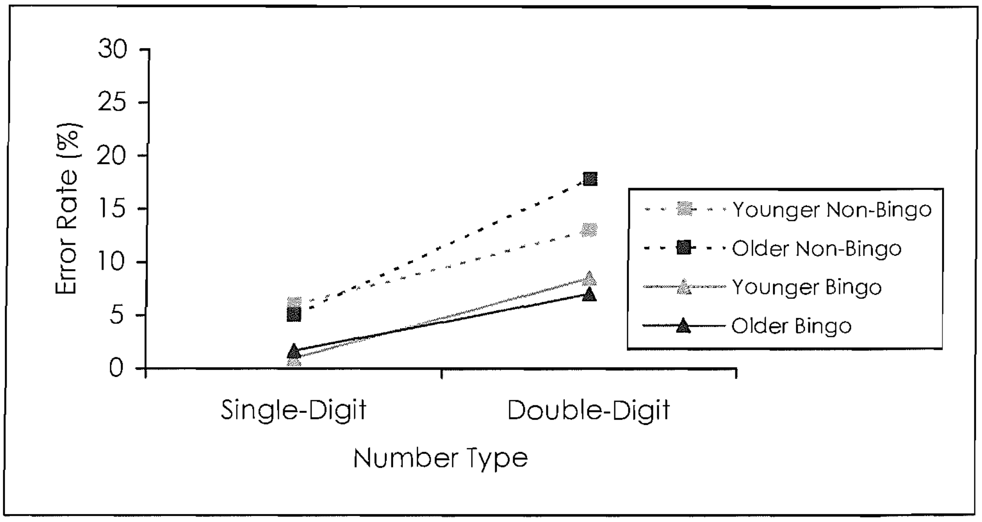

Figure 7.15. Mean percentage errors for single-digit and double-digit conditions as a function of age and Bingo.

Figure 7.15 indicates that although all participants made more errors in the Double-Digit condition, the performance of older non-Bingo players in particular was impaired in the Double-Digit condition in comparison with their performance in the Single-Digit condition. Importantly, there is very little difference in the number of errors made by younger Bingo players in comparison with older Bingo players as task difficulty increases.

Results Summary for Error Rate Data

In summary, it appears that Bingo players demonstrated superior performance over non-Bingo players in both the single- and double-digit conditions. However, the high error rate for younger non-Bingo players in the single-digit condition probably confounded the result for this condition. If the younger non-Bingo players' data were removed for the single-digit set size two condition, errors would have been very low for all participant groups, and would reflect typical error rates on a standard Sternberg Memory Scanning Task (1969). However, the superior performance of Bingo players in the double-digit condition is clearly demonstrated by the significant interaction between Bingo and Set-Size. Importantly, Bingo players are more accurate at scanning their memories than non-Bingo players at the largest, and hence, most difficult set size. This suggests that Bingo players possess better working memory for double-digit numbers than non-Bingo players. Moreover, the older Bingo players appear to be particularly accurate in this condition.

General Discussion

The purpose of the present experiment was firstly, to determine whether Bingo players would demonstrate superior performance on a modified version of the Sternberg memory-scanning task. It is proposed that an important requirement of the game of Bingo is the ability to quickly and accurately scan and compare numbers in memory, It was therefore predicted that because of the thousands of times experienced Bingo players have carried out this operation they would both generate quicker response times and make fewer errors than non-Bingo players in spite of the fact that the task is variedly mapped.

Secondly, this experiment provided a further opportunity to ascertain whether extended practice at scanning memory for digits serves to maintain the processes underlying this task in older Bingo players as reliable age-differences in performance on the Sternberg memory-scanning task have been reported (e.g. Anders, Fozard, & Lillyquist, 1972; Eriksen, Hamlin, & Daye, 1973; Ferraro & Balota, 1999).

The results of the response time data revealed the typical increase in response latency with set size reported by Sternberg (1966, 1969, 1975), suggesting that participants take longer to complete a scan of the memory set as the size of the memory set increases. Further, in support of the studies carried out by Anders et al. (1972), Eriksen et al. (1975) and Ferraro & Balota (1999) older participants produced slower response times overall than younger participants on this task. These results suggest that despite the extended practice at rapidly scanning memory for numbers, the perceptual components underlying memory search are negatively affected by the ageing process. As previously noted, the stimulus-response mapping on this task is varied and research suggests that varied-mapping tasks show little improvement with practice (e.g. Schneider

& Shiffrin, 1977; Shiffrin & Schneider, 1977). The significant main effect of age on this modified version of the Sternberg memory-scanning task provides evidence against the remediation or maintenance hypothesis of the ageing of cognitive skill which purports that molar performance is equivalent in both younger and older adults because the elementary cognitive processes underlying the task are maintained via practice (for a review see Bosman and Charness, 1996). However, it is important to note that the significant interaction between Age Group and Bingo suggests that practice at the game of Bingo is positively affecting the performance of the older Bingo players in comparison with the older non-Bingo players. Indeed, post hoc tests confirmed a significant difference in the response times generated by these two groups. Further, the descriptive data illustrate that the older non-Bingo players are particularly disadvantaged in the double-digit condition, producing slower response times as task complexity increases in comparison with the older Bingo players. Thus, although age negatively affects overall performance on this task it is possible that extended practice at scanning memory for numbers resulting from thousands of games of Bingo (particularly double-digit numbers) helps to offset some of the deleterious effects of age.

It is also important to consider here the fact that the present experiment unlike the previous two experiments measured response times. Thus, the reported differences in performance between younger and older participants may be partially due to the effects of peripheral slowing (Welford, 1977). Certainly, the fact that the older Bingo players did not display the same increases in response time with task complexity in comparison with their younger counterparts, especially in the double-digit condition suggests that their central processing abilities have been partially modified by the practice provided by playing Bingo. Of course the quasi-experimental design utilised here cannot determine a cause and effect relationship.

The single-digit accuracy data, as already reported appear to be confounded by the younger non-Bingo players' performance at set size three. However, despite this anomaly it is apparent that the Bingo players made fewer errors in this condition than non-Bingo players, although overall error rate was very low. Accuracy is a very important requirement of the game of Bingo and a missed number when scanning the Bingo array can result in large sums of money being lost. Thus, it may be possible that both the younger and older Bingo players are favouring accuracy over speed in this task, hence, the non-significant difference in response latency of the younger Bingo and non-Bingo players. Importantly, the older Bingo players produced fewer errors in the single-digit condition than younger non-Bingo players. Moreover, there was no difference between the number of errors made by younger and older Bingo players.

Of more interest, perhaps, are the accuracy results from the double-digit condition. The results from the mixed ANOVA revealed that Bingo players made fewer double-digit errors than non-Bingo players, and also that older Bingo players were more accurate in this condition than both the younger and older non-Bingo players. Furthermore, Bingo players made fewer errors with increased task complexity than non-Bingo players, particularly at the largest set size, and importantly, older Bingo players made fewer errors at the largest memory set size than their younger Bingo playing counterparts. These results suggest that extended practice at playing Bingo enhances the ability of Bingo players to accurately search memory for digits and particularly double-digits. Furthermore, this ability is maintained into older adulthood. The fact that the older Bingo players made fewer errors than the younger Bingo players on this task implies that they may be compensating for a deficit in response speed by employing a strategy that favours accuracy over response. However, the results do not provide evidence for a general speed-accuracy trade-off that is often reported in the ageing literature as the older non-Bingo players made more errors than younger-non Bingo players along with generating slower responses.

In conclusion, the results of the present study do not fully support the hypotheses that Bingo players are able to scan their memories for digit targets more quickly than non-Bingo players or that extended practice at Bingo serves to maintain this ability in older adults, although older Bingo players did produce quicker response times than older non-Bingo players. However, the results do support the hypotheses that Bingo players are able to more accurately scan their memories for digit targets than non-Bingo players especially when the memory set comprises double-digit numbers. Extended practice at Bingo appears to maintain this ability in older adults.

The present experiment provides an initial attempt to measure one of the elementary cognitive processes thought to underlie the game of Bingo. The following experiment continues this theme by assessing performance of younger and older Bingo and non-Bingo players on a general measure of visual search.

CHAPTER EIGHT

EXPERIMENT 4: DIGIT CANCELLATION AS A MEASURE OF ELEMENTARY COGNITIVE PROCESSING UNDERLYING BINGO PERFORMANCE

Introduction

The purpose of the present experiment is to further explore if extended practice at Bingo leads to superior performance on tests of the elementary cognitive processes underlying the game. The first experiment presented in this thesis examined performance differences on the domain-specific task of Bingo search and perhaps not surprisingly found that both younger and older skilled Bingo players performed better on this task than younger and older non-Bingo players. The second experiment investigated whether extended practice at Bingo search would transfer to a task comprising the same rules but different stimuli and found evidence to suggest positive transfer occurred for both younger and older Bingo players, but especially younger Bingo players. However, the question of whether experienced Bingo players demonstrate superior performance on a more general measure of visual search has yet to be addressed. Thus the aim of the present experiment is to examine differences in performance between Bingo players and non-Bingo players on a domain-general visual search task.

Cancellation tests are pen and paper tasks that can be used to measure a wide range of perceptual and cognitive abilities such as sustained, selective and divided attention, visual-spatial scanning ability, and visual-motor speed and coordination. These tests are widely used in clinical settings as a means of assessing neuropsychological dysfunction (Lezak, 1983, 1995). Cancellation tests appear in numerous guises according to the perceptual or cognitive variable of interest. For example, cancellation tests may be structured (linear-array) such that the stimuli are arranged in rows with targets randomly or pseudo-randomly interspersed among distractors (see Diller, Ben-Yishay, Gerstman, Goodkin, Gordon, & Weinberg, 1974; Spinnler & Tognoni, 1987). Conversely, cancellation tasks may be unstructured (random-array) such that the spatial positioning of target and distractor stimuli is randomly arranged on a page (see Geldmacher, 1996; Geldmacher, Doty, & Keilman, 1994). Cancellation tests may also differ in terms of the nature of instructions given to participants. For example, emphasis may be placed on speed, accuracy, or a mixture of both. In addition, participants may either be given a designated amount of time to cancel as many targets as they can or the experimenter may record the amount of time it takes to complete the whole task. Cancellation tests also vary widely in format. For example, they may differ in terms of type and size of stimuli, spatial location of stimuli, target-distractor similarity and target-to-distractor ratio (e.g. Geldmacher & Hills, 1997). Importantly, all of these factors have been found to influence performance (for a review see Uttl & Pilkenton-Taylor, 2001).

The Digit Cancellation Task (DCT), for instance, is a timed pen and paper test of visual information processing that requires participants to search and cancel every instance of a specified target digit or digits recurring within a matrix of similar distractor stimuli. Thus, the participant is required to selectively attend to the relevant features of the visual array while inhibiting the irrelevant ones. Importantly, the DCT provides measures of both participant response time and accuracy level. The origins of the DCT can be traced back to the early attentional work of Neisser (1964), although numerous variations of the task have subsequently been developed (e.g. Diller, Ben-Yishay, Gerstman, Goodkin, Gordon, Weinberg, 1974; Spinnler & Tognoni, 1987; Weinberg & Diller, 1968). Importantly, the DCT can be manipulated to obtain performance measures of sustained, selective and divided attention as well as perceptual speed and working memory.

As outlined in Experiment 1, a primary requirement of the game of Bingo is the ability to scan a visual array (90 numbers if playing six cards) and locate a designated target digit, amongst distractor digits. Moreover, this action must be performed within a given time limit (approximately 2-3 seconds). Failure to complete this task successfully within the allotted time is likely to cost the player financially should they be lucky enough to hold a winning card. In addition, it is likely that Bingo players are required to hold more than one number in memory at a time while scanning the visual array as a game may be won on any of the cards that a player is playing. Thus, a player must be aware of the numbers that are required on each card to win the game, whether it is for a line, two lines, or 'full house'. The DCT therefore provides a means by which these important Bingo abilities can assessed.

Importantly, a number of researchers have recorded age-differences in performance on the DCT. This is perhaps not surprising considering the task requires many of the elementary cognitive processes that exhibit reliable declines in performance with age. Filley and Christopher (1994), for example, carried out two experiments to examine age differences on various measures of attention using the structured version of the DCT. Significantly, they found age differences in performance on a number of digit cancellation tasks, with older participants cancelling fewer digits within the allotted time. More recently, Uttl and Pilkenton-Taylor (2001) investigated cancellation test performance across the lifespan using a large sample of adults between the age of 18 and 91 years and reported negative effects of age on speed of cancellation but no age-differences in the spatial distribution of the errors made by participants.

In light of the evidence presented above the present experiment will utilise an adapted version of the structured digit cancellation test developed by Spinnler and Tognoni (1987). This DCT comprises three separate tests that vary in complexity by increasing the number of digit targets to be cancelled from one digit to three digits. Thus, although the DCT comprises stimuli that are especially familiar to persons who play Bingo, the production rules underlying the DCT are different to those used to play the game of Bingo in that participants are required to search from left to right along each row, whereas, Bingo players search in columns. Moreover, unlike in the search carried out in the game of Bingo, the DCT does not include any contextual information relating to the location of the target digit(s). Thus the present experiment will provide a measure of Bingo players' ability to rapidly search a random array for a target digit or digits. Finally, the present experiment will also ascertain if extended practice at Bingo serves to maintain this ability in older adulthood.

Method

Design

This experiment employed a mixed design in which Age Group (younger/older) and Bingo (player/non-player) were between-subject factors and target Set Size (1, 2, and 3) was the within-subject factor. Performance in this experiment comprised both response speed (percentage of digits cancelled) and error rates (percentage of missed digits).

Participants

As described in Experiment 3.

Materials

The stimulus set used in this experiment comprised three sheets of A4 paper on which were printed grids measuring 176mm x 196mm. Each grid comprised 25 rows x 25 columns of the digits 0 to 9 printed in 18pt Arial font (see Appendix). The digits were pseudo-randomly distributed with the provisos that (i) no two identical digits appear adjacent to one another, and that (ii) the total number of target digits per page equalled 120. Thus, each grid comprised 120 targets and 505 distractors.

At the top of each page an example of the target digit(s) were displayed in a separate box as a reminder to participants of the particular digit(s) that had to be located. On the first page, the digit *5* was the target, on the second page, the digits *2* and *6* were targets, and on the third page, the digits *1, 4,* and *9* were targets. Participants were also given a felt pen known as a 'Bingo dabber' with which to mark each instance of the target digit(s). A Bingo dabber has a flattened nib that makes a circular mark approximately 3mm in diameter.

Procedure

Participants performed experiments 4-7 during one experimental session lasting approximately half an hour (non-Bingo players did not take part in experiment 7). All participants were tested individually. Participants performed the digit cancellation task in the following order: target set size 1, 2, and 3. Participants were seated at a desk and given standardized verbal instructions. The experimenter informed participants that the task was designed to measure their ability to pick out digit targets from distractors. Participants were told that the experiment comprised three one-minute tasks and that the instructions for each task were the same. The experimenter then placed an exemplar form in front of the participant and said "Here you see a number of rows of digits. Your task is to find the digit or digits that appear at the top of the page. Each time you find the digit(s), I want you to cross it out with a felt pen like this (experimenter demonstrates a single 'dab' over the digit). Every time you see the digit(s) cross it out. I want you to work as quickly and as accurately as you can. You should cancel all instances of the digit(s) but no other digit(s). Please start with the first row and work across the page from left to right. When you are finished go straight on to the next row until the buzzer sounds at which point you should put down your page and wait to begin the next test". The experimenter then asked the participant if she or he had any questions or was ready to begin the test. When the participant was ready, the experimenter placed the first Trial 1 grid in front of the participant and said 'Go'. The experimenter started an electronic timer that counted down from 60 seconds at which point a buzzer sounded and the participant put down his or her pen. The Trial 2 grid and Trial 3 grid were administered in exactly the same manner after allowing the participant a brief intermission.

Results and Discussion

The design of the present study allowed two analyses to be conducted. First, response speed was examined by calculating the number of target digits cancelled by each participant for each set size within the designated time. The mean percentage of cancelled digits was collated for all participants so that a 2 (Age Group) x 2 (Bingo) x 3 (Set Size) mixed design ANOVA could be performed on the data. Following this, error rate was examined by calculating the number of target digits missed by each participant for each set size within the designated time. The mean percentage of missed target digits was collated for all participants so that a 2 (Age Group) x 2 (Bingo) x 3 (Set Size) mixed design ANOVA could be performed on the data. For both analyses, the between-subject factors were Age Group and Bingo and the within-subject factor was target Set Size. Further, for all analyses the Alpha value was set at .05.

Response Speed Data

Table 8.1. Mean percentage of cancelled target digits (with their standard deviations) for set sizes 1, 2, and 3 across all participants.

	Non-Bingo			Bingo		
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	49.32	(2.69)	28	59.46	(3.81)	28
2	35.21	(4.07)	28	47.53	(5.09)	28
3	31.40	(4.35)	28	46.37	(7.11)	28
Older						
1	39.64	(4.41)	28	53.24	(6.26)	28
2	30.74	(4.94)	28	41.88	(1.47)	28
3	28.51	(4.63)	28	37.71	(1.35)	28

The descriptive data presented in Table 8.1 and in Figure 8.1 show that as set size increased, the number of target digits that participants were able to cancel within the allotted time decreased. This main effect of Set Size was confirmed by the results of the mixed ANOVA, $F(2, 216) = 1066.35$, $p < .01$.

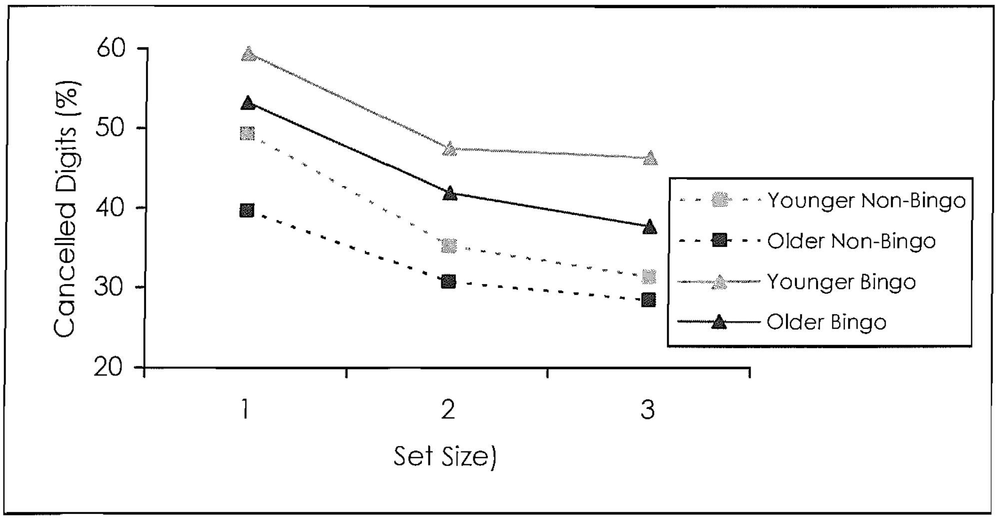

Figure 8.1 Mean percentage of target digits cancelled for set sizes 1, 3, and 5 as a function of age group and Bingo.

The data displayed in Figure 8.1 also illustrate that those with Bingo experience performed better on this task, $F(1,108) = 158.29$, $p < .01$. Also, Figure 8.2 illustrates that older participants cancelled fewer digits overall than younger participants, $F(1, 108) = 43.84$, $p < .01$.

This main effect of age suggests that although Bingo players demonstrated superior performance overall, the component processes underlying the task are negatively affected with age despite the continued practice of the older Bingo-players. However, it should be noted that the digit cancellation task assesses performance of more than one cognitive process. Firstly, there is the process of speeded visual search (searching for and locating a target digit amongst distractors). Secondly, there is the process of holding one, two, or three numbers in short term memory while conducting the visual search and thirdly there is the action of marking the located digit or digits.

