Automatic Intelligent Cruise Control

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ABSTRACT

This paper reports a study on the evaluation of automatic intelligent cruise control (AICC) from a psychological perspective. We anticipated that AICC would have an effect upon the psychology of driving—namely, make the driver feel like they have less control, reduce the level of trust in the vehicle, make drivers less situationally aware, but might reduce the workload and make driving might less stressful. Drivers were asked to drive in a driving simulator under manual and automatic intelligent cruise control conditions. Analysis of Variance techniques were used to determine the effects of workload (amount of traffic) and feedback (degree of information from the AICC system) on the psychological variables measured—locus of control, trust, workload, stress, mental models, and situational awareness (SA). The results showed that locus of control and trust were unaffected by AICC, whereas SA, workload, and stress were reduced by AICC. Ways of improving SA could include cues to help the driver predict vehicle trajectory and identify conflicts.

KEYWORDS

automation, driving, workload, stress, trust, situational awareness

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1. INTRODUCTION

1.1 Aims of the Study

Further to our call for more studies on vehicle automation to be published in the open literature (Stanton & Young, 1998), researchers are beginning to make their investigations public (e.g., Hoedemaeker, 1999; Hoedemaeker & Brookhuis, 1998; Marsden et 2001; Sonmezisik et al., 1998). The trend, however, is to concentrate on the failure of such systems (e.g., de Waard et al., 1999; Desmond et al., 1998) rather than on how they will operate in normal use. Although considering the safety critical aspects of any new technology is prudent, to focus on its failure might also be considered inappropriate. Ergonomics is in danger of being ignored by engineers if it fails to communicate how best to implement new technology. Furthermore, the current movement is toward proactive design solutions rather than reactions to accidents or failures (e.g., Wickens et al., 1998). In that vein, Young & Stanton (1997) argued that research effort might be better spent investigating how we should design automation systems, given that their implementation is inevitable, to optimize performance. Therefore, the aims of this paper are to indicate which aspects of driver psychology are likely to be important and to investigate their application to automatic intelligent cruise control. A consensus appears to be growing among the Ergonomics community about which psychological factors are likely to be the best candidates for investigation. In a previous paper (Stanton & Young, 2001), we suggested that researchers should consider locus of control, trust, situational awareness (SA), mental representations, workload, and stress. These factors are at issue in other environments in which automation is considered, such as aviation (Billings, 1993) and process control (Hancock, 1997). These factors have been further confirmed in the automotive context by leading researchers, such as the keynote address by Parasuraman (2000) at the International Conference on Engineering Psychology and Cognitive Ergonomics in Edinburgh. Such verification gives us some degree of confidence that the six factors are likely to be the most important variables in driving automation. To put the research into context, we will first explain how automatic intelligent cruise control (AICC) works, before considering the psychological issues in detail.

1.2 Automatic Intelligent Cruise Control

Automatic intelligent cruise control is based on a range sensor and a distance-control system that are linked to a conventional cruise control system. Contemporary systems also have limited braking authority, up to 0.3 g, which together with the throttle control the speed of the AICC-equipped vehicle and the time-based separation from the vehicle in front. In the Jaguar XK series, a microwave-based radar is used as the range sensor. This device was found to be superior to the laser-based equivalent because it is less likely to be affected by environmental conditions like raid or fog (Richardson et al., 1997). The microwave-based radar was designed to detect only vehicles that are traveling in the same lane as the AICC vehicle. The control system comprises a speed controller and a headway controller. The control system switches between speed and headway control in response to data from the range sensor. To achieve the speed and headway, the control system has authority over the throttle and brakes. Unlike conventional cruise control (CCC), which has five operational modes (off, on, cruising, driver override, and standby), AICC has a sixth *following* mode. The respective differences in system state between CCC and AICC are shown in Figs. 1 and 2. As Fig. 1 shows, once switched on, CCC can be put into cruising mode by setting the cruising speed. The system can move from cruising mode to four other modes if the driver accelerates, brakes, cancels the set speed, or switches the CCC off. If the driver accelerates, then the system automatically returns to cruise mode after the period of intervention. If the driver brakes, then CCC is put into standby

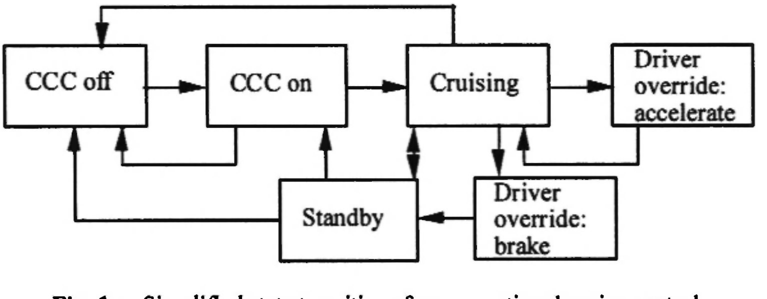


Fig. 1: Simplified state transitions for conventional cruise control.