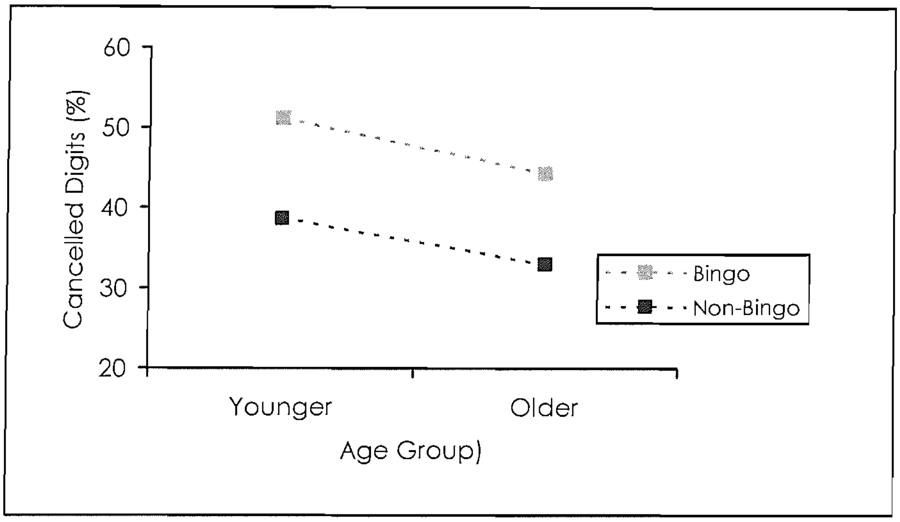

Figure 8.2. Mean percentage of target digits cancelled as a function of age and Bingo.

Thus, although the non-significant interaction between Bingo and Age Group, $F < 1$, suggests that the negative effect of age is similarly affecting the performance of both Bingo and Non-Bingo players, the significant three-way interaction between Set Size, Age Group, and Bingo, $F(2, 216) = 24.31$, $p < .01$, implies that there may be performance differences in these two processes. The data displayed in Figure 8.1 indicates that for the younger Bingo players, Bingo is not just improving performance overall, but improving it most at the larger set size (set size 3). However, for the older players, Bingo appears to be aiding performance at the small set size (set size 1) more than at the larger set size.

As previously mentioned, the set size 1 condition is dependent primarily on search ability, whereas the larger set sizes require both search ability and to a larger degree short-term memory. It therefore might be suggested that for older Bingo players search ability is being better maintained than their short-term memory ability. This is further supported by the fact that the older non-Bingo players' performance at set size one is significantly lower than the other three groups in this condition, Tukey HSD <. 05.

However, it must be pointed out that this preservation of performance for the older Bingo players at set size one does not occur to the same extent for the larger set sizes. It might therefore be possible that age is differently affecting the short-term memory ability of Bingo players compared to their visual search ability, although performance is still greater overall for older Bingo players than younger non-Bingo players or older non-Bingo players.

On reflection, this finding is not unexpected because Bingo is primarily a game of visual search. Moreover, only one number is searched for on each trial (although unlike this cancellation task, it is usually a two-digit number). Therefore, Bingo players would not be practiced at searching for more than one number simultaneously. These findings therefore provide some support for the hypothesis that continued practice at playing Bingo maintains performance on the component processes underlying the game. It may be, for instance, that when Bingo players search for a target and scan their card for the numbers that are required to win a game they rely more on visual search rather than holding numbers in short term memory.

Error Rate Data

Table 8.2. Mean percentage of missed target digits (with their standard deviations) for set sizes 1, 2, and 3 across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	SD	N	Mean	SD	N
Younger						
1	1.98	(3.14)	28	0.67	(1.00)	28
2	7.24	(5.73)	28	1.61	(1.96)	28
3	9.78	(7.61)	28	2.14	(1.95)	28
Older						
1	3.28	(2.53)	28	0.00	(0.00)	28
2	9.11	(5.72)	28	0.29	(0.73)	28
3	12.62	(11.22)	28	0.58	(2.27)	28

The descriptive data presented in Table 8.2 and in Figure 8.3 illustrate that as with the response time data, Bingo players demonstrated superior performance on this measure. Namely, Bingo players missed fewer digits overall than non-Bingo players, thus, producing a significant main effect of Bingo, $F(1, 108) = 97.37$, $p < .01$.

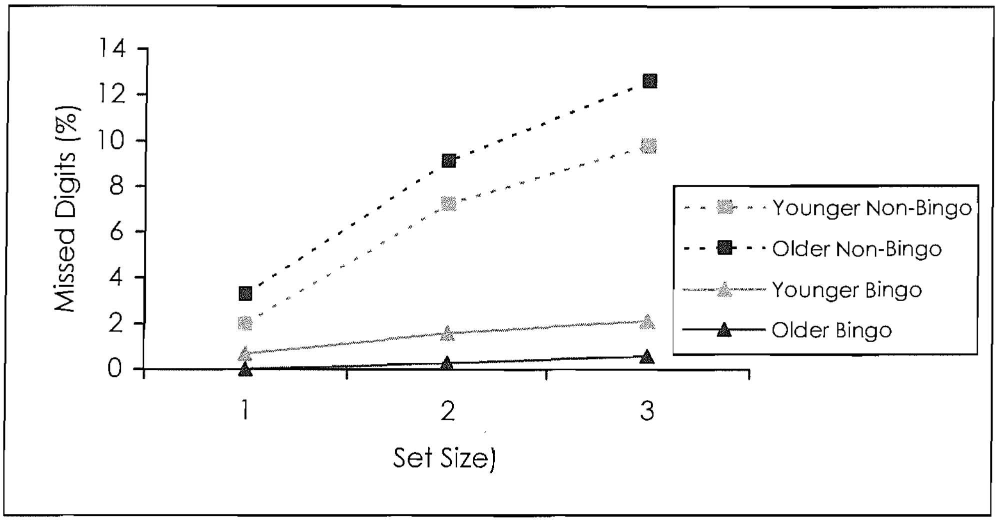

Figure 8.3. Mean percentage of missed digits for set sizes 1, 3, and 5 as a function of Bingo and age group.

Conversely, unlike the results of the response time data, the number of digits missed was not significantly affected by Age Group, $F < 1$. There is, however, a surprising interaction between Age Group and Bingo, $F(1, 108) = 5.95$, $p < .05$. While younger non-Bingo players miss fewer digits than older non-Bingo players, the pattern is actually reversed among the Bingo players.

In accordance with the results of the response time data, the pattern of performance of participant's error rates was affected by Set Size. Namely, the number of target digits missed by participants increased as the number of targets to be searched for increased, $F(2, 216) = 38.90$, $p < .01$. However, when the mean numbers of missed digits (see Table 8.2) are compared for each group across the three set sizes, it is apparent that Set Size is not affecting the Bingo players nearly as much as it is affecting the non-Bingo players. This was confirmed by a significant interaction between Set Size and Bingo $F(2, 216) = 24.16$, $p < .01$. The data displayed in Figure 8.4 illustrate that the number of digits missed by both younger and older non-Bingo players in comparison with younger and older Bingo players increased as the number of target digits increased. To explore this interaction further, two separate 2 (Bingo) x 2 (Set Size) mixed ANOVAs were performed on the data for set sizes one and two, and set sizes two and three respectively. The results revealed a significant interaction between Bingo and Set Size for both set sizes one and two, $F(1, 110) = 40.65$, $p < .01$, and for set sizes two and three, $F(1, 110) = 4.50$, $p < .05$.

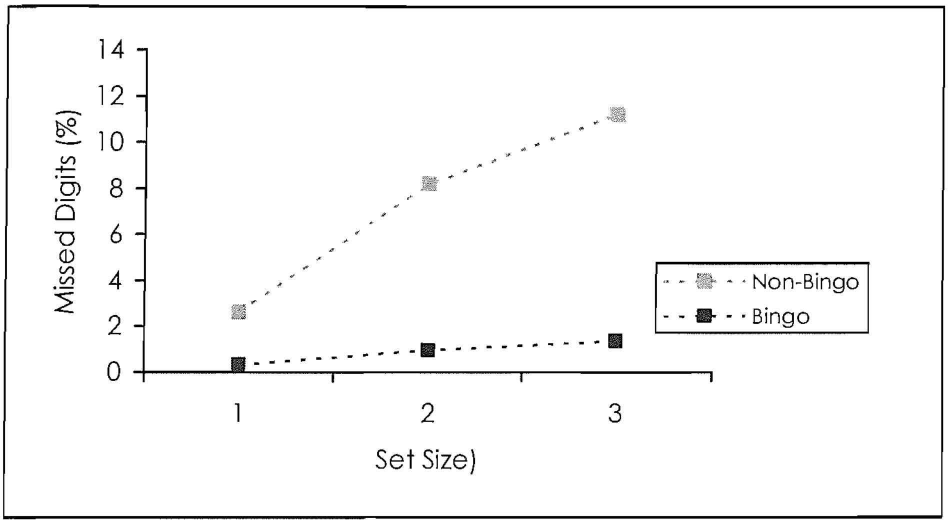

Figure 8.4. Mean percentage of missed digits for set sizes 1, 3 and 5 as a function of Bingo.

Importantly, Figure 8.3 shows that the older Bingo players missed fewer digits than even the younger Bingo players did. Further exploration of the simple-main effects of the interaction between Age Group and Bingo by means of an independent t-test using a Bonferonni correction for multiple tests found the difference in error rate between the older and younger Bingo players to be significant, $t(54) = 4.81$, $p < .01$. However, if the response time and error rate data for this task are compared it is apparent that a speed-accuracy trade-off is occurring here. As set size increases, the number of digits that the younger Bingo players cancel compared to the older Bingo players also increases, but so does the number of missed digits. It suggests therefore that the younger Bingo players are favouring speed over accuracy unlike the older Bingo players who have chosen to adopt the more cautious strategy of accuracy over speed. These differences in strategy have occurred despite equal importance being placed on both attributes in the instructions for this task.

Summary of Results

Analysis of both response times and error rates demonstrated significant differences in the performance of Bingo and non-Bingo players on this task with Bingo players demonstrating superior performance both in terms of the number of digits cancelled within the allotted time and in the number of errors made. The error rate data demonstrates that older Bingo players missed fewer digits than both the younger and older non-Bingo players and made fewer errors than their younger Bingo playing counterparts. A speed-accuracy trade-off is occurring, with older Bingo players favouring accuracy over speed and younger Bingo players favouring speed.

General Discussion

The purpose of the present experiment was to assess one of the elementary cognitive processes underlying the game of Bingo, namely, the perceptual skill of visual search for digit targets. Unlike the domain-specific task of Bingo search utilised in the first experiment, the current experiment employed a general measure of visual search as commonly used in psychometric tests to measure participants' perceptual speed and accuracy at locating digit targets. Importantly, in the present experiment Bingo players could not employ the search strategies used in Bingo search as there were no contextual cues as to the location of the target digits. Also, in the present experiment participants were instructed to search each stimulus sheet from left to right whereas in the game of Bingo, players search from top to bottom within a particular column.

The superior performance demonstrated by Bingo players on this task suggests that regular practice at Bingo improves performance on this basic perceptual-cognitive ability. Overall, Bingo players were able to cancel more target digits within the designated time than non-Bingo players suggesting that the thousands of trials spent searching for target digits in the game of Bingo has enhanced their general ability to search for digit targets. It is important to point out however, that the quasi experimental design employed in the present experiment cannot establish a causal relationship between playing Bingo and superior visual search performance. The results do suggest, however, some possible explanations for the means by which Bingo players are able to search for target digits more efficiently than non-Bingo players. Firstly, it cannot be ruled out that people who are better at visual search are more likely to play the game of Bingo. Future research could assess participants' search ability before they learn to play the game. However, it is also possible that experience at Bingo gives players an acquired ability to both determine features that are specific to a given digit and to discriminate a particular digit from other digits, thus resulting in faster and more accurate detection (e.g. Lunn, 1948). Indeed, as reported by Haider and Frensch (1996), improvements in perceptual performance are often found to occur as a result of a reduction in the processing of irrelevant features. It is also possible that an enhanced ability to discriminate between digits could lead to a reduction in the ability of target-distractor similarity to disrupt search performance (e.g. Duncan & Humphreys, 1989).

In addition, the superior performance demonstrated by Bingo players on this task might have occurred because they are highly practiced at inhibiting distracting information, particularly non-target digits, so that their search for a particular digit is not impeded by the surrounding distractor digits to the same extent as non-Bingo players.

However, it is important to note that in accordance with the research reported by Filley and Christopher (1994) and Uttl and Pilkenton-Taylor (2001), the results of the response time data revealed that older Bingo players are negatively affected by age on this task. Thus, even though the older Bingo players cancelled more digits than both younger and older non-Bingo players, their performance was significantly reduced in comparison to the younger Bingo players.

Significantly, however, the analysis of the error rate data revealed that older Bingo players missed fewer digit targets than both older and younger non-Bingo players and their younger Bingo playing counterparts, suggesting that the ability to accurately search for target digits is maintained and possibly improved in older adulthood by practice at Bingo search. Accuracy at target detection is an extremely important requirement of the game of Bingo. If a number is missed, substantial sums of money may be lost. It is possible that the older Bingo players, who inevitably have many more years of experience than the younger players, are more aware of this fact than the younger players are. Perhaps older Bingo players have experienced the consequence of missing numbers themselves or have witnessed it in other people. It has often been reported that older people, in general, are more cautious, often favouring accuracy over speed (e.g. Birren, 1964; Botwinick, 1973). However, if this were to be the only explanation for the above findings then no significant differences in accuracy between the older Bingo and non-Bingo players would be expected. Yet, this clearly is not the case as the older non-Bingo players exhibited a steeper increase in errors with increased set size than the older Bingo players did. One possible avenue for further research here would be to manipulate the emphasis on speed versus accuracy when giving instructions in this task and compare each group's ability to adopt a particular response strategy.

In summary, the results of the present experiment suggest that playing Bingo enhances performance at visual search for digit targets in terms of both the speed with which younger Bingo players are able to locate targets and in the number of omission errors they such that both younger and older Bingo players are less likely to miss targets than their non-Bingo playing counterparts. The data also suggest that this skilled visual search ability for target digits is relatively well maintained by older Bingo players, although the speed with which the older Bingo players are able to search for digits exhibits a greater decline with set size in comparison to younger Bingo players. However, part or all of this slowing be explained by a speed-accuracy trade-off whereby the younger Bingo players miss more digits as set size increases in comparison to the older Bingo players. Further research will seek to elucidate this phenomenon by manipulating the variable of response strategy.

This experiment cannot however determine whether the enhanced performance at a domain-general measure of visual search exhibited by the Bingo players is limited to a specific stimulus, i.e. digits. We therefore turn to look at the next experiment, which utilises another form of the cancellation task to explore the possibility of skill 'generalization' or 'transference'.

CHAPTER NINE

EXPERIMENT 5: LETTER CANCELLATION AS A GENERAL TEST OF THE TRANSFERABILITY OF BINGO SEARCH

Introduction

The purpose of the present experiment is to examine whether the superior performance demonstrated by Bingo players on a general measure of visual search, the digit cancellation task (DCT) reported in the previous experiment, transfers to other stimuli.

The second experiment reported in this thesis investigated whether extended practice at Bingo search would transfer to a task comprising the same rules but a different class of stimuli, namely, symbols. Positive transfer was predicted to occur for Bingo players in the experiment because the cognitive abstractions, in other words, the rules formed in the original learning context, would be transferred to the new situation (e.g. Anderson, 1983; Bovair, Kieras, & Polson, 1990). The results from Experiment 2 suggest that Bingo players required less time to search the ninety-symbol array than non-Bingo players and that they were able to perform the task more efficiently (as evidenced by significant *d'* scores). Importantly, as the rules of the experimental task were kept constant the results imply that Bingo players were able to positively transfer the search strategies utilised in Bingo search to a new situation. However, the results of Experiment 2 cannot determine whether Bingo players have developed an increased ability to search for targets in general. The inclusion of contextual information has previously been reported to aid the visual search performance of skilled medical technicians (e.g. Hoyer & Ingolfsdottir, 2003). Thus, it is important to examine whether removal of contextual cuing information from the search task affects the ability of Bingo players to search for non-digit stimuli.

Furthermore, the results of Experiment 2 revealed significant age differences in performance; namely, older participants demonstrated a reduction in both the efficiency and proficiency of visual search for symbol targets in comparison to their younger counterparts. These results led to the suggestion that older Bingo players are not able to completely transfer the search strategies they have developed over years of practice at Bingo search to a new situation. This was further supported by the finding that younger non-Bingo players correctly identified more target symbols than older Bingo players.

However, the older Bingo players did correctly identify more target symbols than their non-Bingo playing counterparts suggesting that some degree of positive transfer had taken place. However, the experimental design utilised in Experiment 2 cannot reveal whether the superior performance demonstrated by older Bingo players in comparison with older non-Bingo players on the symbol search task was due to some degree of transfer of the strategies used in Bingo search or whether their superior performance was due to an increase in the older Bingo players' general ability to visually search for targets.

Thus, the present experiment aims to examine whether the positive transfer demonstrated in Experiment 2 was a result of the transfer of strategy or was instead due to a general increased ability to search for visual targets. The letter cancellation task (LCT) provides an opportunity to experimentally test this hypothesis. LCT's, like digit cancellation tasks are pen and paper tasks which can be used to measure a wide range of perceptual and cognitive abilities depending upon their structure, format, and instructions (e.g. Geldmacher, 1996; Geldmacher, Doty, & Keilman, 1994). Importantly, researchers have reported reliable age-differences in performance of letter cancellation tasks. A recent example is the experiment conducted by Uttl and Pilkenton-Taylor (2001) that explored cancellation test performance over the lifespan. Uttl and Pilkenton-Taylor found that older adults were able to cancel fewer letter targets within the designated time than younger adults. However, they found no age-difference in the spatial distribution of errors made by participants.

The present experiment will further modify the adapted structured digit cancellation test developed by Spinnler and Tognoni (1987) by substituting each digit for a letter target, thus keeping the layout and target-to-distractor ratio the same as in the previous digit cancellation experiment. The present experiment, therefore, will not contain the contextual information found in Bingo search, nor will it utilise the class of stimuli found in the game of Bingo. Thus, a measure of Bingo players' ability to search a structured random-array for a target letter or letters will be provided. Further, the present experiment also aims to ascertain if extended practice at Bingo serves to maintain this ability in older adulthood.

Method

Design

This experiment employed a mixed design. Age Group (younger/older) and Bingo (player/non-player) were between-subject factors and target Set Size (1, 2, and 3) was the within-subject factor. Performance comprised both participant response speed (percentage of letters cancelled) and error rates (percentage of missed letters).

Participants

As described in Experiment 3.

Materials

The stimulus sets used in this experiment comprised three sheets of A4 paper on which were printed grids measuring 176mm x 196mm. Each grid contained 25 rows x 25 columns of the uppercase letters *A, B, C, G, I, J, L, P, Q,* and *S* printed in 18pt Arial font (see Appendix). The letters were pseudo randomly presented with the provisos that (i) no two identical letters appear adjacent to one another, and that (ii) the total number of target letters equalled 120. Thus, each grid comprised 120 targets and 505 distractors.

At the top of each page an example of the target letter(s) were displayed in a separate box as a reminder to participants of the particular letter(s) that had to be located. On the first page, the letter *G* was the target, on the second page the letters *J* and *C* were targets, and on the third page the letters *I, A,* and *P* were the targets. Participants were also given a felt pen, known as a 'Bingo dabber' with which to mark each instance of the target letter(s).

Procedure

All participants were tested individually and performed the letter cancellation task in the following order: target set size 1, 2, and 3. Participants were seated at a desk and given standardized verbal instructions. The experimenter informed participants that the task was designed to measure their ability to pick out letter targets from distractors. Participants were told that the experiment comprised three one-minute tasks and that the instructions for each task were the same. The experimenter then placed an exemplar form in front of the participant and said "Here you see a row of letters. Your task is to find the letter or letters that appear at the top of the page. Each time you find the letter(s) I want you to cross it out with a felt pen like this (experimenter demonstrates a single 'dab' with the felt pen over the letter). Every time you see the letter(s) cross it out. I want you to work as quickly and as accurately as you can. You should cancel all instances of the letter(s) but no other letter(s). Please start with the first row and work across the page from left to right. When you are finished go straight on to the next row until the buzzer sounds at which point you should put down your pen and wait to begin the next test". The experimenter then asked the participant if she or he had any questions or was ready to begin the test. When the participant was ready, the experimenter placed the first Trial 1 grid in front of the participant and said 'Go'. The experimenter started an electronic timer that counted down from 60 seconds at which point a buzzer sounded and the participant put down his or her pen. The Trial 2 grid and Trial 3 grid were administered in exactly the same manner after allowing the participant a brief intermission.

Results and Discussion

The design of the present study allowed two analyses to be conducted. First, response speed was examined by calculating the number of target letters cancelled by each participant for each set size within the designated time. The mean percentage of cancelled letters was collated for all participants and a 2 (Age Group) x 2 (Bingo) x 3 (Set Size) mixed design ANOVAs was performed on the data. Following this, error rate was examined by calculating the number of target letters missed by each participant for each set size within the designated time. The mean percentage of missed target letters was collated for all participants and a 2 (Age Group) x 2 (Bingo) x 3 (Set Size) mixed design ANOVA was performed on the data. For both analyses, the between-subject factors were Age Group and Bingo and the within-subject factor was target Set Size. Further, for both analyses the alpha value was set at .05

Response Speed Data

Table 9.1. Mean percentage of cancelled target letters (with their standard deviations) for set sizes 1, 2, and 3 across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	45.83	(3.65)	28	53.96	(5.18)	28
2	31.70	(3.98)	28	39.05	(4.75)	28
3	36.73	(4.56)	28	44.38	(6.21)	28
Older						
1	39.76	(4.45)	28	48.18	(6.24)	28
2	27.86	(4.49)	28	33.84	(6.48)	28
3	32.23	(5.13)	28	37.86	(7.56)	28

The descriptive data presented in Table 9.1 and in Figure 9.1 illustrate that participants cancelled fewer letters within the allotted time at Set Sizes two and three than at Set Size one, producing a significant main effect of Set Size, $F(2, 216) = 1064.75$, $p < .01$.

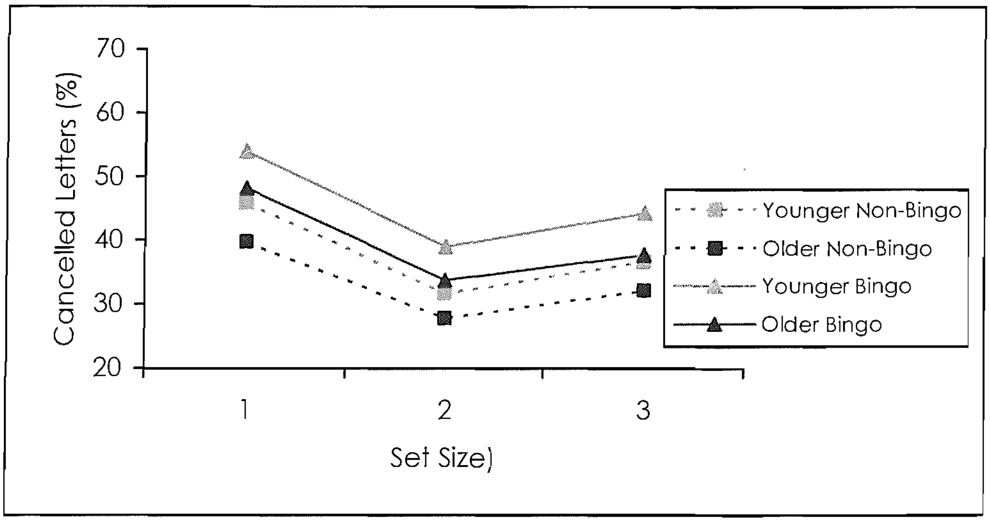

Figure 9.1. *Mean percentage of letters cancelled for set sizes 1, 3, and 5 as a function of Bingo and age.*

Interestingly, the data also suggest that this decrease in cancellation of letters with set size was not linear since all participant groups cancelled more target letters at set size 2 than they did at set size 3. Subsequent questioning of participants revealed that they experienced great difficulty in searching for the designated target letters at set size 2 (J and C); more difficulty in fact than they experienced searching for any of the digit targets or the three letter targets. The most likely explanation for participants' difficulty with this set size is that the letters 'C' and 'G' are easily confused with one another. Indeed, with the exception of the tail of the letter 'G' both letters share the same features. Conversely, digits share less featural similarity. Support for this explanation comes from a study by van der Heijden, Malhas, and van den Roovaart (1984) that examined the confusability of uppercase English letters. Each letter of the alphabet was presented 1,200 times and the proportion of times that a stimulus letter was identified as a response letter was recorded in a confusion matrix. The proportion of times that the letter *G* was given in response to the stimulus letter *C* was .101. Conversely, the proportion of times that the letter *C* was given in response to the stimulus letter *G* was .05. These proportions were only surpassed by the letters *E* (confused with *F* .183) and *L* (confused with *I* .147). Conversely, the proportion of times the letter *A* was given in response to letter *V* was .001. Such a result could explain why participants did not report any difficulty in searching for the target letter *G* in the set size 1 condition. It is extremely difficult to select target letters that differ both visually and phonetically.

In contrast to the results reported in the digit cancellation task the main effect of Set Size interacted with that of Bingo, $F(2, 216) = 4.72$, $p < .05$. It appears that the advantage for Bingo players might be slightly stronger at set size one than at the other set sizes; although the difference is very small (see Figure 9.2).

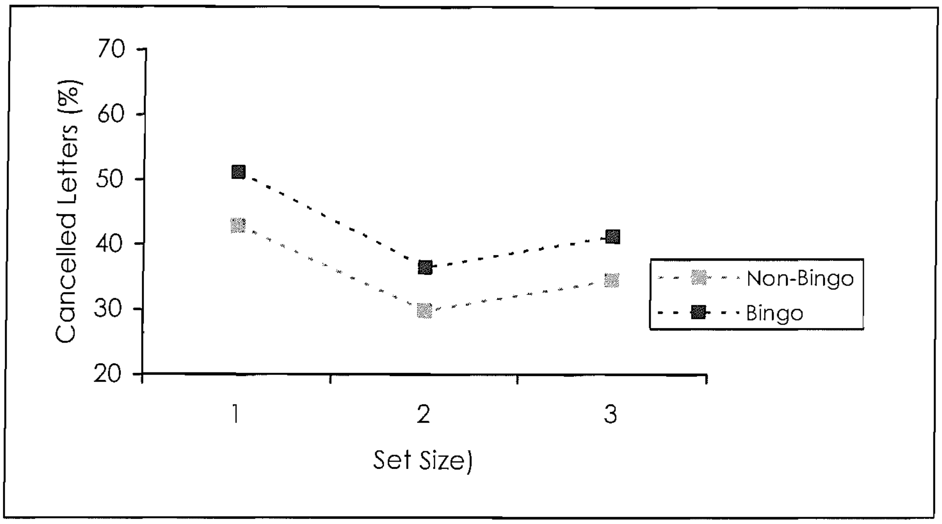

Figure 9.2. Mean percentage of letters cancelled at set sizes 1, 3 and 5 as a function of Bingo.

The finding that Bingo especially improved performance at the smallest set size provides more support for the proposal that Bingo players are particularly efficient at searching for a single target, and perhaps even more importantly, suggests that it is not necessary for the single target to be a digit. However, in this task, unlike in the digit cancellation task, it is not clear whether there is a different pattern of performance across set size for either the younger and older Bingo players or the younger and older non-Bingo players as any such pattern has been obscured by the previously discussed confound occurring at set size 2. Further research should be conducted using more easily distinguishable letter targets at set size 2.

Despite the effects of the particular stimulus letters, this experiment shows that Bingo positively affected performance, $F(1,108) = 57.80$, $p < .01$. Such a result suggests some degree of skill generalisation or positive transfer. The skilled visual search for digits that has been acquired by Bingo players following extended practice is enhancing performance of visual search for a different stimulus. This finding is especially important considering the lack of evidence supporting the transference of skill outside a specific domain (Ericsson & Charness, 1994). Much of the research investigating the extent to which practice on one skill can improve or maintain performance on other similar skills has tended to examine skills that are more complex than Bingo, for example, crossword solving skills (see Hambrook, Salthouse, & Meinz, 1999). Hence, the measures that are used to evaluate skill transference also tend to be more complex, such as measures of general problem solving ability. Conversely, the skills underlying the game of Bingo can be more easily specified, at least at the level of visual search. Thus, it is possible to measure the extent of skill transference at a very simple and specific level. An added advantage of this method is that measures can be developed that gradually move away from the domain-specificity of the skill, thus, ascertaining the point at which the skill no longer transfers.

However, the finding that the skilled visual search acquired by Bingo players transfers to visual search outside of the specific domain of search for digits should be interpreted with caution, as Bingo players might be more likely to engage in other activities involving letter search than non-Bingo players. For instance, a number of both the younger and older Bingo players listed 'word search' as an additional regular activity to Bingo. Yet, many of the non-Bingo players, especially the older non-Bingo players also listed word-search, scrabble, or crossword puzzles as activities that they performed on a regular basis. Further experimentation could be conducted including the additional variable of participants' experience with search activities involving letter stimuli.

Older participants, however, cancelled fewer target letters overall than younger participants producing a significant main effect of Age Group, $F(1, 108) = 31.59$, $p < .01$. Moreover, the factor of Age Group did not interact significantly with that of Bingo, $F < 1$, nor with Bingo and Set Size, $F(2, 216) = 1.93$, $p > .05$, suggesting that the negative effects of age uniformly affect Bingo and non-Bingo players.

Error Rate Data

Table 9.2. Mean percentage of missed letters (with their standard deviations) at set sizes 1, 3, and 5 across all participants.

		Non-Bingo			Bingo	
Set Size	Mean	(SD)	N	Mean	(SD)	N
Younger						
1	1.22	(1.37)	28	.65	(1.02)	28
2	1.34	(1.39)	28	.92	(1.23)	28
3	2.14	(1.81)	28	1.07	(1.50)	28
Older						
1	.92	(1.12)	28	.30	(.61)	28
2	3.10	(2.53)	28	1.16	(1.35)	28
3	3.39	(2.53)	28	1.37	(1.54)	28

The descriptive data presented above in Table 9.2 and in Figure 9.3 illustrate that as with the response time data, Bingo positively affected performance on this measure, $F(1,108) = 22.33$, $p < .01$. That is, Bingo players missed fewer target letters overall than non-Bingo players. The number of target letters missed by participants also increased significantly with Set Size, $F(2, 216) = 28.99$, $p < .01$. Moreover, as Figure 9.3 shows, the pattern of missed target letters is different for non-Bingo players and Bingo players in that non-Bingo players exhibit steeper increases in the number of missed target letters with set size, $F(2, 216) = 4.26$, $p < .05$.

Moreover, comparing the difference in slope for each group across set size, it is apparent that set size is not affecting older participants in the same way that it is affecting younger participants, $F(2, 216) = 4.26$, $p < .01$. However, although the data displayed below in Figure 9.3 suggests that older non-Bingo players missed a greater number of letters at the larger set sizes than did the other three groups, the three-way interaction between Set Size, Age Group and Bingo did not attain significance, $F(2, 216) = 2.497$, $p = .085$.

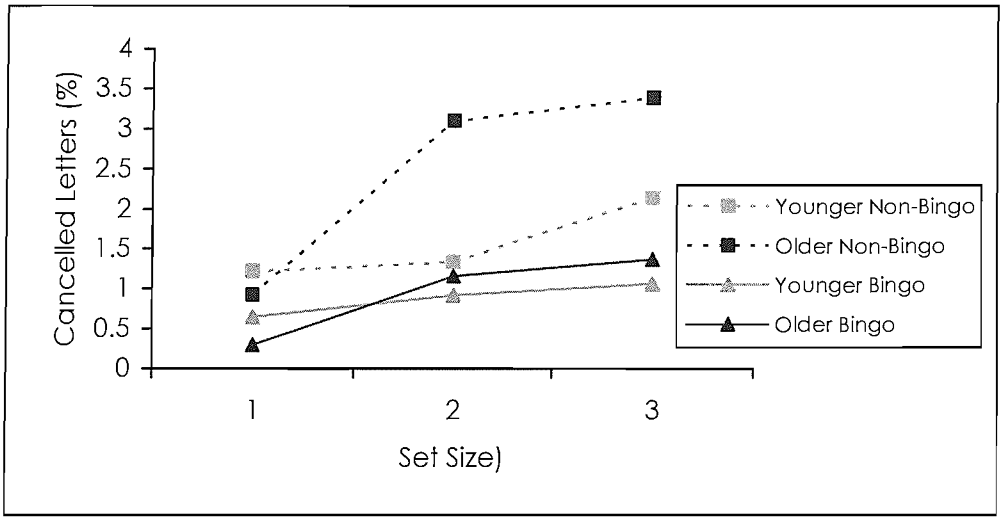

Figure 9.3. Mean percentage of missed digits at set sizes 1, 3, and 5 as a function of Bingo and age group.

Summary of Results

Analysis of both response times and error rates demonstrated significant differences in the performance of Bingo and non-Bingo players on this task with Bingo players demonstrating superior performance both in terms of the number of letters cancelled within the allotted time and in the number of errors made. Further, the lack of a significant interaction between Age Group and Bingo for the response time data suggest that age is affecting both older Bingo and non-Bingo players in the same way, although as in the digit cancellation task, older Bingo players cancelled more letters within the allotted time than both younger non-Bingo players and older non-Bingo players. The confounding variable occurring at set size two, however, makes it impossible to determine the effects of Bingo and Age Group on Set Size. The error rate data, in accordance with the results of the digit cancellation task, demonstrates that Bingo players missed fewer target letters than non-Bingo players. However, unlike in the previous experiment, older Bingo players missed more letter targets overall than their younger Bingo playing counterparts. Importantly, though, older non-Bingo players missed more target letters in comparison with the other three groups. Further, this difference in performance is especially apparent at set size two where participants reported search being particularly difficult for the target letter 'C'.

General Discussion

The purpose of the present experiment was to assess whether one of the elementary cognitive processes underlying the game of Bingo, namely the perceptual skill of visual search would transfer to a different stimulus class such as letters. Unlike the transfer task of symbol-search utilised in Experiment 2, the current experiment did not include any of the contextual information that was available to participants in the Symbol search experiment. Thus, Bingo players could not employ the search strategies used in Bingo search as there were no contextual cues as to the location of the target letters. Moreover, the Bingo players used in the present experiment have not had the same amount of practice at searching for letter stimuli as they have experienced for digit stimuli. However, the anecdotal evidence above suggests that Bingo players are more likely to engage in activities such as word search than non-Bingo players.

The results reported from the analyses of variance suggest that Bingo facilitates players' performance at visual search for letter targets in terms of both the speed with which they are able to search and locate targets and the accuracy with which they are able to carry out the task. Perhaps more importantly, these findings suggest that Bingo players' skilled visual search ability for target digits might be transferred to at least one other stimulus category, namely, letters. However, the extent of transference cannot be answered by the results of this study. Neither can a cause and effect relationship be established due to the quasi-experimental design used in this experiment. Further research should be conducted using stimuli that are not as familiar to either Bingo players or non-Bingo players. The symbol stimuli used in Experiment 2, for example, could be integrated into a general search task. In addition to providing evidence as to the degree of skill transference, such a manipulation would also help reduce or eliminate the confounding variables of stimulus familiarity and target confusability that are present in the current study. For instance, participants are likely to have less experience in searching for symbols than they have experience in searching for letters. Moreover, it should be possible to design shape stimuli that are not as easily confused as letter stimuli.

Importantly, the data reported in the present experiment suggest that age is negatively affecting performance on this task, thus providing no support here for the maintenance or remediation hypothesis of ageing (for a review see Bosman & Charness, 1996). However, it is not clear whether the pattern of performance exhibited by older Bingo players across set size is the same for younger Bingo players because of the confounding variable occurring at set size two. The older Bingo players made more errors on this task than their younger counterparts contrary to the results reported in the digit cancellation task, suggesting that the search for letter targets by older Bingo players is not as proficient as their search for digit targets.

So far the experiments presented in this thesis have focussed mainly on domain-specific tasks. It is important to assess both the Bingo and non-Bingo players' performance on more general tests of perceptual speed, memory, and also verbal ability so that group differences can be explored. The following chapter therefore utilises a number of measures often used within the area of psychometric research to assess participants' fluid and crystallised ability.

CHAPTER TEN

EXPERIMENT 6: PEN & PAPER TASKS OF PERCEPTUAL SPEED, SHORT-TERM MEMORY, WORKING MEMORY, AND VERBAL ABILITY

Introduction

The previous experimental chapters reported in this thesis have focussed primarily on the domain-specific abilities of Bingo players and the transfer of these to tasks comprising either different rules or different stimuli. However, it is important to examine whether differences exist between younger and older Bingo and non-Bingo players on more general tests of perceptual speed and memory as differences in performance on these measures have been found to predict performance on more general intellectual abilities. Further, as all the tests administered to participants so far have measured performance on fluid abilities it is also pertinent to consider whether Bingo and non-Bingo players differ on a measure of crystallised performance such as verbal ability. Thus, the administration of such tests will create a more detailed picture of the overall abilities possessed by Bingo and non-Bingo players. The results from these tests will also establish whether age-related declines in performance are the same for both older Bingo and older non-Bingo players. This experimental chapter therefore utilises a number of measures often used within the area of psychometric research to assess participants' fluid and crystallised abilities.

Digit Symbol Substitution

As discussed in Chapter 2, one of the predominant theories of cognitive ageing is that of a general reduction in information processing speed (e.g. Birren, 1965; Salthouse, 1991; 1996). Birren (1965) argued that a decrease in the speed that elementary processes are carried out is solely responsible for the age-related variance found in performance of older adults on measures of cognitive ability. Subsequently, Salthouse (1991, 1996) accumulated a large body of evidence in support of this theory from the results of a number of pen and paper tasks that were designed to assess perceptual speed. Essentially, these tasks require participants to make speeded perceptual judgements by comparing, for example, pairs of digits, letter strings or substituting digits for a specified symbol. The performance measure referred to as rate of processing is taken as the number of correctly completed items within a designated amount of time (varying from one to three minutes). Salthouse suggests that much of the age-related variance found on perceptual and cognitive tasks can be explained with the knowledge of a participant's rate of processing. For instance, when the factor of rate of processing is statistically controlled for, many of the age-differences in performance reported on working memory tasks are significantly reduced.

The Digit-Symbol Substitution Test (DSST) is one such measure of perceptual-cognitive speed. The DSST forms one of the subtests of the Weschler Adult Intelligence Scale (WAIS; Wechsler, 1955), and the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). Moreover, of all the different measures of perceptual speed available, the DSST has reported the strongest correlation between speed and intelligence (Wechsler, 1955). Importantly, experiments utilising the DSST have reported reliable and significant negative correlations with age (e.g. Birren & Morrison, 1961; Salthouse, 1992, 1993).

Numerous versions of substitution tests have been created that differ in terms of (a) the nature of the stimulus items (e.g. digits, and symbols), (b) the arrangement of the code table and the probe items, and (c) the type of response that is required. The goal of the task, however, remains the same, namely, to use the code table to determine which response item is associated with the stimulus item in the top box, and then write it in the bottom box as quickly as possible. Piccinin and Rabbitt (1999) have proposed that participants undertake a number of different actions while completing a DSST. For instance, the probe (e.g. digit or letter) to be decoded must be identified and held in memory while the participant locates it in the top box which contains the code table. The correct response item (e.g. symbol) must then be determined and held in working memory while the participant locates the original probe in the bottom box. Finally, the response item is written underneath the correct probe.