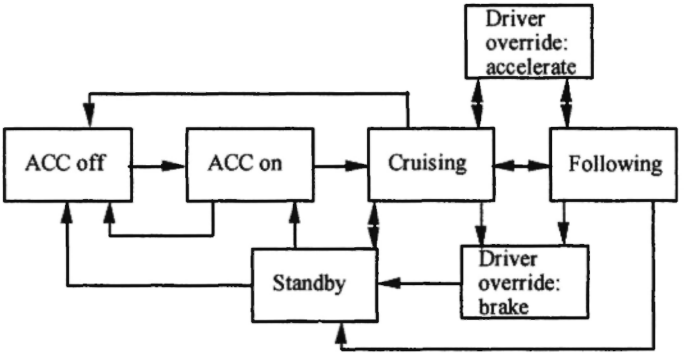


Fig. 2: Simplified state transitions for automatic intelligent cruise control

mode and the vehicle is under manual control. From standby mode, the driver can either resume cruise mode or reset the cruising speed. The driver can choose to switch the system off from any of the other modes. The control modes for AICC are shown in Fig. 2.

As with CCC, the AICC system can switch between control modes—from off to on, from on to cruising, from cruising to intervene, from intervene to standby, from standby to off. The additional following mode means that the driver does not have to brake when the car closes in on another vehicle. On such occasions, the car moves from cruising mode into following mode. If the vehicle in front moves out of the way of the AICC-equipped car, then the system will revert to cruising mode. The driver is at liberty to override both cruising and following modes, as shown in Fig. 2.

Stanton & Young (1998) argued that the addition of the extra mode had a dramatic effect on the nature of the cognitive tasks of the driver. The apparently simple removal of the physical braking task would, on the face of it, reduce driver workload. Some dispute has arisen over whether driving with AICC is accompanied by a workload reduction. Nilsson (1995) and Young & Stanton (1997) suggest that workload is about the same as for manual driving, whereas a study by Stanton et al. (1997) suggests a workload reduction with AICC. The driver's tasks with CCC and AICC are compared in Fig. 3.

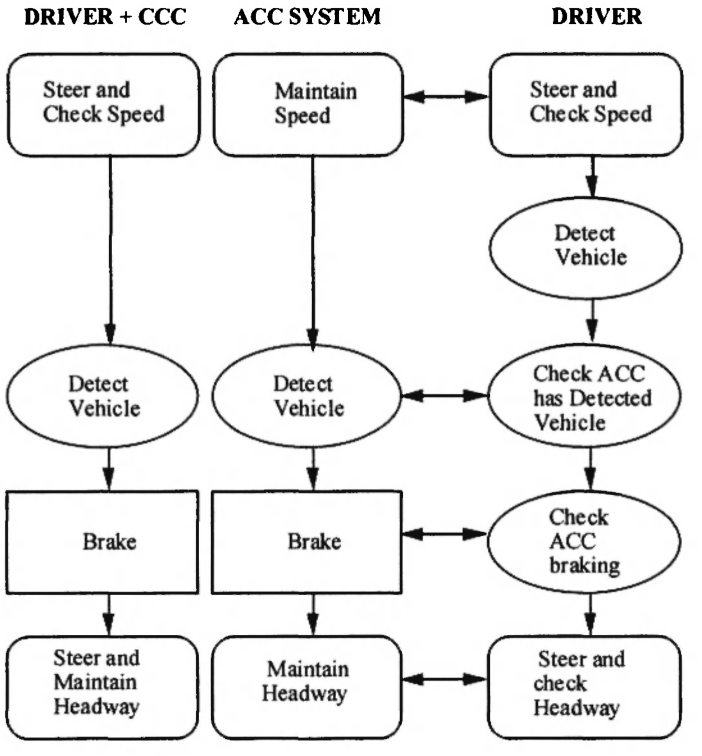


Fig. 3: Driver tasks with CCC and AICC showing a mixture of cognitive and physical tasks (in the lozenge), cognitive tasks (in the oval), and physical tasks (in the rectangle).