A number of researchers have offered suggestions as to what the DSST measures. For instance, Thorndyke (1926) proposes that the test measures an individual's ability to learn. Certainly, as the test progresses and participants become more familiar with the digit-symbol pairs there is likelihood that these associations will be assimilated in memory. Bromley (1974) on the other hand suggests that the DSST assesses translation ability. Indeed, the coding and subsequent translation of the digit into the associated symbol is a requirement of the task. However, Salthouse (1992) reported that while a large amount of the age-related variance found on tests of digit-symbol substitution could be accounted for by controlling for perceptual comparison speed, a substantial amount of the age-related variance on the DSST can be explained by working memory ability. Indeed, Lindenberger, Mayr, & Kliegl (1993) argue that the DSST is not a pure measure of speed but rather comprises a number of different processes such as motor persistence, sustained and selective attention, perceptual comparison speed and hand-eye co-ordination. In other words, the DSST employs many of the skills used in Bingo search. The DSST thus provides a convenient means of testing a number of the skills used in the game of Bingo in a domain-general way.

Method

Design

This experiment employed a 2 x 2 between-subjects design with factors of Bingo (non-Bingo player/Bingo player) and Age Group (younger/older). Performance was measured by calculating the number of correctly completed digit-symbol pairs within ninety seconds.

Participants

As described in Experiment 3.

Materials

The Digit Symbol Substitution Test from the Wechsler Adult Intelligence Scale-Revised (1981) is a paper-and-pencil test consisting of a 2 row x 9 column code table at the top of the page. The top row of the table comprises the digits 1 to 9 and the bottom row contains nine symbols. Thus, each digit has a corresponding symbol below it. Underneath the code table are printed four rows of boxes containing 100 digits (not in numerical order) with an empty box underneath each one. Test-retest reliability for the digit-symbol substitution test is .82 (Wechsler, 1981).

Procedure

All participants were tested individually. The test sheet was placed in front of participants on a desk with a smooth surface and standardized verbal instructions were given. Participants were first told to attend to the code table at the top of the page. It was explained that each number has its own symbol underneath it. Participants were then directed to look at the four rows of numbers with empty boxes underneath them. It was explained that the task was to put the corresponding symbol underneath each number. The experimenter then demonstrated the task by filling in the first three items. Participants were then instructed to practice the task by filling in the next four boxes after which point a thick line separated the seventh and eighth box. The test did not proceed until the practice items had been filled in correctly and participants fully understood the task. On successful completion of the practice items participants were instructed that on the experimenter's command, the word *GO*, they were to continue filling in the boxes one after the other, without missing any out, until they were told to stop. Participants were advised that both speed and accuracy were equally important and that when they had completed one row they should continue on to the next row beginning again at the left-hand side. Participants were given 90 seconds to fill in as many boxes as they could. At the end of the 90 seconds, the experimenter gave the verbal command *stop*. One point was allotted for each item filled in correctly with a maximum score of ninety-three.

Results and Discussion

The mean number of correct digit symbol pairs completed within the 90-second time limit (excluding the seven practice pairs) was calculated for all groups and are presented in Table 10.1 below along with their standard deviations.

A between–subjects 2 (Age Group) x 2 (Bingo) analysis of variance was then conducted on the data. For all analyses the Alpha value was set at 0.05.

Table 10.1. Mean number of correctly substituted digit symbol pairs (with their standard deviations) for younger and older Bingo and non-Bingo players.

	Non-Bingo			Bingo		
Age Group	Mean	(SD)	N	Mean	(SD)	N
Younger	66.04	(6.13)	28	56.82	(9.84)	28
Older	45.96	(7.14)	28	43.96	(11.90)	28

The descriptive data presented in Table 10.1 and in Figure 10.1 illustrate that younger participants correctly completed more digit-symbol pairs than older participants within the allotted time, $F(1, 108) = 92.89$, $p < .01$. Further, the data also suggest that non-Bingo players correctly completed more digit-symbol pairs overall than Bingo players. Indeed, this was confirmed by a significant main effect of Bingo, $F(1, 108) = 10.77$, $p < .01$. In addition, these two factors interacted significantly, $F(1, 108) = 4.46$, $p < .05$, and it can be seen from looking at the data displayed in Figure 10.1 that the younger non-Bingo players correctly completed significantly more digit-symbol pairs than the younger Bingo players. However, performance is uniformly low for both the older non-Bingo and Bingo players.

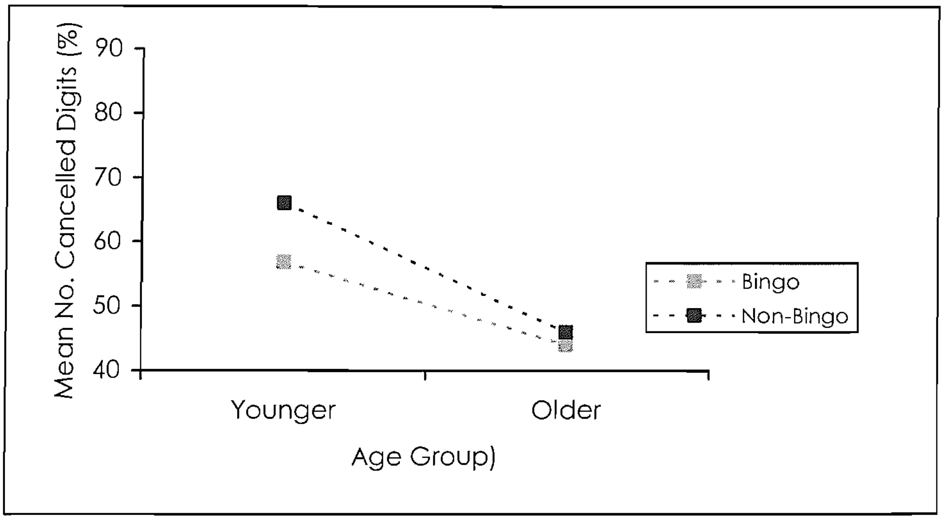

Figure 10.1. Mean number of correctly completed digit-symbol pairs as a function of age and Bingo.

One possible explanation for this pattern of results is that the skills used in Bingo are not employed in this particular task. Alternatively, however, the superior performance of the younger-non Bingo players could have occurred because an age-matched sample of the younger age group was not obtained. That is, the age range of the younger non-Bingo players was 18-21 whereas the age range of the younger Bingo players was 22-40. The age range of the older participants was more closely matched; non-Bingo players' ages ranged from 60 to 78 years, and older Bingo players' ages ranged from 60 to 81 years. Moreover, most of the younger non-Bingo players were undergraduate students and therefore in full time education, whereas all of the younger Bingo players had left school. Thus, it is possible that since the younger non-Bingo players have left school they have had no experience on this type of test. Indeed, Salthouse (1990) suggests that most novel tasks are carried out during school years.

There were also differences in education level between the younger non-Bingo players and the younger Bingo players, with the younger non-Bingo players averaging more years of education. It may also be the case that the younger non-Bingo players, as well as having more education than the younger Bingo players, are more used to performing novel tasks. Further research could perhaps examine the effects of Bingo and Age group on a different version of the DSST, for example, the Symbol Digit Modalities Test (SDMT) developed by Smith (1968, 1973). Unlike the DSST which requires participants to decode digits and translate them into unfamiliar symbols, the SDMT reverses the presentation so that participants are able to execute the more familiar response of writing a digit. In addition, a baseline measure of participants' speed at writing digits could be taken so that the motor response component of the task could be controlled for.

Finally, although there was no significant difference in the number of correctly completed digit symbol pairs by older non-Bingo players and older Bingo players, the older non-Bingo players have had more years of education than the older Bingo players.

In summary, the results of the digit-symbol substitution task revealed no benefits of playing Bingo. Moreover, the performance of the younger Bingo players was impaired in comparison with their non-Bingo playing counterparts. In accordance with the research carried out by Birren & Morrison (1961) and Salthouse (1992, 1993) age was found to negatively affect performance on this task.

As mentioned earlier the digit-symbol task comprises more than one perceptual-cognitive skill. Thus, it may be useful to explore one of the components of the task in isolation from the others. The next experiment to be reported therefore is a test of participants' immediate and working memory.

Forward and Backward Digit Span

The Digit Span test is a sub-test of both the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981) and the Wechsler Memory Scale-Revised-III (1987). The Digit Span test is made up of two separate test components. The first is the Digits Forward test and the second is the Digits Backward Test. Performance on each test depends on a separate set of cognitive processes. Both tests comprise seven pairs of random digit strings ascending in length from four digits for the Digits Forward test and from two Digits for the Digits Backward test. The mode of presentation is verbal and therefore auditory attention is a requirement of this task (Lezak, 1983). It has also been suggested that the Digits Forward test measures the efficiency of attentional processes rather than memory (Spitz, 1972). Hayslip and Kennelly (1980) refer to the Digits

Forward test as measure of *passive span of attention.* Results from the Digits Forward test have reported relatively little impairment with increasing age (e.g. Botwinick & Storandt, 1974). Conversely, backward digit span has been reported to reduce significantly in older adulthood (Hayslip & Kennely, 1980). The Digits Backward test requires participants to maintain the digit strings in memory while simultaneously manipulating them so that they can be repeated back to the experimenter in reverse order. Thus, the Digits Backward task measures the more effortful ability of working memory. As previously mentioned in Chapter 2, working memory capacity exhibits a reliable decline as age increases (e.g. Craik & Byrd, 1982; Park, 2000). Further, working memory has been found to affect performance on a wide variety of cognitive tasks including non-memory tasks (Salthouse, 1991).

The present experiment administered the Digits Forward and Digits Backward test as per the instructions contained within the handbook of the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981). However, because the two components of the test tap into different cognitive processes they were not combined to produce an overall score as suggested in the WAIS manual. Instead, a separate score was calculated for the Digits Forward test and the Digits Backward test so that the effects of Bingo and Age Group on the elementary cognitive processes underlying these two tests could be examined.

Method

Design

This experiment employed a 2 x 2 between-subjects design with factors of Bingo (non-Bingo player/Bingo player) and Age Group (younger/older). Performance was measured by calculating the mean number of correctly repeated forward digit strings and the mean number of correctly repeated backward digit strings.

Participants

As described in Experiment 3.

Materials

The Digit Span Test, a sub-test of the Wechsler Adult Intelligence Scale-Revised (1981) comprises two parts – Digits Forward and Digits Backward. Both parts consist of seven verbally presented items; an item is made up of two digit strings 3 to 9 digits in length (totalling two digit strings of each length). Thus, item one = 2 x 3-digit strings, item two = 2 x 4-digit strings, etc. A record sheet is used to document correct and incorrect recall of the items.

Procedure

The two parts of the Digit Span Test were administered separately. First, the Digits Forward Test was administered. The experimenter informed participants that they were to be read aloud some numbers and that they should listen carefully as they would be asked to repeat them afterwards. The digits were read aloud at the rate of one per second with the pitch of the voice dropping on the last digit of each trial indicating the end of the string. The participant then repeated the string back to the experimenter. Both trials of each item were administered even if the participant correctly repeated trial 1. However, the test was discontinued after failure on both trials of any item. Second, the Digits Backward Test was administered. The experimenter informed participants that they were to be read aloud some more numbers, but that this time they would be required to repeat them in reverse order. The experimenter then gave an example of the test by reading the digits 7-1-9 and asking the participant to repeat them in reverse order. If the participant answered correctly, the experimenter proceeded with the test. However, if the participant answered incorrectly, the experimenter gave the correct version and then administered another practice trial. If the participant failed this trial however, the experimenter continued with the test without further correction. As in the Digit Forward Test, both trials of each item were administered even if the participant correctly repeated trial 1, and the test was discontinued after failure on both trials of any item.

The experimenter recorded the scores for each test on the record sheet by giving 2 points if the participant passed both trials, 1 point if the participant only passed one trial and 0 points if the participant failed both trials. The maximum score for each test was 14 points.

Results and Discussion

The mean number of correct forward and backward digit strings recalled by participants along with their standard deviations was calculated and presented in Table 10.2 below. In addition the combined mean number of correct forward and backward digit strings was then calculated for all participants.

Two separate 2 (Bingo) x 2 (Age) between-subject ANOVAs were then performed, one on the data for the forward digit strings and one on the data for the backward digit strings.

The descriptive data presented in Table 10.2 indicate that younger participants correctly recalled more forward digit strings than older participants. This was confirmed by a significant main effect of Age, $F(1, 108) = 32.14$, $p < .01$.

Table 10.2. Mean number of correctly recalled forward and backward digit strings (with their standard deviations) across all participants.

	Non-Bingo			Bingo		
Forward Digits	Mean	(SD)	N	Mean	(SD)	N
Younger	9.43	(2.19)	28	8.50	(1.07)	28
Older	8.21	(1.60)	28	7.57	(1.69)	28
Backward Digits						
Younger	6.79	(1.83)	28	5.96	(1.04)	28
Older	5.75	(1.01)	28	5.75	(1.71)	28

The results also revealed a significant main effect of Bingo, $F(1, 108) = 6.11$, $p < .05$, with non-Bingo players correctly repeating more forward digit strings than Bingo players. However, there was no significant interaction between the factors of Age group and Bingo, $F < 1$, suggesting that age similarly affects the performance of both non-Bingo and Bingo players (see Figure 10.2).

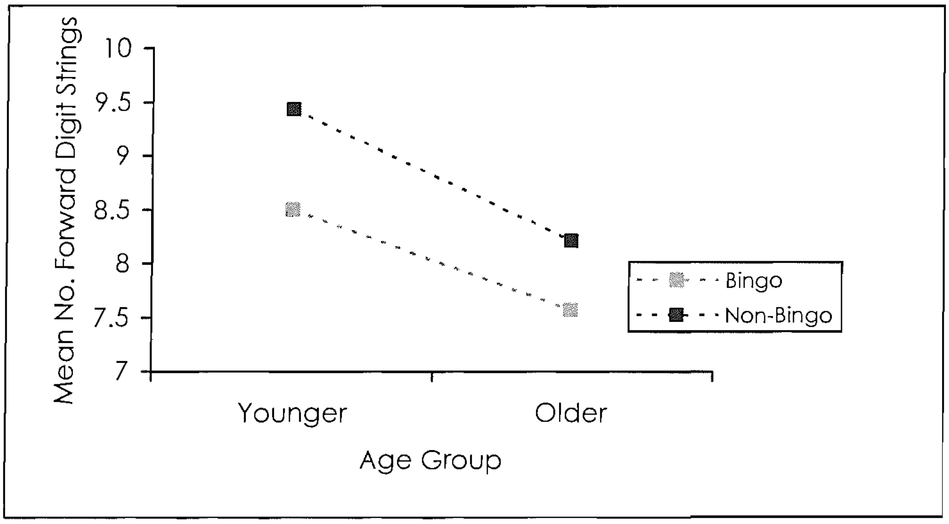

Figure 10.2. Mean number of correctly recalled forward digit strings as a function of age and Bingo.

The descriptive data presented in both Table 10.2 and in Figure 10.3 indicate that as in the forward digit condition younger participants recalled more correct backward digit strings than older participants. This was confirmed by a significant main effect of Age Group, $F(1, 108) = 5.22$, $p < .05$.

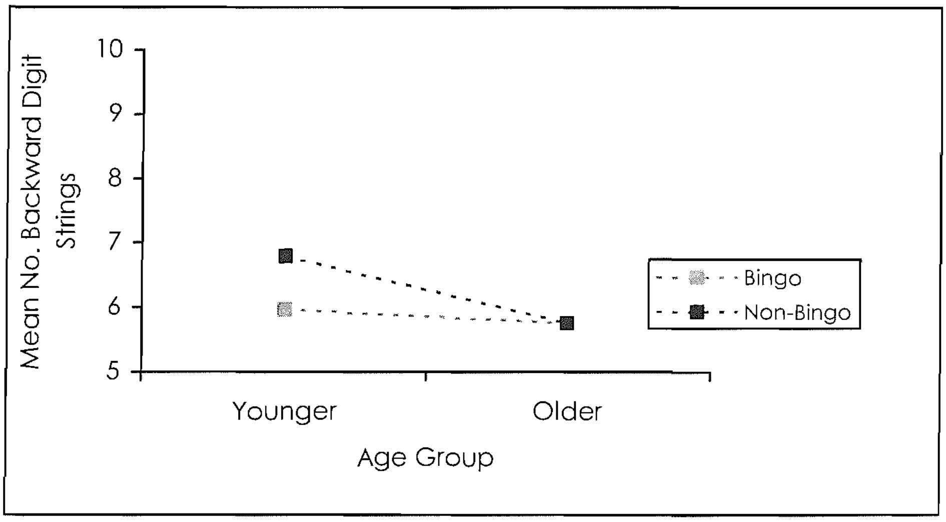

Figure 10.3. Mean number of correctly recalled backward digit strings as a function of age and Bingo.

The data also suggest a difference in the number of backward digit strings correctly recalled by non-Bingo players and Bingo players. However, the main effect of Bingo did not attain significance, $F(1, 108) = 2.26$, $p > .05$. There was also no significant interaction between the number of backward digit strings correctly recalled by younger and older Bingo and Non-Bingo players, $F(1, 108) = 2.26$, $p > .05$.

In summary, the data suggest that Bingo does not improve performance on the digit span task. There are several possible explanations for this result. Firstly, as discussed, the age range of the younger non-Bingo players was much lower than that of the younger Bingo players. This discrepancy in age range between age groups might therefore have biased the results in favour of the younger non-Bingo players.

Secondly, subsequent questioning of both younger and older Bingo players revealed that when they play Bingo, they tend to look at the numbers that are presented on the television screens instead of listening to the Bingo caller. That is, they prefer the visual modality as the method of presentation. However, the digit strings in the current experiment were presented verbally. Thus, it is possible that any effects of playing Bingo on digit span performance are modality specific. Two manipulations of the current experiment that could test this hypothesis are: (1) repeating the digit span task but with visual instead of verbal presentation of digits, and (2) recruiting a group of Bingo players who listen to the Bingo caller when playing rather than watch the television screens. The argument for modality specificity is supported by the results of the visual-memory scanning task reported in Chapter 7. Both younger and older Bingo players were more accurate at this task than non-Bingo players. Importantly, the Sternberg task uses a visual mode of presentation. The Sternberg task is also similar to the final stages of a Bingo game, in which the player should have in memory a few numbers in no particular order. The Digit Span task requires that they remember not only the digits, but also the order they are in. This seems to make a big difference to the performance of Bingo players.

Finally, research has found that both the Digits Forward test and the Digits Backward test are affected by an individual's educational level (e.g. Botwinick & Storandt, 1974) with persons of a higher education background scoring higher on these tests. As previously mentioned in the discussion of the digit-symbol substitution test, there are differences in level of education between both the younger and older Bingo and non-Bingo participant groups. It is therefore, possible that the variable of education is confounding any potential effects of Bingo. Further research should ensure that participant groups are matched for educational level.

Thus far, this thesis has examined performance differences on measures of fluid ability of older and younger Bingo and non-Bingo players. This is justified as the game of Bingo comprises mainly such abilities. However, a more complete picture of the abilities of Bingo players can be achieved by administering one of the most widely used tests of verbal and therefore crystallised ability.

National Adult Reading Test (NART)

The National Adult Reading Test (NART) second edition devised by Nelson (1982) is used to measure prior verbal ability as an element of crystallized intelligence. As outlined by Crawford, Deary, Starr and Whalley (2001), the development of the NART stemmed from the belief that there is a positive relationship between reading ability and overall intelligence level. Indeed, Crawford (1992) reported a correlation between the NART and the WAIS-R of .72. The NART comprises fifty seldom used words of irregular pronunciation and participants are required to read the list of words aloud. Thus, the NART depends on previously stored knowledge, as the words that are selected do not sound the way they look preventing the participant from applying normal phonetic rules.

As previously mentioned, crystallised and fluid intelligence are differentially affected by the ageing process in that fluid abilities are particularly sensitive to age, whereas crystallised abilities tend to remain stable or even improve with age (for a review see Schaie, 1996). The NART therefore provides an opportunity to examine both the overall reading and hence intellectual ability of Bingo and non-Bingo players and also presents a means of measuring age differences in a cognitive ability not utilised in the game of Bingo.

Method

Design

This experiment employed a 2 x 2 between-subjects design with factors of Bingo (non-Bingo player/Bingo player) and Age Group (younger/older). Performance was measured by calculating the mean number of incorrectly pronounced words.

Participants

As described in Experiment 3.

Materials

The National Adult Reading Test (NART) Second Edition (Nelson, 1982) comprises two columns of 25 short words printed in order of increasing difficulty. The NART Word Card is given to participants to read aloud from and the experimenter documents errors on the NART Answer Sheet.

Procedure

The NART word card was given to participants along with standardized verbal instructions. Participants were asked to read aloud slowly down the list of words starting with the top left word (the word ACHE). They were told to read slowly, pausing after each word until the experimenter indicated they should continue by saying the word 'next'. This gave the experimenter time to mark a response as correct or incorrect on the NART Answer Sheet. Participants were informed that there would be many words that they probably would not know, and that, in fact, most people would not know them, but that they should just have a guess at these. The experimenter then instructed participants to start reading the list. Participants were encouraged to attempt every word and their responses were reinforced with the words "that's fine" or "good". No time limit was imposed. If the participants showed any signs of anxiety during the reading of the word-list they were reassured that they are not expected to know all of the words and that the experimenter herself did not know them all when she first saw them.

The NART error score is the total number of errors made on the complete NART.

Results and Discussion

The mean numbers of errors made on the NART were calculated for all participants and are presented in Table 10.3 below. A 2 (Age) x 2 (Bingo) between-subjects ANOVA was then performed on the data.

Table 10.3. Mean number of NART errors (with their standard deviations) across all participants.

	Non-Bingo			Bingo		
Age Group	Mean	(SD)	N	Mean	(SD)	N
Younger	14.46	(5.24)	28	23.71	(7.07)	28
Older	8.00	(5.23)	28	17.50	(7.41)	28

The descriptive data presented in Table 10.3 above and in Figure 10.4 below indicate that younger participants made more errors on the NART than older participants. This was confirmed by a significant main effect of Age Group, $F(1, 108) = 28.20$, p <

.01. Moreover, Bingo players generated more errors on the NART than non-Bingo players, $F(1, 108) = 61.67$, $p < .01$.

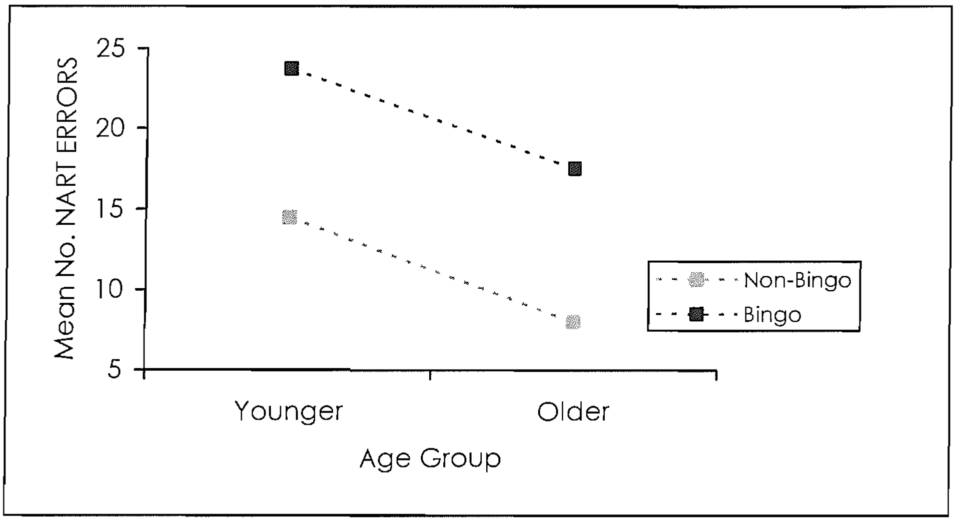

Figure 10.4. Mean number of NART errors as a function of age and Bingo.

It appears that age uniformly affects the performance of non-Bingo players and Bingo players on this task as there was no significant interaction between the factors of Age Group and Bingo, $F < 1$.

In an attempt to explain the results of the NART, a two-way analysis of variance was performed on the mean number of years of education for both younger and older Bingo and non-Bingo players. This analysis was carried out because the NART is a test of verbal ability and is also purported to predict IQ.

The data presented in Figure 10.5 illustrate that Bingo players in this study have received significantly fewer years of education than non-Bingo players, $F(1, 108) = 103.74$, $p < .01$. Further, the older participants have spent fewer years in education than the younger participants, $F(1, 108) = 132.24$, $p < .01$. There is also a significant interaction between the factors of age group and Bingo, $F(1, 108) = 28.80$, $p < .01$, with younger Bingo players in particular receiving fewer years of education in comparison with younger non-Bingo players.

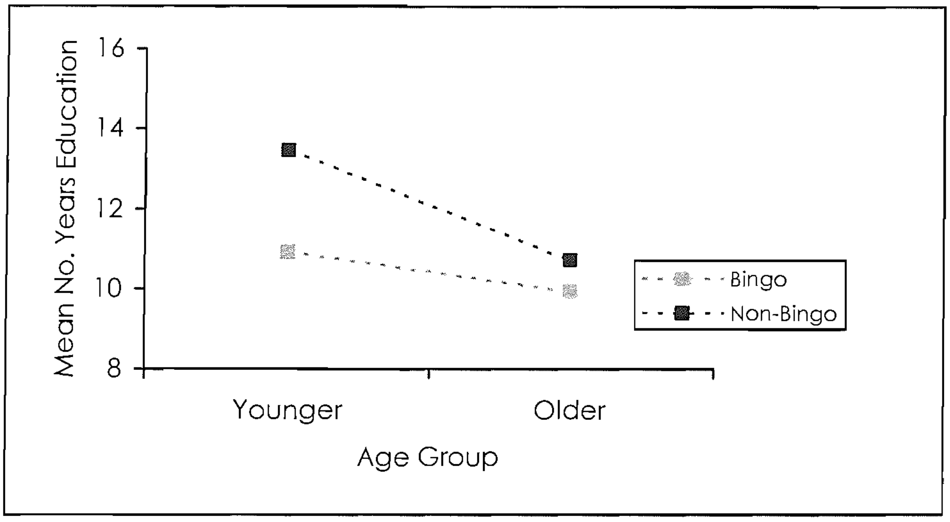

Figure 10.5. Mean years of education as a function of Bingo and age.

Thus, the pattern of data for the errors made on the NART is reflected in the pattern of data for the number of years of education (see Figures 10.4 and 10.5); namely, more errors are made on the NART by participants with fewer years of education.

General Discussion

The experimental data reported in this chapter reveal a number of interesting findings. Firstly, the results of the digit-symbol substitution test (DSST) found that non-Bingo players were able to correctly complete more items within the designated time than non-Bingo players. Thus, even though the DSST comprises a number of the elementary cognitive components that might be expected to underlie the game of Bingo, performance on this test was not facilitated by this factor. Further, both older Bingo and older non-Bingo players were significantly impaired on this task in comparison with their younger counterparts. This again suggests that playing Bingo does not serve to maintain **all** the cognitive processes underlying the game. In agreement with the results of the DSST, the Digits Forward and Digits Backward tests exhibited much the same pattern of results with younger non-Bingo players recalling more correct digit strings than younger Bingo players. The results also revealed a significant effect of age that was not moderated by the factor of Bingo suggesting again that extended practice of Bingo does not help to maintain the cognitive processes underlying performance.

However, the findings of the NART and education analysis offer a possible explanation for the results of the DSST and Digit Span tests. The Bingo players have received significantly fewer years of education than the non-Bingo players. Moreover, this was reflected in the number of errors made on the NART as Bingo players pronounced more words incorrectly than non-Bingo players. Thus, it is possible that extended practice at Bingo has not been able to offset the negative effects of having fewer years of education. Further research should endeavour to recruit control groups of equivalent age and educational status. The present experiment used undergraduate psychology students for the younger non-Bingo playing group. This restricted the age range of this group to 18 and 21 years. However, the age range for the younger Bingo playing group was 22-40 years. As mentioned in Chapter 4, the most common most common age range of people who play Bingo is 30-40 years (Gambling Review, 2001). Thus, it was not possible to recruit younger Bingo players who were of equivalent age to the younger non-Bingo playing group.

In an attempt to further elucidate the factors that contribute to overall Bingo performance, the final chapter aims to measure the relationship between scores on general psychometric tests of intelligence, performance on domain-specific tasks, and molar ability.

CHAPTER ELEVEN

EXPERIMENT 7: RELATIONSHIP BETWEEN BINGO SKILL, BINGO EXPERIENCE, PERCEPTUAL-MOTOR SPEED, SHORT TERM MEMORY, WORKING MEMORY, CANCELLATION PERFORMANCE, VERBAL ABILITY, AND EDUCATIONAL STATUS

Introduction

The purpose of the present study is to examine the relationship between age, Molar Bingo skill, Bingo-playing history, perceptual-motor speed, memory, and performance on a domain-specific task. One of the most interesting findings in the ageing and skill literature is that in spite of reliable age-related declines in many cognitive abilities, many older adults successfully perform cognitively demanding jobs (Czaja & Sharit, 1998). Research suggests that expertise may enable older adults to perform at comparable levels to younger adults in spite of age-related declines in elementary cognitive processes (for a review see Bosman & Charness, 1996).

As discussed in Chapter 3, a primary goal of cognitive ageing research is to determine the means by which older and younger adults are able to achieve comparable levels of performance on skilled tasks even though older adults exhibit significant deficits in performance on laboratory tasks. Salthouse (1986) and Bosman & Charness (1996) have outlined a number of possible explanations for the paradox of cognitive ageing and skilled performance. The first explanation is that of *accommodation,* which refers to the tendency of older adults to avoid taking part in activities that they find too difficult or demanding. Thus they achieve high levels of performance by only undertaking activities they can perform well. The second explanation is that of *compensation.* The compensation hypothesis suggests that older adults develop conscious or unconscious strategies in order to carry out tasks with the same efficiency as younger adults (e.g. Backman, 1989). The maintenance or remediation perspective argues that age-related declines in the elementary cognitive processes underlying skilled performance do not decline because they are maintained with practice. Finally, the encapsulation or compilation hypothesis purports that with practice, skilled behaviour becomes independent of the elementary processes that comprise it, so that age-related declines in these processes will not impair the performance of the skill.

Evaluations of each explanation require different experimental techniques. For example, a key study by Salthouse (1984) investigated the effects of age and skill in typing. The expectation that the net number of words per minute typed should slow down with increased age was based on the numerous reports of age-related declines in many aspects of cognitive functioning (see Salthouse, 1982 for a review). The methodology used by Salthouse to examine his hypothesis differed in key aspects to that of the experimental methods reported so far in this thesis. The approach adopted by Salthouse was originally introduced by Charness (1981a, 1981b, 1981c) in an examination of the relationship between age and skilled performance in chess. This particular technique, most commonly referred to as the "molar equivalence-molecular decomposition procedure", equates age groups on skill (molar behaviour) and then investigates the effects of age on the processes (molecular components) that are thought to underlie the skill. Salthouse (1984) put forward two possible outcomes for the effects of age on the molecular components of a skill. The first is that age effects will mirror the age-related declines found in typical laboratory experiments. This outcome would imply that compensatory mechanisms have been developed to maintain overall performance. The second outcome is that years of practice of the molar behaviour, and hence its underlying components, will have prevented these processes from deteriorating with age. Salthouse reported age-differences in several measures of perceptual-motor performance (e.g. choice reaction time, rate of tapping, and digit-symbol substitution rate), but no age differences in the rate of typing with age. Candidate compensatory mechanisms in the older typists were then sought. A significant relationship between age and hand-eye span was found which suggested that the older typists had adapted to a reduction in information processing resources by looking further ahead in the piece of to-be-typed text.

The present experiment adopts the main tenets of the molar equivalence-molecular decomposition strategy in that the participant sample obtained will not differ in terms of Bingo playing skill (molar behaviour) but will vary widely in age. Performance measures utilised comprise (a) a domain-specific task, namely, the crossing out of numbers on a six-card Bingo grid under timed conditions (b) A measure of basic perceptual-motor speed. The test used to measure perceptual speed is adapted from one of the sub-test items (Tapping) of the MacQuarrie Test for Mechanical Ability (MacQuarrie, 1925, 1953). In the original test a page comprising 70 circles 9mm in diameter is presented and participants are required to make three pencil dots in each circle within a designated amount of time (30 seconds). Emphasis is placed on speed not accuracy so that all attempts to make the correct response will be counted. Thus, the performance measure is the number of circles in which a response was attempted. The present experiment requires the Bingo players to place a mark in each box of an empty six-card Bingo grid. Measure (c) comprises the digit-symbol substitution test used in the previous experiment: (d) the Digit Span test also used in the previous experiment: (e) the digit cancellation test utilised in experiment four, and finally (f) the NART that was administered in the previous experiment. It is important that the Bingo playing history of participants is also taken into account as one of the criticisms made by Salthouse (1990) concerns the problem of determining the amount of experience an individual has with a particular activity. Thus, questions relating to the age at which the skill of Bingo was acquired, the number of years of experience with Bingo, and the number of times per week the game is played were gathered.

The present study therefore aims to determine if comparable molar performance of younger and older Bingo players were attained because the elementary cognitive processes underlying the skill are maintained with practice (maintenance or remediation) or is equivalent molar performance achieved by other means such as compensation or encapsulation? It is important to note however, that if the latter is found to be true, the present experiment will not be able to make any claims about the nature of compensation or encapsulation. In order to do this further research beyond the scope of this thesis will be required.

Method

Design

A correlational design was used to explore the relationship between the co-variables of Bingo skill, Bingo playing history, perceptual-motor speed, Digit-Symbol Substitution, short-term memory, working memory, digit cancellation and verbal ability.

Participants

The participants were 56 skilled Bingo players (skill was determined by the ability to play six Bingo cards simultaneously and to have been playing Bingo at least twice per week for a period of two years or more). Fifty five participants were female. Ages ranged from 22 to 81 years (Mean = 51.11, *SD* = 20.30). Participants were recruited from Gala Bingo, Southampton, and each received a five-pound Gala Bingo voucher on completion of the experiment. All participants had normal or corrected-to-normal vision and reported to be in 'good' or 'excellent' health.

Materials

Two new stimulus sets were used for this study along with the materials used in the Digit-Symbol Substitution task, Digit Span test, Digit Cancellation Test and the National Adult Reading Test (NART) as described in previous experiments. The first new stimulus set consisted of three sheets of A4 paper on which were printed six grids each comprising nine columns by three rows (see Figure 11.1). Each grid measured 10cm wide x 3cm high and the boxes of each grid were shaded grey. There was a gap of 1cm between each grid, thus, resembling a 'typical' 6-card Bingo book but without digits.

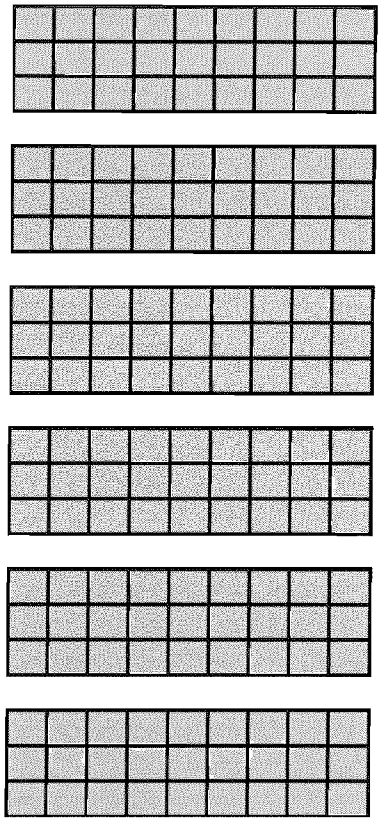

Figure 11.1. Example of stimuli used to test perceptual-motor speed of Bingo players.

The second new stimulus set consisted of three sheets of A4 paper on which each was printed the 6-grid layout previously described. On these pages, fifteen digits were displayed on each grid (see Figure 11.2). The digits were distributed according to UK Bingo-card layout rules and were generated using a program written in Visual Basic (Microsoft Corporation, 1981-2001). Further, at the top of each A4 sheet were 15 digits enclosed in shaded grey boxes displayed horizontally across the page.

68	71	82	35	76	61	45	18	54	13	87	8	64	77	33

3			30		58	63	70	
	12	29		46		65	79	
4	16		31			69		90

7	14	24	32			61		
		25	33	42	54			80
			36		55	66	73	81

	13		37	44		62		83
2		22		47	51		72	
6	19				56		75	84

			38	41	57	60		82
5		23	39	48				88
	10	28			59	67	77	

	15			40		68	71	85
9				43	50		76	87
	17	26	35	49			78	

	11	20	34	45	52			
1	18	21				64		86
8		27			53		74	89

Figure 11.2. Example of stimuli used to measure Bingo skill.

Procedure

All participants were tested individually, and the tasks were performed in the following order for all participants: perceptual-motor speed task, Bingo-card task, Digit-Symbol Substitution Test, Digit Span test, digit cancellation test, and NART.

For the perceptual-motor task, participants were seated at a desk and given standardized verbal instructions. The instructions told them that they would be given a sheet of paper on which was printed an *empty* 6-card Bingo grid. On the experimenter's command, the word *GO*, they were to place a single mark in as many of the boxes as they could within a 30-second time limit. Participants were instructed to mark from left to right along each row in turn and that the procedure would be repeated a further two times.

On completion of the three trials of the perceptual-motor task, the experimenter informed participants that for the second task they would be given a sheet of paper with a *filled* 6-card Bingo grid printed on it along with fifteen individually boxed numbers printed at the top of the page. They were instructed that on the experimenter's command, again the word *GO* they would be given twenty seconds to locate and mark these numbers on the Bingo grid. Importantly, a twenty-second time limit was used for this task as earlier pilot work revealed a ceiling effect at 30 seconds. Participants were instructed to mark off the numbers in the order that they appeared at the top of the page working from left to right. This procedure was repeated a further two times.

The Digit-Symbol Substitution Test was then administered followed by the Digit Span Test, the digit cancellation test, and finally the NART, all using the standardised verbal instructions previously described.

Demographic details of age and education along with details of Bingo-playing history were recorded once the experimental procedure had been completed.

Results and Discussion

The number of *dabs* averaged across the 3 trials for the perceptual-motor task along with the number of correctly marked digits averaged across the 3 trials for the Bingo-card task was calculated so that a Spearman's rho correlation could be performed on the data. Further, participant scores were also calculated for the following: number of correctly completed digit-symbol pairs, number of correctly repeated forward and backward digit strings, number of digits cancelled for the three set sizes combined, number of digits missed for the three set sizes combined, and number of NART errors. Finally, the number of years Bingo experience, age when the skill of Bingo was acquired, number of times Bingo is played per week, and years of education were recorded for each participant. The means and standard deviations for the all of the above measures are presented in Table 11.1 below.

Table 11.1. Mean scores (and their standard deviations) of measures of perceptual-motor speed, molar performance, DSST, Digit Span, digits cancelled, missed digits, NART errors, Bingo experience and educational status.

Variable	Mean	SD	N
Age (years)	51.11	20.30	56
Education (years)	10.43	0.89	56
Number of years Bingo experience	18.36	13.61	56
Age Bingo skill acquired	33.11	14.65	56
Number of times per week Bingo played	3.29	1.41	56
Perceptual-motor speed	89.70	19.77	56
Bingo card task	33.54	2.75	56
Digit-Symbol Substitution	50.39	12.61	56
Digits Forward	8.04	1.48	56
Digits Backward	5.86	1.41	56
Digits cancelled (set sizes 1, 2, and 3 combined)	47.70	6.80	56
Digits missed (set sizes 1, 2, and 3 combined	0.88	1.09	56
NART errors	20.61	7.83	56

A correlation matrix was then created comprising correlations for the above variables (see Table 11.2).