The tasks for CCC and AICC shown in Fig. 3 suggest that removing the physical task of braking adds a cognitive overhead of checking that the vehicle is behaving appropriately in response to changes in the road environment. Instead of braking when a vehicle is detected, when using CCC the driver of an AICC vehicle has to check that the AICC system has (a) detected the vehicle, (b) detected that it is braking, and (c) detected that an appropriate headway is maintained for the duration in which the following mode is operational. Thus seemingly, although the physical workload is reduced, the mental workload is increased. These two types of workload might cancel each other out, showing no net increase or decrease in the overall workload. Workload and other psychological issues will be presented in the next section.

1.3 Driver Behavior

Now that the operational characteristics of AICC have been presented, the potential impact on the driver can be considered. Studies that report the effects of automation on driver behavior typically report on only one or two psychological variables, such as stress (Desmond et al., 1998) or workload (de Waard et al., 1999), in addition to the performance measures of driving (such as speed, leading headway, and position in lane). In this paper, we are aiming to consider six factors that we suspect are likely to be affected by automation of longitudinal control. In addition to workload and stress, which have already been shown to be affected, we plan to consider locus of control, trust, SA, and mental representations. Each micro-review will contain a summary of the main issues and an experimental hypothesis (H). A detailed review of the factors can be found in Stanton & Young (2001).

One of the biggest unknowns in AICC operation is the reaction of the driver to the apparent loss of some of their driving autonomy. The idea that *locus of control* might have an effect upon performance is not new. Locus of control is determined by the extent to which drivers attribute their own activities as responsible for the behavior of the vehicle (an internal locus of control) or whether the behavior of the vehicle is due to the automated system (an external locus of control). An external locus of control might lead an individual to assume a passive role with the automated system, whereas an internal locus of control may lead individuals to assume an active role. Research in other domains suggests that drivers with an internal locus of control generally perform better than do individuals with an external locus of control (Rotter, 1966; Parkes, 1984). Montag & Comrey (1987) applied this research to driving and developed a subjective questionnaire for drivers to rate their own internality an externality scores. Although such factors are normally long-term personality traits, we wonder if the degree of internality/ externality reported might, to some extent at least, be affected by the environment. Do drivers report greater externality in the automated condition than when they are in the manual condition (H1)?

Muir (1994) proposed a model of *trust* between human and automated systems that could be applied to vehicle automation. This model identifies the three main factors of trust as predictability, dependability, and faith. The relation between predictability, dependability, and faith in humans is supposed to be temporal—predictability is the basis of dependability, which in turn leads to faith. If experience with a machine provides predictable outcomes, then an individual may start to depend upon that system. The increase in dependency may be observed by a decrease in sampling behavior as the outcome proves to be predictable. Increased dependency may lead the individual to believe that the machine is more capable than it actually is. We anticipate that drivers might have greater trust in the AICC system with higher levels of feedback (H2), despite Muir & Moray (1996) also showing that their participants would rather do the task manually than leave it to an automatic system.

Research on *situational awareness* (SA) in aviation and process control shows that the separation of perceived machine state from actual machine state leads to operational problems (Woods, 1988). This finding would imply that SA of the AICC system and the road environment is crucial for optimum performance. Endsley's (1995) model of SA proposes three levels of understanding—perception of the elements (e.g., reading the set speed), comprehending the situation (e.g., knowing that the vehicle is following a leading vehicle), and projecting future status (e.g., anticipating the trajectory of the vehicles and identifying any potential conflicts). This approach has been applied in many contexts, particularly in aviation, for which Taylor et al. (1995) developed a set of subjective rating scales for situational awareness. From the research literature on automation and SA (Woods, 1988), we anticipate that drivers with AICC will have less awareness of the situation when compared with manual driving (H3).

The concept of *mental models* is linked to SA, as an understanding of the current situation and projecting the future relies upon some model of the world and behavior of system elements. Internal mental representations about the behavior of devices are built up from exposure (Johnson-Laird, 1989). The accuracy of the models is determined by the effectiveness of the system interfaces (Norman, 1988) and the variety of situations encountered. Often approximations and incompleteness are found in these models, but they serve as working heuristics (Payne, 1991). These models can sometimes be wildly inaccurate (Caramazza et al., 1981). We anticipate that the accuracy of the mental model of the AICC system can be improved with higher levels of feedback (H4), as this informs the development of the model and helps the driver interpret what is going on.

Some controversy remains about whether AICC reduces *workload.* Some studies suggest that activating AICC is accompanied by reduction in driver workload (e.g., Stanton et al., 1997), whereas others suggest that it is not (e.g., Young & Stanton, 1997). In other domains, some authors have claimed that automation actually increases workload rather than reducing it (Reinartz & Gruppe (1993). Without a doubt, driving with AICC is quite different from driving with CCC, as Fig. 3 illustrates. The two tasks are qualitatively different. Whereas AICC subtracts the physical task of depressing the brake pedal, the device adds the task of monitoring the AICC system to ensure that it is operating effectively. This task swap might support the notion that overall workload is likely to remain unchanged (H5).