Table 11.2 Correlations among Age, Education (Edu), Bingo Experience (Exp), Age Bingo skill acquired (Acq), times per week Bingo is played (TPW), perceptual-motor speed (P-M sp), Bingo task (Bingo), Digits Forward (Digits, F), Digits Backward (Digits, B), digits cancelled (DCT), digits missed (DCT err), and NART errors (NART).

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	-	-.58**	.72**	.74**	-.09	-.65**	-.22	-.59**	-.32*	-.07	-.58**	-.49**	-.40**
2. Edu	-.58**	-	-.53**	-.32*	.14	.42**	.25	.51**	.62**	.33*	.45**	.20	-.06
3. Exp	.72**	-.53**	-	.08	.07	-.35**	.06	-.40**	-.27*	-.03	-.17	-.42**	-.25
4. Acq	.74**	-.32*	.08	-	-.18	-.60**	-.39**	-.47**	-.18	-.05	-.66**	-.30*	-.35**
5. TPW	-.09	.14	.07	-.18	-	-.01	.29*	-.13	.09	.18	.18	-.14	-.10
6. P-M sp	-.65**	.42**	-.35**	-.60**	-.01	-	.45**	.59**	.44**	.15	.65**	.37**	.24
7. Bingo	-.22	.25	.06	-.39**	.29*	.45**	-	.30*	.26	.18	.53**	-.19	-.07
8. DSST	-.59**	.51*	-.40**	-.47**	-.13	.59**	.30*	-	.41**	.17	.59**	.27*	.13*
9. Digits, F	-.32*	.62**	-.27*	-.18	.09	.44**	.26	.41**	-	.61**	.43**	.02	-.40**
10. Digits B	-.07	.33*	-.03	-.05	.18	.15	.18	.17	.61**	-	.32*	.03	-.54**
11. DCT	-.58**	.45**	-.17	-.66**	.18	.65**	.53**	.59**	.43**	.32**	-	.17	.01
12. DCT err	-.49**	.20	-.42**	-.30*	-.14	.37**	-.19	.27*	.02	.03	.17	-	.20
13. NART	-.40**	-.06	-.25	-.35**	-.10	.24	-.07	.13	-.40**	-.54**	.01	.20	-

Note. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

The data displayed in the correlation matrix above (see Table 11.2) indicates a significant negative correlation between Age and performance on the Perceptual-Motor Speed task, $r(56) = -.65$, $p < .01$, suggesting that age is adversely affecting performance on this task. However, the negative correlation between age and performance on the Bingo-card task did not attain significance, $r(56) = -.22$, $p > .05$. Such a result suggests that despite a significant decrease in perceptual speed with age, older Bingo players were able to locate and cross-off as many numbers on the Bingo card as the younger Bingo players. However, it should be noted that although the correlation between age and performance on the Bingo card test was non-significant, it was nevertheless in the negative direction. Further, scores on the Perceptual-Motor Speed task positively correlated with performance on the Bingo-card task, $r(56) = .45$, $p < .01$, suggesting that participants with faster motor responses did better on this task. The finding that there was a significant positive correlation between perceptual motor speed and performance on the Bingo card task is in agreement with the results reported by Salthouse (1984), and suggests that older Bingo players are able to preserve overall Bingo playing ability (molar performance) by implementing a compensatory mechanism. Increased hand-eye span appeared to be the method of compensation employed by the older typists in Salthouse's study. Therefore, it might be appropriate to test for such a compensatory strategy in the older Bingo players.

Importantly, there was no significant correlation between performance on the Bingo card task and number of years of experience with Bingo, $r(56) = .06, > .05$. This was to be expected as Bingo is not a complex skill and requires only a small amount of practice to be able to perform the activity well in comparison with more complex cognitive activities such as chess. Moreover, all of the Bingo players recruited in this study were required to have at least two years of Bingo playing experience. Thus, it is very likely that they had all achieved asymptote performance at the skill; hence, there was no relationship between number of years experience and molar performance. However, there was a significant negative correlation between the age that the skill was acquired and performance on the Bingo card task, $r(56) = -.39$, $p > .05$, implying that performance at the molar skill is better for those participants who learned to play Bingo at an earlier age. This finding supports research conducted by Salthouse and Somberg (1982) who examined age differences in the ability to acquire new skills. Salthouse and Somberg found that although older and younger participants exhibited comparable acquisition functions, older participants did not achieve the same level of performance on the skill even after fifty hours of practice had been completed. The results of the present study also produced a significant positive correlation between the number of times per week the game is played and performance on the Bingo card task, $r(56) = .29$, $p < .05$, suggesting that the skill does need a certain amount of regular practice for it to be maintained.

Importantly, there was a significant positive correlation between the number of digits that participants were able to cancel and their performance on the Bingo card task, $r(56) = .53$, $p < .01$, suggesting that this task does indeed tap into the perceptual and cognitive processes underlying the game. There was also a significant positive correlation between participants' scores on the DSST and their performance on the Bingo card test, $r(56) = .30$, $p < .05$, suggesting that this general measure of information processing speed is predictive of molar Bingo performance.

In summary, the results of the present study suggest that older Bingo players are able to achieve comparable performance with younger Bingo players at the skill (molar performance) in spite of a significant decline in perceptual-motor speed. This supports the results reported earlier in Experiment 1 which revealed that younger and older Bingo players achieved the same level of performance at the skill of Bingo search when motor response was controlled for. Importantly, variables such as age of acquisition of the skill of Bingo and number of times per week Bingo is played were found to have a positive effect on performance of the molar skill. Moreover, the finding that there is a positive relationship between general measures of perceptual-cognitive ability (e.g. digit-symbol substitution and digit cancellation) and performance of the molar skill suggests that the encapsulation hypothesis cannot account for the finding that older and younger participants are able to achieve comparable levels of performance at the skill of Bingo. It is more probable that the older Bingo players have developed a compensatory mechanism in order to maintain performance. Moreover, the compensatory mechanism is likely to be implemented unconsciously, as older Bingo players report that they have not overtly changed the way they play the game when questioned. It is beyond the scope of this thesis to determine the nature of the compensatory mechanism that might be used by the older Bingo players. However, it is hoped that future research will be able to do so.

CHAPTER TWELVE

GENERAL DISCUSSION

The aim of this thesis was to gain a deeper understanding of the mechanisms underlying skilled performance and to explore the effects of skilled behaviour on age-cognition relations. This was achieved by (a) conducting an empirical demonstration of the effects of extended practice at the social-recreational activity of Bingo on elementary cognitive processes and (b) examining the effects of cognitive limitations in older adulthood on skilled Bingo performance. Throughout this thesis a number of hypotheses have been tested. These have arisen through interpretation of the existing empirical literature. The first hypothesis was that experienced Bingo players would exhibit superior performance to non-Bingo players on a domain-specific task of visual search. In other words, it was predicted that experienced Bingo players would produce the efficient and accurate responses that characterise skilled performance (e.g. Matthews, Davies, Westerman, & Stammers, 2000). This prediction was made in spite of the fact that Bingo is a relatively simple cognitive skill in comparison with complex skills like chess or bridge. The second hypothesis was that older Bingo players would demonstrate comparable levels of performance to younger Bingo players on a test of the overall (molar) skill, thus providing support to a number of studies advocating the maintenance of skilled performance in the face of age-related declines of elementary cognitive processes (e.g. Salthouse, 1984). The third hypothesis was that Bingo players would be able to positively transfer the cognitive skills utilised in Bingo to a new task comprising the same production rules (Anderson, 1983). This prediction was made on the basis that Bingo players would explicitly encode the generalisations between the two tasks and therefore apply the old rules to a new situation (Druckman and Bjork, 1994). It was further hypothesised that older Bingo players would demonstrate a lesser degree of positive transfer than younger Bingo players, as research suggests older adults are less able to develop new efficient task strategies (for a review see Salthouse, 1991). Another hypothesis tested in this thesis predicted that Bingo players would demonstrate superior performance to non-Bingo players on domain-general cognitive tasks comprising digit stimuli (e.g. visual memory scanning and cancellation of digits). This prediction was made on the basis that skilled Bingo players have not only acquired expert knowledge of the game but have also gained a great deal of experience with the stimulus class used in the game. Thus, Bingo players may possess a superior ability to both discriminate between different digits and scan their memories more efficiently for digits than non-Bingo players (e.g. Kristofferson, 1992; Proctor & Dutta, 1995). These domain-general tests also provided an opportunity to test the maintenance and compensation hypotheses of cognitive ageing (e.g. Backman, 1992; Salthouse, 1984, 1990). The maintenance hypothesis asserts that older adults are able to maintain skilled performance because they are constantly rehearsing the elementary cognitive processes underlying the skill. The maintenance hypothesis therefore predicts no difference in the performance of older and younger Bingo players on tests measuring the components of the skill. The compensation hypothesis on the other hand, argues that older adults achieve equivalent performance to younger adults on tests of the molar skill because they implement compensatory mechanisms to aid performance. The compensation hypothesis thus predicts that the performance of older adults on tests of the age-sensitive components of the skill of Bingo will be impaired in comparison with younger adults. The final hypothesis tested in this thesis was that Bingo players would positively transfer the skilled visual search abilities they have acquired to a search task that (a) comprised a different stimulus class, and (b) contained no contextual information relevant to the game of Bingo. This prediction was made on the basis that most of the research that has failed to find evidence of positive transfer has examined skills that are more complex than Bingo. Thus, the measures that are used to evaluate skill transfer are also more complex (Winder, 1993, Forshaw, 1994). It was also predicted that older Bingo players would not demonstrate the same amount of positive transfer on this task as older adults because they would not be able to develop new efficient strategies to carry out the task (see Salthouse, 1991).

These hypotheses were tested by administering a number of domain-specific and domain-general perceptual and cognitive tasks that manipulated either the familiarity of the stimuli, the contextual information included in the task, or both. In this chapter, the findings of the experiments will be compared and then integrated to describe the effects of extended practice at Bingo and its influence on age-cognition relations. First, however, the methodologies used will be summarised with a view to their strengths and to areas of improvement.

Summary of methods used

Participants recruited in the experiments were either undergraduate students within the University of Southampton or community dwelling adults living in the Southampton area. The older and younger Bingo players were recruited from Gala Bingo, Southampton. Participants who volunteered and took part in Experiment One did not take part in any other experiment. This was also the case for Experiment Two. This was done to ensure that non-Bingo players would be naïve to the search task used in Experiment Two. Experiments Three, Four, Five, Six, and Seven formed a battery of tests that were administered to the same group of participants on a number of different occasions. However, none of these participants took part in Experiment One or Two.

Stimuli used in the experiments comprised computer generated digits, letters, or symbols. All stimuli were created to be easily viewable by both younger and older adults with normal or corrected-to-normal vision. The stimuli used in Experiments One and Two were created with a specially designed program and administered via computer using the experimental software Superlab Pro (Superlab Corporation, 1991). The stimuli used in Experiment Three were created using Microsoft Paint (Microsoft Corporation, 1981-2001) and administered via computer using Superlab Pro (Superlab Corporation, 1991). The stimuli used in Experiments Four, Five, Six, and Seven were created in Microsoft Word and Microsoft Excel (Microsoft Corporation, 1981-2001) with the exception of the psychometric tests. Experiments Four, Five, Six, and Seven comprised pen and paper tasks. All stimuli used in these experiments were printed on white A4 paper.

The tasks used in the first and second experiment were present/absent visual search tasks utilising the time-accuracy method of presentation. This method records the accuracy of response at different stimulus presentation times. It thus removes the motor component from the task so that older and younger participants can be fairly compared. Additionally, in Experiments One and Two, measures of sensitivity and bias were calculated. Parametric measures of sensitivity *(d')* and bias *(c)* were used as the number of experimental trials in each condition was deemed large enough. Experiment Three used a present/absent memory search task that measured both response speed and accuracy. However, measures of sensitivity and bias were not able to be calculated here as present and absent data were combined during the programming of this experiment. Experiments Four and Five were pen and paper cancellation tasks that measured both response speed (number of items cancelled within the time limit) and error rate (number of items missed). Experiment Six comprised a number of psychometric tests which have their own standard instructions. The Digit-Symbol Substitution Test measures response time (number of correctly completed items within time limit). The Digit Span Test measures accuracy (number of correctly repeated forward and backward digit strings) and the National Adult Reading Test measures error rate (number of mispronounced words). The final experiment included the psychometric measures used in Experiment Six along with two new experimental tasks. Both the perceptual-motor task and the Bingo card task were pen and paper tasks that measured response time (number of correctly completed items within time limit).

Analyses on the differences between these measures used parametric tests, as the number of participants in each condition was great enough to allow this, and data were approximately normally distributed.

Summary of main findings

In Experiment One, a present/absent visual search task was used to test the hypotheses that (a) experienced Bingo players would exhibit superior performance to non-Bingo players on a domain-specific task of visual search, and (b) that older Bingo players would demonstrate comparable levels of performance to younger Bingo players on a test of the molar skill. Skill was quasi-manipulated by comparing the performance of both non-Bingo and Bingo players. Age was also a quasi-variable as groups of younger and older adults were recruited. The purpose of the experiment was to determine if Bingo players would demonstrate superior performance on a domain-specific task underlying the skill as this would provide evidence that skill acquisition has taken place (Proctor & Dutta, 1995). It was also important to establish whether overall performance is maintained in older Bingo players so that the maintenance and compensation hypotheses of cognitive ageing could be examined in later experiments. The results found that Bingo players did indeed demonstrate superior performance to non-Bingo players on this task. The accuracy rate search slopes suggested that Bingo players required considerably less time to search the six-card array for the target digit than non-Bingo players. Moreover, the sensitivity (*d'*) data confirmed Bingo players to be more proficient at this type of visual search. Experimental validity was achieved by ensuring that *all* participants were provided with knowledge of the rules of the task. This ensured that the only difference between the Bingo and non-Bingo players was the number of times they had previously carried out this type of search. Importantly, older Bingo players achieved equivalent levels of performance to the younger Bingo players on this task, suggesting that the molar skill is maintained into older adulthood. Further, the performance of the older non-Bingo players was particularly impaired for the most difficult task conditions (i.e. shorter presentation times). However, it must be stressed that the experimental design employed in this experiment cannot infer causality.

The second experiment aimed to test whether the cognitive skills practiced by Bingo players transfer to other stimuli. It was predicted that Bingo players would be able to positively transfer the cognitive skills utilised in Bingo to a new task that comprised the same production rules as the original task. However, older Bingo players were not expected to demonstrate the same degree of positive transfer as younger Bingo players because research suggests they have a diminished capacity for generating new task strategies (for a review see Salthouse, 1991). This experiment comprised the same task as Experiment One with certain exceptions. Firstly, symbol stimuli were used instead of digits. Secondly, longer stimulus presentation times were used to offset the unfamiliarity of the symbol stimuli. Thirdly, each digit was always replaced by the same symbol, and there was a different symbol to replace each digit. Finally, the number of the column that the target symbol(s) would appear was indicated above the target symbol(s). This was done to provide the same contextual cueing information for participants as in the Bingo search experiment. The results of this experiment again demonstrated the superior ability of Bingo players to carry out a visual search task. Both the accuracy and sensitivity (*d'*) data indicated that Bingo players required less time to search the visual array than non-Bingo players and were able to perform the task more proficiently (although no participant reached asymptote performance). These results suggest therefore that the skills underlying Bingo search are transferable at least to one other stimulus. However, the performance of the older participants was negatively affected by age and the lack of a significant interaction between the factors of Age Group and Bingo suggested that age was affecting older Bingo and non-Bingo players in a similar way. Importantly however, the older Bingo players achieved the same level of accuracy of performance as the younger non-Bingo players (as evidenced by the sensitivity (*d'*) data). Moreover, as in the Bingo search experiment, older non-Bingo players were particularly disadvantaged on this task. The combined data from Experiment One and Experiment Two revealed that the performance advantage for Bingo players was greater for digit stimuli. However, the data reported in this experiment must be interpreted with caution as a quasi-experimental design cannot determine cause and effect.

The third experiment aimed to measure the performance of Bingo players on one of the general skills thought to underlie Bingo performance (visual memory-scanning). It was argued that an important requirement of the game of Bingo is to quickly scan and compare numbers in memory. The experiment also aimed to examine whether extensive practice at scanning memory for digits maintains this ability in older adulthood. The standard Sternberg (1966) paradigm was utilised along with an additional condition that used double-digit numbers. Unlike in the first two experiments, both response time and error rate were measured. The response time data for both the single- and double-digit conditions yielded the typical increase in latency with set size suggesting participants took longer to complete a memory scan as numbers in the set increased. The results also revealed a significant effect of Bingo. However, the significant interaction between Age Group and Bingo indicated that Bingo was differently affecting the younger and older participants. Further, analyses revealed no differences in the response times of younger Bingo and younger non-Bingo players on either condition of this task. Thus, the effect was occurring for the older participants. Importantly, although the older Bingo players were not as fast to respond as the younger non-Bingo players, they did produce significantly quicker response times than the older non-Bingo players. Moreover, this was particularly evident in the double-digit condition. The response time data therefore suggest that Bingo does not necessarily facilitate performance for the younger Bingo players as short-term memory is good with or without Bingo at their age. However, it is possible that practice at Bingo might offset some of the age-related deficits in short-term memory for the older players. The error rate data revealed a somewhat different pattern of results to the response time data. Errors in the single-digit condition were typically low with the exception of the younger non-Bingo players at set size two. In spite of the low error rates, Bingo players made significantly fewer single-digit errors than non-Bingo players. Moreover, older Bingo players were more accurate than younger Bingo players in this condition. In the double-digit condition, Bingo players again made fewer errors than non-Bingo players. Importantly, they made fewer errors than non-Bingo players as set size increased. Furthermore, the older Bingo players were more accurate than the younger Bingo players, especially at the largest memory set size. Again, however, the quasi-experimental design used in this experiment cannot establish a cause and effect relationship.

In Experiment Four pen and paper digit cancellation tasks (DCT) were used to further test the hypothesis that Bingo players would demonstrate superior performance on a domain-general test of the cognitive processes underlying the Bingo. Complexity in this experiment was manipulated by increasing the number of to-be-searched digits from 1 to 3. Measures of response time (number of digits cancelled) and error rate (number of digits missed) were taken. The results revealed that Bingo players were both quicker and more accurate at this task than non-Bingo players. Further, it appears that the ability of Bingo players to quickly and accurately scan a visual array for target digits is relatively well-maintained in older adulthood, although older Bingo players did produce slower response times than the younger Bingo players. Importantly, however, older Bingo players were more accurate than younger Bingo players (they missed fewer digits). This indicates that a speed-accuracy trade-off was occurring here, a phenomenon that is commonly reported in the ageing literature (Birren, 1964; Botwinick, 1974).

Experiment Five tested whether the superior performance demonstrated by Bingo players to search for digits in Experiment Four would transfer to a different stimulus class (letters). This experiment used the pen and paper cancellation task administered to participants in Experiment Four. However, each digit used in the DCT was substituted by a letter with the following provisos; each digit was always replaced by the same letter and there was a different letter to replace each digit. It was considered important to maintain the same spatial layout of target and distractors used in Experiment Four so that performance on this task could not be attributed to differences in the number or position of targets and distractors on a particular row of the stimulus grid. As in the previous experiment measures of response time (number of letters cancelled) and error rate (number of letters missed) were taken. In accordance with Experiment Four, this study demonstrated the superior ability of Bingo players to search for targets. Further, the response time data revealed Bingo players to be particularly efficient at searching for single targets. Importantly, the results suggested that it is not necessary for the single target to be a digit. However, any possible differences in performance between Bingo and non-Bingo players as set size increased were obscured by a confound at set size two. The confusability between the letters *G* and *C* led to disproportionately lower responses at set size two. The results of the response time data further revealed that older participants were negatively affected by age on this task. Moreover, the lack of an interaction between Age Group and Bingo suggests that age is similarly affecting Bingo and non-Bingo players. The error rate data also demonstrated that Bingo players were able to search more accurately on this task. However, in contrast to Experiment Four, older Bingo players produced more errors (missed more digits) than younger Bingo players on this task, suggesting that their superior ability to discriminate between target digits is not as great for letter targets (although older non-Bingo players were particularly disadvantaged on this task). A further confound, however, was discovered upon completion of data collection. Bingo players revealed that they were more likely to carry out word search activities than non-Bingo players. This provides an alternative explanation for their superior performance on this task which cannot be ignored. However, the quasi-experimental design utilised in this experiment means that it is not possible to determine the causal relationship between Bingo and non-Bingo players on this task.