Driver *stress* has become a subject of much research in recent years. The research on this topic suggests that fatigue from the lack of stimuli is what drivers find most stressful, i.e., task underload rather than task overload (Matthews & Desmond, 1995; Matthews et al., 1996). Matthews et al. report that when the driving task is relatively difficult, fatigued drivers perform significantly better than when the driving task is easy. Matthews & Desmond suggest that in-car systems should be designed to create more attentional demand, not less. This notion seems to be counter to the research and development effort in vehicle automation, which is aimed at reducing driver workload. From this view, we might hypothesize that driving with AICC will be more stressful (H6). Yet, driving in congested traffic increases stress, which has been linked to road traffic offences (Simon & Corbett, 1996). From this finding, we might hypothesize that under high traffic conditions, AICC will actually reduce stress (H7).

2. EXPERIMENTAL

2.1 Participants

The study recruited 110 participants from the University of Southampton campus and via the local media. Ethical permission to conduct the research was sought and granted from the Department of Psychology at the University of Southampton. Participants were selected to reflect the age and gender of the driving population at large in the United Kingdom (U.K.). Of the participants, 42 were female. The average age was 33.6 years (minimum 18 years, maximum 73 years, standard deviation 12.7 years). The mean driving distance per annum of the participants was 10.5 thousand miles (standard deviation 6.6 thousand miles). Participants were randomly assigned to experimental conditions to match for age and gender.

2.2 Study Design

The study had three independent variables (automation, workload, feedback), three dependent variables associated with driving behavior (speed, lateral position, on road and headway), and six dependent variables associated with the psychology of the driver (locus of control, trust, workload, stress, mental models, and situational awareness). The assignment of the numbers of participants to the experimental conditions is presented in Table 1.

TABLE 1

Numbers of participants assigned to experimental conditions.

Workload/Feedback	Low	Medium	High
Low	12	12	12
Medium	12	14	12
High	12	12	12

The three levels of workload were determined by manipulating the throughput of vehicles per hour (VPH) as follows: 800 VPH (Low), 1600 VPH (Medium), and 2400 VPH (High). The three levels of feedback were manipulated by the degree of information provided by the AICC system as follows: auditory feedback only (Low); auditory feedback, plus standard messages on AICC display embedded in the instrument panel (Medium); and auditory feedback, plus standard messages on AICC display embedded in the instrument panel, together with a head-up display of the same information. The manual condition had no manipulation of feedback.

2.3 Equipment

The equipment comprised a driving simulator based on the Jaguar XK8 and a series of tools to measure the dependent variables. The driving-simulator environment is based around a fixed-based Jaguar XK8, a semi-immersive environment, with the emphasis on psychological and operational fidelity, placing it in the mid-range of driving simulators. Transducers connected to the steering, brake, and accelerator send digital signals to an Acorn Archimedes RISC PC. Software inside the Acorn interprets the signals to position the driver's trajectory along the motorway. The driver is presented with a three-lane motorway on a projection screen viewed through the windscreen of the XK8 via an Epson color LCD projection monitor. The simulation is fully interactive—the driver has full vehicle control and can interact with other vehicles on the road. The data logged include speed, position on the road, distance from other vehicles, steering wheel and pedal positions, overtakes, and collisions (taken every 0.5 seconds automatically by the simulator software). The AICC interface comprises a Liquid Crystal Display in the instrument cluster and a set of buttons inset into the steering wheel. A separate PC was used to drive this interface (an Elenex PC-466/1 and monitor). A Panasonic VCR NV-180 video recorder was used to record each participant's drive so that pertinent parts on the driver's interaction with the AICC could be assessed in a playback session.

The dependent measures were collected using the following tools:

1. A multidimensional trust scale based upon Muir (1994)
2. The Locus of Control inventory (LOCI) from Rotter (1966)
3. Driving Internality-Externality (MDIE) scales from Montag & Comrey (1987)
4. A subjective, multidimensional, workload scale: the NASA-TLX (Hart & Staveland, 1988)
5. The Dundee Stress State Questionnaire (DSSQ) (Matthews et al., 1999).
6. Situational Awareness Rating Technique (SART) (Taylor et al., 1995)

7. Two questionnaires about AICC operation: a ten-item multiple-choice questionnaire, and a series of 'what happens next' scenarios, to which a free-form response is required. These measures were developed by the researchers specifically for this project.
8. A post-task verbal protocol was used to assess how well the participants were able to explain their actions with AICC in the driving context. A video cassette player (Panasonic VCR NV-180) and monitor (LG 14" color TV) were used.