Experiment Six utilised a number of standard pen and paper psychometric tests to measure general fluid and crystallised abilities of Bingo and non-Bingo players (i.e. information processing speed, short-term memory, working memory, and verbal ability). The Digit-Symbol Substitution Test (DSST) is a measure of perceptual-cognitive speed and has been found to strongly correlate with general intelligence (Wechsler, 1991). Previous tests of the DSST also reveal significant declines in performance with age (e.g. Birren & Morrison, 1961; Salthouse, 1992, 1993). The DSST measures the number of items correctly completed within ninety seconds and therefore provides a measure of response speed. The results of the DSST in the present experiment revealed significant differences in performance for both the factors of Bingo and Age Group. Non-Bingo players demonstrated superior performance over Bingo players on this task running counter to the results produced in the first five experiments. Moreover, older Bingo and non-Bingo players were equally impaired on this task suggesting that extensive practice at Bingo does not help maintain the processes underlying this task. However, significant differences in educational level were also reported with non-Bingo players having received more years of education that non-Bingo players. This provides a further methodological confound as education has been shown to correlate positively with performance on this task (Wechsler, 1995). The Digit Span Test (Weschler, 1981) produced a similar pattern of results with non-Bingo players recalling more correct forward and backward digits strings than Bingo players and younger participants recalling more correct items than older participants. However, the confound between the difference in educational status of the non-Bingo players and Bingo players may have affected the results as performance on this task has also been shown to correlate positively with education (Wechsler, 1995). Finally, the results of the National Adult Reading Test (NART), a measure of crystallised ability, revealed significant differences in performance between non-Bingo and Bingo players. Bingo players made more errors on this test than non-Bingo players. Moreover, older non-Bingo players and older Bingo players appeared to be similarly affected by age. However, as with the DSST and the Digit Span Test, performance on the NART has been shown to positively correlate with education (Nelson, 1982). Thus, it is important to point out that the tests administered in this experiment cannot offer a causal explanation for performance differences in older and younger Bingo and non-Bingo players for two reasons. Firstly, the quasi-experimental design employed in this experiment does not allow causal inferences to be drawn, and secondly, the confound of education appears to be having its own moderating effects on the data.

Finally, Experiment Seven used the molar equivalence-molecular decomposition technique (Charness, 1981) to explore the relationship between Bingo performance and measures of experience, perceptual-motor speed, memory, visual search, verbal ability, and educational status. The Bingo players from Experiments Three, Four, Five, and Six were used in this study. The maintenance and compensation hypotheses relevant to cognitive-ageing and skilled performance were then tested. The maintenance hypothesis predicts that younger and older Bingo players will achieve the same levels of molar (Bingo) performance and molecular (tests of the component processes of Bingo) performance. In contrast, the compensation hypothesis predicts that although younger and older Bingo players will attain comparable levels of molar performance, older Bingo players will be impaired on tests of the molecular components underlying the skill. All participants selected in this study played six Bingo cards simultaneously, thus demonstrating equivalent molar performance. Further, there was no significant correlation between age and performance on the Bingo card task (although the correlation was in the negative direction). However, older Bingo players scored lower on the perceptual-motor speed task. This suggests that older Bingo players are possibly compensating for a deficit in motor speed in order to maintain molar performance. Interestingly, there was no significant correlation between performance on the Bingo card task and the number of years Bingo playing experience. This result was to be expected however, as Bingo is not a complex skill and therefore does not require years of practice to attain maximum performance. Importantly, there was a significant positive relationship found between performance on the Bingo card task and both the number of times per week Bingo is played and the age at which the skill was acquired.

In summary, the findings reported from Experiments One to Seven provide some correlational support for the proposal that Bingo players have acquired superior skills of visual search as a result of extensive practice at Bingo. Moreover, evidence has also been presented that suggests the visual search abilities of Bingo players are partly transferable to two other stimulus classes (symbols and letters). Bingo players also demonstrated superior performance on several **but not all** measures of cognitive processes underlying the game. Finally, older Bingo players were found to maintain the overall skill of Bingo and some of the cognitive processes underlying the game. Some degree of positive transfer to other types of visual search was also found for older Bingo players although not to the same degree as their younger counterparts. The remainder of this chapter will discuss the theoretical implications of the above findings, the methodological limitations of the research and its future direction.

Theoretical implications

This thesis began by presenting theoretical models and processes that have been influential in describing the mechanisms underlying skilled performance. An overview was then provided of the theories that have been significant in describing the mechanisms underlying the ageing of cognitive abilities. Finally, this thesis integrated the cognitive ageing and skill literatures to provide a description of the mechanisms purported to underlie the ageing of cognitive skill. How do the findings from this thesis fit within these theoretical models?

Skilled performance

Bryan and Harter (1897, 1899) conducted an early study into the acquisition of cognitive skill and reported that experts were less susceptible to interferences from their surroundings than novices and exhibited less interindividual variability in performance. Some years later Rosenbaum, Carlson and Gilmore (2001) noted that during the acquisition of a skill, changes in performance are both qualitative and quantitative, with improvements in both the efficiency and the nature of performance taking place. Further, Matthews et al. (2000) observed that a task carried out by an unskilled performer looks both clumsy and effortful in comparison to the effortless way a skilled performer carries out the same task. The first aim of this thesis was therefore to determine if experienced Bingo players exhibit these characteristics of skilled performance. Bingo provided a unique opportunity to study the effects of practice on performance as the type of visual search task involved in the game is not one that is usually associated with efficient and effortless performance. As previously mentioned in the introduction, Carlson (1997) argues that the most important factor in skill acquisition is the consistency of practice. Indeed, Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) demonstrated that unless a target stimulus always evokes the same response, performance will remain slow, effortful and conscious. Importantly, the stimuli used in the game of Bingo can appear as a target on one trial and as a distractor on the next, thus requiring a player to first pay attention to it and then ignore it for the rest of the game. To test whether experienced Bingo players would exhibit the characteristics of varied-mapping performance, a group of Bingo players were compared against a group of non-Bingo players on a test of the visual search task used in Bingo. The results revealed that the Bingo players' performance was efficient and accurate in comparison to that of non-Bingo players. Moreover, there was also less interindividual variability in their performance, thus providing further support to Bryan and Harter's findings.

Two main theories are offered here to explain how Bingo players are able to perform a varied-mapping task with such efficiency. The first makes reference to the perceptual learning literature and the second draws on the cognitive skill acquisition literature. As previously discussed, the defining feature of a perceptual skill is the acquired ability to both determine features that are specific to a particular stimulus and to discriminate it from other stimuli (Proctor and Dutta, 1995). Importantly, a number of factors can affect the ease with which perceptual stimuli can be detected and discriminated. Duncan and Humphreys (1989) for instance, reported that a visual target is particularly difficult to locate if (a) it is similar to other items in the array, and (b) if the distractor items in the array are very different to each other. On the face of it, Duncan and Humphreys findings would suggest that Bingo players find it very difficult to search for target digits. However, if Bingo players have indeed acquired a superior ability both to discriminate between digits and to determine features relevant to specific digits, then target-distractor difference and distractor-distractor difference will not impair their performance to the same extent as it would non-Bingo players. Duncan and Humphreys' findings might also account for the superior performance demonstrated by Bingo players on the digit cancellation tests. That is, Bingo players' enhanced ability to discriminate between digit stimuli might have enabled them to search the array of digits more efficiently than non-Bingo players.

In addition, it might also be suggested that with practice at Bingo, the double-digit numbers used in the game become 'unitised' such that they are perceived as a single entity (e.g. Goldstone, 1998; Grossberg, 1984, 1991). This would considerably reduce the size of the visual array to be searched. The experiments presented in this thesis however, have not been able to determine if unitisation does occur. Perhaps a more likely explanation is that skilled Bingo players use the contextual information provided by the target digit to automatically locate the correct column and then ignore the left-hand number (if it is a double-digit column). This again would reduce the amount of stimulus items to be searched as the left hand digit in each column becomes irrelevant once the correct column has been located. Indeed, Haider and Frensch (1996) found evidence to suggest that improvements in perceptual performance are often found to occur as a reduction in the processing of irrelevant features.

The second main theory put forward to explain the superior visual search performance of skilled Bingo players is that the declarative knowledge related to the game is compiled into production rules which results in players committing fewer errors and implementing more efficient task-related decisions (Anderson, 1982, 1983, 1995). Thus the *strategies* underlying Bingo performance may become automated rather than the visual search process. The novice Bingo player, for instance, may have knowledge of the rules of the game but it has not yet become proceduralised; thus the novice Bingo players' search is not automatically directed to the correct column when locating a target digit. However, as a player becomes more skilled the rules of Bingo are proceduralised such that the game can be played without the active maintenance of declarative knowledge. The target digit then becomes a cue to automatically guide attention to the important part of the visual array (e.g. Cave and Wolfe, 1990). Thus, the efficient visual search performance demonstrated by Bingo players on Experiment One might result not from a superior ability to search and detect specified digit targets, but from the contextual cuing of the learned regularities within the six-card Bingo grid (e.g. Hoyer & Ingolfsdottir, 2003). One of the characteristics of this kind of automatic performance is the ability to carry out additional tasks concurrently (Fitts, 1962, 194). Certainly, Bingo players are certainly able to do this. For example, successful Bingo performance requires not only the locating and marking of target digits, but also the ability to hold winning numbers in memory so that a claim can be made before the Bingo caller moves on to the next number.

The ability of Bingo and non-Bingo players to scan their memories for target digits was tested by the Sternberg memory scanning paradigm (1966). To make the task domain-specific to the game of Bingo the standard Sternberg task was adapted to include double-digit numbers. It was hypothesised that Bingo players would be able to scan their memories more quickly for target digits as during the game of Bingo players need to be aware of the numbers needed to win on each of their six Bingo cards. The result that younger Bingo players were no quicker to scan their memories than younger non-Bingo players was unexpected. It is possible, however, that as the younger Bingo players (22-40 years) were somewhat older than the younger non-Bingo players (18-21), peripheral slowing could have reduced the response times of the younger Bingo players, thus masking any effects that might have otherwise occurred (e.g. Welford, 1977). However, it is also possible that the visual search abilities of younger Bingo players are so good that they do not need to hold the numbers in memory. It is also conceivable perhaps, that short-term memory ability in younger adulthood is optimal. Therefore, Bingo will not necessarily improve it further. The Sternberg error rate data, however, revealed a different pattern of results suggesting that Bingo players might place more importance on the accuracy of information held in memory rather than the speed with which it can be retrieved. The error rate data revealed Bingo players to be far more accurate in their probe-to-memory set decisions than non-Bingo players. Moreover, this effect was particularly strong for larger set sizes and for double-digit numbers. It is therefore possible that skilled Bingo players unconsciously adopt the strategy of accuracy over speed, at least in this aspect of the game. This strategy then becomes proceduralised along with the other task rules. Certainly, Bingo players would have learned the association between missing a number and losing a game. Young Bingo players, however, were not as accurate in the Digit Span Test as younger non-Bingo players. This was somewhat surprising as this test also measures the accuracy of short-term memory. On the one hand, it is possible that the difference in age range between the two groups might have biased the results in favour of the younger non-Bingo players. On the other hand, it is possible that the difference in results between these two tasks highlights the specificity of the effects of practice, and therefore its limitations. The Bingo players, for instance, revealed that they do not listen to the Bingo caller read out the numbers, but instead watch the numbers as they are presented on the television screens around the room. Thus, they have a preference for the visual modality of presentation. However, in the Digit Span Test digit strings are presented verbally to participants. It is therefore possible that the superior ability of Bingo players to accurately retrieve numbers from short-term memory is modality specific. Further, the dependent variable measured in the Sternberg memory scanning task is the number of correct probe-to-memory set responses. This is a measure of recognition memory. In contrast, the Digit Span test requires participants to repeat stings of digits back to the experimenter and as such is a test of recall. Further, the Digit Span Test requires participants to repeat the digit strings in the correct serial order whereas the Sternberg task does not. The Sternberg task may be more similar to the type of short-term memory used in the game of Bingo as a player might not hold numbers in memory in any particular order.

Finally, the results of the Digit-Symbol Substitution Test further highlight the specificity of Bingo practice, as Bingo players did not complete as many items as non-Bingo players. However, the confound of educational status mentioned earlier may have obscured any possible effects.

The next section in this chapter discusses the theoretical implications and issues raised by the two transfer studies presented in this thesis.

Transfer of the skills underlying Bingo performance

Two transfer studies have been presented in this thesis. The first, Symbol search, used a different class of stimulus items than Bingo search but retained the same rules including contextual information. The second transfer study, letter cancellation, used both a different stimulus class (letters) and comprised a new set of task rules. The aim of these studies was to determine if practice at Bingo search transfers, and if so, what is more important for successful transfer; task rules or stimulus characteristics.

Several theories of skill transfer have been described in this thesis. Each theory differs in terms of the nature and degree of similarity required between the original task and the to-be-learned task. Firstly, the *doctrine of formal discipline* (Locke, 1700, as cited in Higginson, 1931) argues that practice at one cognitive skill improves performance of all other cognitive abilities because the mind is like a muscle which if exercised results in general mental fitness. The *theory of identical elements* (Thorndyke & Woodworth, 1901), finding no evidence to support Locke's theory, proposed that transfer only occurs for new tasks which comprise the same stimulus-response elements as the original task. More recent studies of skill transfer have argued that transfer is neither as general as Locke proposes nor as specific as purported by Thorndyke and Woodworth. Anderson (1983) for instance, argues that positive transfer occurs when the rules of the original task are kept constant in the new task.

The results of the Symbol search task revealed that Bingo players were both more efficient (faster) and more proficient (accurate) at searching the symbol array than non-Bingo players. However, not surprisingly, Bingo players were significantly better at Bingo search than Symbol search despite the extended presentation times for Symbol search; this is counter to what would be predicted by the doctrine of formal discipline. However, the positive transfer demonstrated by the Bingo players provides support for the notion that transfer does not entirely depend on the consistency of stimulus and response as purported by Thorndyke and Woodworth (1901). It is suggested therefore, that most of the positive transfer found on this task occurred as a result of the consistency between the rules of Bingo search and Symbol search, thus, supporting Anderson's (1983) theory of skill transfer. It is probable that the Bingo players identified the shared features (e.g. contextual cuing information) between the two tasks and then applied them to the new task environment. It is also possible that Bingo players ignored the left hand side of the double-symbol columns, thus reducing the number of to-be-searched items. It is likely that Bingo players' Symbol search performance was impaired relative to their Bingo search performance because they do not have an acquired ability to discriminate between unfamiliar symbol stimuli, thus demonstrating the specificity of perceptual learning. It is also important to note however, that the factor of Search-Type was a between-subjects factor as participants only took part in either the Bingo search or Symbol search experiment. The difference in performance found on these two tasks could therefore be due to group differences. However, this is not likely as participant groups were rated similarly on important status variables such as education and health.

The second transfer task, letter cancellation revealed that once again Bingo players demonstrated superior performance in comparison to non-Bingo players. Bingo players were both more efficient (faster) and proficient (accurate) at locating and marking target digits. This result seems to imply that positive transfer is possible when both task rules and stimulus characteristics are different on the original and the new task. It is possible that Bingo players are more used to focussing their attention, or more practiced at inhibiting irrelevant information. It is also possible that Bingo players are more motivated to do well at these tasks as the experiment presents an opportunity for them to 'show-off' their skills. However, the letter cancellation task comprised an unfortunate extraneous variable. Following completion of the experiment, participants were asked a number of questions about other activities they enjoy doing. Bingo players overwhelmingly listed word search puzzles as a favourite leisure activity. On closer inspection it was also noted that many Bingo players complete word search puzzles in between games. This observation raises another important issue. Is it possible that Bingo players play Bingo because they are naturally better at visual search? The answer to this question is beyond the scope of this thesis. However, it is just as likely that Bingo players do word search puzzles because Bingo has made them better visual searchers. Further research could attempt to eliminate one or both of these possibilities.

The next section in this chapter discusses the theoretical implications and issues raised by the effects of age group on performance presented in this thesis.

Ageing of skilled performance

All of the studies reported in this thesis included the quasi-independent variable of age. The aim of the first study was to establish whether older Bingo players are able to achieve comparable levels of molar performance to their younger counterparts. Research presented earlier in this thesis suggests that *skill* may enable older adults to perform at equivalent levels to younger adults in spite of age-related declines in the cognitive processes underlying skilled performance (e.g. Salthouse, 1987, 1989, 1990). A number of theoretical perspectives relating to the ageing of skilled performance have attempted to explain the mechanisms responsible for the maintenance of skilled behaviour in older adulthood. The accommodation perspective (Salthouse, 1990) purports that older adults avoid taking part in activities which they can no longer perform well. The compensation hypothesis (Backman, 1992) suggests that older adults implement strategies so that they can achieve the same level of performance as younger adults. The maintenance hypothesis, akin to the disuse theory (Thorndyke, 1928) argues that regular practice at the skill prevents both it, and the underlying cognitive processes, from declining. Finally, the encapsulation hypothesis (Bosman & Charness, 1996) suggests that skilled performance does not rely on the cognitive abilities that underlie it. The results of the first experiment clearly demonstrated that older Bingo players were able to achieve comparable performance with younger Bingo players on a test of molar performance. Moreover, the time-accuracy method utilised in this study removes the motor component from the task; thus any variation in performance between the two groups is likely to be a result of differences in central processing. Thus, older Bingo players were able to search as efficiently and proficiently as younger Bingo players on this task. This finding supports the idea that *skill* enables older adults to achieve the same performance levels as younger adults. However, these results are important in light of evidence which suggests that the abilities underlying this task, e.g. visual search (Humphrey & Kramer, 1979), exhibit reliable declines with age. However, the second experiment revealed that older Bingo players were not able to transfer their Bingo search skills to a new task situation as effectively as younger adults. This provides evidence for theory that older adults have a diminished ability to adopt new efficient strategies (see Salthouse, 1991). However, older Bingo players performed better on this task than both younger and older non-Bingo players, suggesting that some degree of positive transfer occurred. A further explanation is therefore offered to account for the performance differences between younger and older Bingo players, that is, a reduction in processing resources. The symbol search draws on additional cognitive processes to Bingo search. Participants were observed assigning verbal labels to the symbol stimuli. Thus, participants did not only have to search for the target symbol(s) but also maintain in memory the verbal labels assigned to the target. Many of the older participants, including the older Bingo players reported difficulty in remembering the symbol pairs. Thus, older participants may have used up most of the available processing time trying to both label and remember the target symbols. This would leave little time to carry out the later operation of visual search (for a review see Park, 2000). The finding that older Bingo players were not able to scan their memories for target digits as quickly as either younger Bingo players or younger non-

Bingo players in Experiment Three supports a resource reduction explanation. However, it is important to note that the older Bingo players were often more accurate than even the younger Bingo players, suggesting that Bingo may adopt an accuracy-over-speed strategy as they get older (a possible compensatory mechanism). Further, older Bingo players were also particularly disadvantaged on the Digit-Symbol Substitution Task and the Digit Span Test in comparison with the other three participant groups. This indicates that extended practice at Bingo is not attenuating the negative affects of age on these processes. Yet, older Bingo players did exhibit superior performance to younger non-Bingo players and older non-Bingo players on the digit and letter cancellation tasks. However, the 'word search' confound alluded to above, may go some way to explaining this effect.

Importantly, older Bingo players demonstrated superior performance to older non-Bingo players on many of the domain-specific tasks suggesting that there is some benefit to be had from playing the game in later life. Importantly, the last study revealed that older Bingo players were able to achieve comparable levels of molar performance with younger Bingo players in spite of a significant reduction in perceptual-motor speed. This result suggests that Bingo players are implementing a compensatory mechanism to maintain performance (e.g. Salthouse, 1985). However, the experiments reported in this thesis are not able to determine what this compensatory mechanism might be, although it is likely to be an unconscious strategy as older Bingo players report that they have not overtly changed the way they play the game.

Important findings from Experiment Seven were that the regularity of practice was positively correlated with Bingo performance and the age at which the skill was acquired was negatively correlated with Bingo performance. This supports Salthouse and Somberg's (1982) findings that older adults do not achieve the same level of performance on a newly acquired skill even after considerable practice.

In summary, the experiments presented in this thesis provided some support for the notion that certain cognitive abilities are maintained into older adulthood through continued practice. However, the tasks that produced comparable levels of performance for both the younger and older Bingo players tended to be very specifically related to the molar skill. Conversely, general psychometric measures of the cognitive abilities underlying Bingo performance produced typical reliable age-related differences in performance.

Methodological limitations

The research presented in this thesis utilised the age comparative cross-sectional design whereby the performance of groups of participants differing in age and Bingo experience is compared at one point in time. This experimental design, whilst commonly used in cognitive ageing research has a number of inherent biases and limitations. Firstly, it is possible that the Bingo players were more motivated to perform well on Experiments One, Two, Four and Five because these experiments resembled the kind sort of things they do when playing Bingo. Thus, these tasks may have been enjoyed by Bingo players in particular because they were familiar. All of the experiments presented in this thesis are limited by their cross-sectional design. The independent variables of Bingo and Age Group were not manipulated by the experimenter. This meant that participants could not be randomly assigned to experimental conditions and thus participants who differ in terms of Bingo experience and age may differ on other important characteristics. However, it is important to point out that the Bingo players had lower levels of education overall. Therefore it is not likely they were more intellectually able than the non-Bingo players.

Importantly, participants recruited for all the experiments presented in this thesis were self-selecting, that is, they volunteered themselves for study. It is possible that volunteers may differ in terms of important variables such as motivation and attitude. Further, the undergraduate students used in Experiments Three, Four, Five, Six, and Seven received only course credit for taking part. Thus, their motivation may not have been as high as the other participant groups who received a more tangible reward.

Finally, it is especially important to note that none of the quasi-experiments reported in this thesis are able to infer a cause and effect relationship between the variables of age and Bingo.

Furthering the findings from this thesis

The findings described in this thesis have, in some sense, been surprising, and for this reason a number of future projects are required to confirm and extend the results. Firstly, the experiments in which confounding variables were reported should be manipulated to remove these effects. Thus, the letter cancellation tasks should be replaced by tasks comprising stimuli which are equally unfamiliar to both Bingo and non-Bingo players. Secondly, experiments could be designed to test for the likely compensatory mechanisms used by older Bingo players to maintain molar performance. For instance, an experiment akin to the one carried out by Salthouse (1984) could attempt to manipulate the preview span available to Bingo players as they search a six-card Bingo grid. Importantly, eye movement studies could be conducted so that the visual search patterns of skilled younger and older Bingo players can be compared against novice younger and older Bingo players. Currently, Derrick Watson and Elizabeth Maylor are conducting eye movement studies to find out how older age affects the ability to locate a target item among a set of distractor items. Studying the visual search abilities of Bingo players could help inform such research as Bingo players have experienced much practice at locating targets amongst distractors.

The Bingo and Symbol search tasks utilised in this thesis could be used in training studies to examine how Bingo search abilities are acquired and maintained. It would also be useful to test Bingo players before they first play the game and monitor their progress as they become more proficient at the skill. Further, there are many other social recreational activities that are enjoyed by a large percentage of the population which have yet to receive significant attention from cognitive skill researchers. For instance, the game of darts requires focussed attention, the ability to locate and select a target while at the same time inhibiting the other numbers on the board. The game also requires players to be particularly skilled at mental arithmetic as they have to count backwards from 501 as the game progresses. The game is also played by persons of all ages and, unlike Bingo, is favoured by males.

Finally, the experiments presented in this thesis could have been improved by the addition of a middle-aged group for comparison. Extreme age groups cannot be used to explore developmental change in cognitive abilities. Importantly, age-related differences in skilled performance have been reported for middle aged medical technicians (see Hoyer et al., 2003).

Conclusions

The experiments conducted within this thesis have provided evidence for a difference between the visual search abilities of skilled and novice Bingo players. This difference has been shown in both response time and accuracy tasks. As predicted Bingo players were both more efficient and proficient at searching for target digits. Evidence for the positive transfer of the skills underlying Bingo was also found, providing support for theories advocating the importance of contextual information and rule generalisation. Importantly, older Bingo players were able to achieve comparable levels of performance to younger Bingo players on the molar skill despite the fact that the processes underlying the game are sensitive to the negative effects of age. However, the results of the studies presented in this thesis demonstrated that even with extensive practice, older adults were not able to maintain performance on the more general measures of cognitive abilities underlying the game of Bingo. Importantly, variables of regularity of practice and age of skill acquisition were found to influence the molar performance of Bingo players.

Finally, it is felt that the main aims of this thesis, that is, to gain a deeper understanding of the mechanisms underlying skilled performance and to explore the effects of skilled behaviour on age-cognitions, have been realised.

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APPENDIX A

DIGIT CANCELLATION STIMULUS SHEETS

Digit cancellation stimulus sheet for set size 1 (target digit 5)

5

3	6	0	8	5	6	8	2	5	2	6	4	5	2	3	5	8	2	6	5	4	1	9	5	7
5	6	3	5	7	1	5	3	9	3	5	6	7	8	5	9	8	4	1	9	8	7	5	3	6
0	5	9	7	4	5	3	0	4	6	0	1	5	8	3	7	5	4	1	3	7	5	1	0	4
6	2	3	5	9	4	6	8	5	6	0	2	4	6	5	2	1	6	5	2	9	7	8	5	3
5	4	0	1	2	3	5	4	0	4	5	8	3	8	4	8	4	5	6	0	9	6	8	7	6
3	6	5	8	1	7	2	3	5	4	5	3	9	1	5	6	4	7	6	0	5	2	9	8	9
5	8	0	4	6	5	2	4	7	6	1	9	5	1	7	1	5	6	3	7	5	4	8	6	4
1	5	4	1	7	1	2	5	1	0	7	4	1	7	2	4	6	5	2	3	1	5	1	2	5
0	8	5	1	8	3	6	8	4	8	5	0	6	4	3	5	2	1	8	6	5	9	4	5	7
7	5	7	5	1	4	6	0	2	9	1	5	7	8	6	5	3	2	1	6	4	2	8	5	9
5	7	3	0	5	3	7	6	8	7	5	8	0	7	3	1	7	6	8	5	1	3	5	3	1
7	5	4	7	4	8	5	8	0	3	5	6	2	7	1	3	8	5	0	5	2	7	8	9	7
5	8	2	1	5	6	8	3	6	4	6	5	8	7	4	8	0	5	2	1	3	8	6	0	9
3	1	5	7	5	8	2	6	2	7	3	1	0	5	4	5	6	0	6	7	4	2	8	0	2
1	3	1	4	8	5	1	9	5	2	5	8	7	2	8	9	5	2	1	8	6	1	9	0	5
1	7	2	1	4	5	1	2	5	9	0	4	5	3	7	5	8	9	6	8	4	6	0	5	6
7	0	7	6	1	9	0	5	3	8	1	5	6	4	3	6	8	1	3	5	2	5	3	4	2
5	4	3	8	0	5	2	6	2	9	5	4	7	2	3	1	3	1	7	5	3	4	5	4	2
0	3	1	5	6	4	3	5	3	6	5	2	3	2	4	7	5	8	5	1	2	4	6	1	5
8	4	8	5	7	2	8	9	3	5	7	9	5	4	5	9	5	8	1	0	6	5	0	2	6
8	4	5	6	0	1	3	7	1	7	5	8	1	8	6	8	3	2	1	5	1	4	6	2	5
7	6	9	1	3	5	6	8	0	2	4	7	1	5	6	5	7	3	5	4	2	9	6	8	2
9	6	9	8	0	2	6	5	4	6	4	2	1	4	2	7	5	7	4	2	8	5	3	8	1
4	5	7	2	0	2	0	5	4	9	4	5	4	7	4	8	5	6	4	6	8	4	5	2	0
9	2	4	7	0	9	1	5	8	5	6	2	8	0	6	5	4	6	7	3	5	9	5	4	2

Digit cancellation stimulus sheet for set size 2 (target digits 2 and 6)

2	6

5	4	6	3	8	3	2	7	8	9	5	4	1	9	4	8	3	2	3	4	8	5	6	4	2
8	7	0	5	3	5	8	2	6	0	1	0	5	8	9	4	7	2	5	9	6	0	8	0	6
6	4	5	3	1	2	8	4	8	4	3	5	6	9	5	7	2	9	1	7	5	4	1	6	4
5	9	2	3	6	9	3	7	1	9	8	7	9	6	7	0	3	4	7	3	0	6	2	8	5
0	7	5	6	7	4	2	5	3	1	4	5	9	0	3	1	8	4	5	6	9	6	0	5	2
7	2	4	5	7	0	4	8	2	8	3	5	7	0	7	5	3	6	1	9	3	1	2	5	6
2	5	6	1	7	2	8	3	7	5	1	0	7	4	3	1	8	5	0	9	6	1	7	0	3
1	9	2	5	9	8	4	6	5	2	5	0	4	8	7	4	0	7	6	7	9	5	3	7	8
4	2	4	5	6	7	4	5	4	1	5	4	0	9	8	1	6	1	6	2	5	3	7	8	5
7	5	6	4	6	2	7	4	1	4	5	9	4	5	0	8	5	7	2	3	1	2	5	1	0
1	3	2	4	9	5	8	0	1	6	7	3	5	8	2	9	5	2	4	7	8	1	9	6	5
2	6	5	9	0	1	5	1	3	6	8	1	5	2	5	9	7	9	7	6	8	5	8	7	1
1	8	2	1	8	5	3	8	3	6	3	1	5	4	1	9	7	4	2	3	2	3	5	9	6
3	4	8	7	8	2	1	3	6	9	0	6	4	0	8	0	5	4	7	1	5	2	3	6	5
4	9	4	5	2	9	3	9	3	8	2	8	7	3	9	7	6	0	5	2	7	4	5	6	8
6	5	0	4	6	7	4	5	8	0	2	3	9	3	9	3	1	8	5	2	5	8	7	8	4
3	5	9	4	8	0	2	6	7	1	7	4	9	4	5	9	8	1	2	6	7	9	1	2	8
2	5	1	9	8	4	3	8	3	1	4	7	1	2	7	1	2	7	6	1	3	5	8	6	9
1	7	0	9	8	3	5	8	3	6	2	1	3	9	0	4	6	0	3	2	7	1	4	8	6
5	2	8	1	5	6	8	7	5	2	4	9	8	2	3	7	6	7	9	1	0	7	5	9	1
1	3	7	1	3	2	1	6	7	5	3	6	4	7	5	2	3	4	8	9	9	1	4	2	1
4	3	6	8	3	9	1	8	5	2	9	4	0	1	0	1	6	0	7	9	5	2	5	8	6
6	3	9	5	2	9	4	1	8	4	7	0	9	1	4	7	6	1	7	8	5	7	5	2	3
3	4	8	1	7	9	0	4	6	5	8	1	7	1	4	3	2	8	2	3	4	1	7	9	6
2	9	4	6	4	5	9	0	1	9	8	5	0	5	1	5	7	6	7	1	6	8	2	1	6

Digit cancellation stimulus sheet for set size 3 (target digits 1, 4, and 9)

1	4	9

2 4 3 0 6 1 8 7 0 3 5 9 0 8 7 3 2 1 7 0 5 4 3 5 0
8 6 9 4 0 5 3 7 0 8 0 5 1 5 8 0 2 9 7 3 0 5 7 6 4
1 2 0 7 8 4 5 0 9 6 8 7 0 5 2 4 6 2 8 0 7 3 8 5 9
2 5 1 0 8 7 2 5 2 8 7 0 3 2 8 7 0 6 7 6 9 4 1 9 2
9 8 2 5 0 8 3 1 7 6 8 5 0 4 5 8 2 7 9 0 6 5 3 8 3
4 2 6 0 7 9 5 3 6 5 2 8 4 1 0 7 5 2 8 7 0 3 5 1 5
6 2 5 8 1 0 7 9 6 4 6 0 7 5 2 3 1 9 3 5 6 3 0 8 2
0 5 6 4 2 8 7 0 3 5 9 7 6 5 3 2 6 8 0 1 7 5 2 9 6
8 9 3 6 2 0 3 1 7 8 0 9 4 6 5 3 8 7 1 2 6 8 3 5 3
3 1 5 1 9 8 5 6 2 8 4 5 8 7 0 5 6 0 2 8 2 4 5 6 8
8 7 1 2 0 5 3 6 8 0 9 0 6 5 2 4 8 7 3 9 0 2 8 7 1
2 3 4 0 9 8 7 2 5 1 5 6 0 8 4 2 7 5 7 9 6 0 7 2 3
5 3 1 5 8 2 7 9 3 6 0 4 9 3 5 7 2 0 3 7 1 0 2 6 2
9 0 2 8 4 0 3 7 3 5 2 6 8 7 1 2 0 8 6 5 9 4 3 5 8
4 0 7 5 6 2 1 8 3 7 6 0 5 4 0 7 3 5 7 8 3 0 6 2 9
2 8 9 0 5 2 6 7 1 8 2 7 4 0 8 6 1 2 0 5 6 8 2 0 3
9 3 0 1 2 6 0 8 7 4 5 6 8 2 4 0 9 7 6 2 5 1 2 3 8
0 4 3 2 5 8 7 6 4 5 1 7 0 3 8 7 9 2 8 6 8 5 1 2 0
2 9 4 6 7 5 2 8 5 7 0 2 1 6 4 0 8 5 2 7 0 5 9 2 8
1 3 1 9 4 0 5 2 8 0 6 3 2 3 7 5 0 7 3 4 6 7 8 6 2
6 2 4 3 1 8 7 6 5 3 7 8 7 6 9 2 5 3 8 4 0 7 5 3 1
3 4 0 6 2 7 8 9 5 0 3 7 8 2 6 8 1 0 7 5 6 1 4 2 0
9 7 5 4 3 2 6 1 9 8 5 7 3 0 8 7 0 2 3 7 5 2 6 2 4
0 3 1 9 0 8 3 5 7 5 3 8 0 2 4 6 5 0 8 3 2 0 7 9 5
5 6 2 0 1 3 9 0 3 8 0 2 1 5 6 2 8 0 3 5 7 0 4 5 2

APPENDIX B

LETTER CANCELLATION STIMULUS SHEETS

Letter cancellation stimulus sheets for set size 1 (target letter G)

G

B C Q S G C S J G J C A G J B G S J C G A I P G L
G C B G L I G B P B G C L S G P S A I P S L G B C
Q G P L A G B Q A C Q I G S B L G A I B L G I Q A
C J B G P A C S G C Q J A C G J I C G J P L S G B
G A Q I J B G A Q A G S B S A S A G C Q P C S L C
B C G S I L J B G A G B P I G C A L C Q G J P S P
G S Q A C G J A L C I P G I L I G C B L G A S C A
I G A I L I J G I Q L A I L J A C G J B I G I J G
Q S G I S B C S A S G Q C A B G J I S C G P A G L
L G L G I A C Q J P I G L S C G B J I C A J S G P
G L B Q G B L C S L G S Q L B I L C S G I B G B I
L G A L A S G S Q B G C J L I B S G Q G J L S P L
G S J I G C S B C A C G S L A S Q G J I B S C Q P
B I G L G S J C J L B I Q G A G C Q C L A J S Q J
I B I A S G I P G J G S L J S P G J I S C I P Q G
I L J I A G I J G P Q A G B L G S P C S A C Q G C
L Q L C I P Q G B S I G C A B C S I B G J G B A J
G A B S Q G J C J P G A L J B I B I L G B A G A J
Q B I G C A B G B C G J B J A L G S G I J A C I G
S A S G L J S P B G L P G A G P G S I Q C G Q J C
S A G C Q I B L I L G S I S C S B J I G I A C J G
L C P I B G C S Q J A L I G C G L B G A J P C S J
P C P S Q J C G A C A J I A J L G L A J S G B S I
A G L J Q J Q G A P A G A L A S G C A C S A G J Q
P J A L Q P I G S G C J S Q C G A C L B G P G A J

Letter cancellation stimulus sheet for set size 2 (target letters J and C)

J	C

G A C B S B J L S P G A I P A S B J B A S G C A J
S L Q G B G S J C Q I Q G S P A L J G P C Q S Q C
C A G B I J S A S A B G C P G L J P I L G A I C A
G P J B C P B L I P S L P C L Q B A L B Q C J S G
Q L G C L A J G B I A G P Q B I S A G C P C Q G J
L J A G L Q A S J S B G L Q L G B C I P B I J G C
J G C I L J S B L G I Q L A B I S G Q P C I L Q B
I P J G P S A C G J G Q A S L A Q L C L P G B L S
A J A G C L A G A I G A Q P S I C I C J G B L S G
L G C A C J L A I A G P A G Q S G L J B I J G I Q
I B J A P G S Q I C L B G S J P G J A L S I P C G
J C G P Q I G I B C S I G J G P L P L C S G S L I
I S J I S G B S B C B I G A I P L A J B J B G P C
B A S L S J I B C P Q C A Q S Q G A L I G J B C G
A P A G J P B P B S J S L B P L C Q G J L A G C S
C G Q A C L A G S Q J B P B P B I S G J G S L S A
B G P A S Q J C L I L A P A G P S I J C L P I J S
J G I P S A B S B I A L I J L I J L C I B G S C P
I L Q P S B G S B C J I B P Q A C Q B J L I A S C
G J S I G C S L G J A P S J B L C L P I Q L G P I
I B L I B J I C L G B C A L G J B A S P P I A J I
A B C S B P I S G J P A Q I Q I C Q L P G J G S C
C B P G J P A I S A L Q P I A L C I L S G L G J B
B A S I L P Q A C G S I L I A B J S J B A I L P C
J P A C A G P Q I P S G Q G I G L C L I C S J I C

Letter cancellation stimulus sheet for set size 3 (target letters I, A, and P)

I	A	P

J A B Q C I S L Q B G P Q S L B J I L Q G A B G Q

S C P A Q G B L Q S Q G I G S Q J P L B Q G L C A

I J Q L S A G Q P C S L Q G J A C J S Q L B S G P

J G I Q S L J G J S L Q B J S L Q C L C P A I P J

P S J G Q S B I L C S G Q A G S J L P Q C G B S B

A J C Q L P G B C G J S A I Q L G J S L Q B G I G

C J G S I Q L P C A C Q L G J B I P B G C B Q S J

Q G C A J S L Q B G P L C G B J C S Q I L G J P C

S P B C J Q B I L S Q P A C G B S L I J C S B G B

B I G I P S G C J S A G S L Q G C Q J S J A G C S

S L I J Q G B C S Q P Q C G J A S L B P Q J S L I

J B A Q P S L J G I G C Q S A J L G L P C Q L J B

G B I G S J L P B C Q A P B G L J Q B L I Q J C J

P Q J S A Q B L B G J C S L I J Q S C G P A B G S

A Q L G C J I S B L C Q G A Q L B G L S B Q C J P

J S P Q G J C L I S J L A Q S C I J Q G C S J Q B

P B Q I J C Q S L A G C S J A Q P L C J G I J B S

Q A B J G S L C A G I L Q B S L P J S C S G I J Q

J P A C L G J S G L Q J I C A Q S G J L Q G P J S

I B I P A Q G J S Q C B J B L G Q L B A C L S C J

C J A B I S L C G B L S L C P J G B S A Q L G B I

B A Q C J L S P G Q B L S J C S I Q L G C I A J Q

P L G A B J C I P S G L B Q S L Q J B L G J C J A

Q B I P Q S B G L G B S Q J A C G Q S B J Q L P G

G C J Q I B P Q B S Q J I G C J S Q B G L Q A G J