2.4 Procedure

The experimental procedure was as follows:

1. On agreeing to participate, participants met the experimenter at his office at a time arranged for the study.
2. On arrival, participants were escorted to the driving simulator laboratory.
3. Participants were briefed immediately prior to the study as follows:

   This study is investigating a new vehicle technology called Automatic Intelligent Cruise Control. In a moment, I will ask you to drive a practice run in the simulator, followed by two test runs. There are some questionnaires to be completed before and after these runs. At the end of the study, you will receive £10 for your participation. You are free to withdraw from the study at any time. Unless you have any objections about the study, would you please sign this consent form.

4. The participants then signed the consent form.
5. Then the participants completed the three pre-trial questionnaires on a computer, to establish a baseline. These questionnaires were the DSSQ, Rotters I-E scales, and the MDIE.
6. The participants were then asked to read the AICC manual to familiarize themselves with its operation and behavior.
7. When the participants were satisfied that they understood the operation of the AICC system, they were allowed to practice driving the simulator for 5 minutes under both AICC and manual control.
8. Participants who were undertaking the manual drive first received the following instructions:

You are on your way to work, which involves a 20-minute motorway drive. You are requested to keep your speed as close to 70 mph as possible. Other than that you should drive in your normal manner.

9. Participants who were undertaking the AICC drive first had the following instructions:

   You are on your way to work, which involves a 20-minute motorway drive. You are requested to keep your speed as close to 70 mph as possible. You should engage the AICC system as soon as possible with a set speed of 70 mph and leave it engaged for the remainder of the journey. Other than that you should drive in your normal manner.

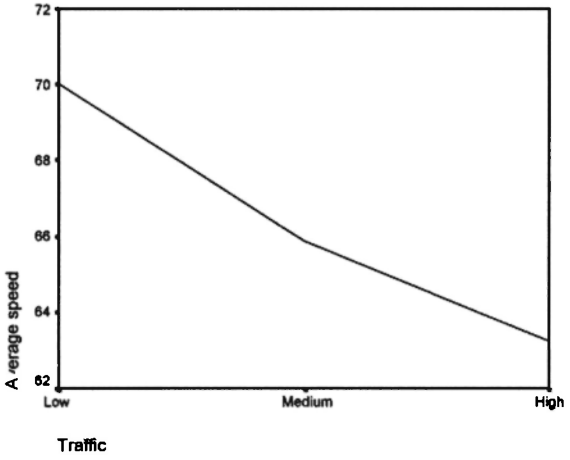
10. After completing each drive, the participants completed the NASA-TLX, SART, and DSSQ questionnaires on the computer. If they had completed the AICC drive, then they also completed the mental-model questionnaires and the trust questionnaire. Neither of these questionnaires was relevant to the manual condition.
11. After both drives, the participants were debriefed on the nature of the study and received a £10 payment.

2.5 Analysis

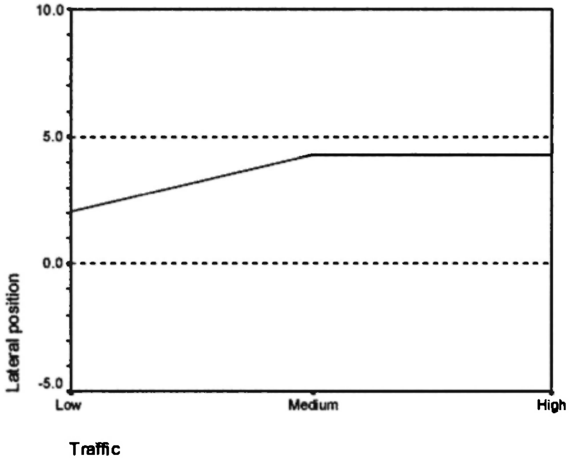
The Analysis of Variance (ANOVA) technique was used to see whether manipulation of the three independent variables (automation, workload, and feedback) had any effect upon the dependent variables (driving variables—speed, lateral position on road and headway; and psychological variables—locus of control, trust, workload, stress, mental models, and SA). Post-hoc contrasts and independent t-tests were computed for statistical significance.

3. RESULTS

The ANOVA was conducted on all driving and psychological variables. Because of the wealth of data produced, the analyses are divided according to factors, beginning with the objective driving performance data before moving on to the subjective psychological variables.



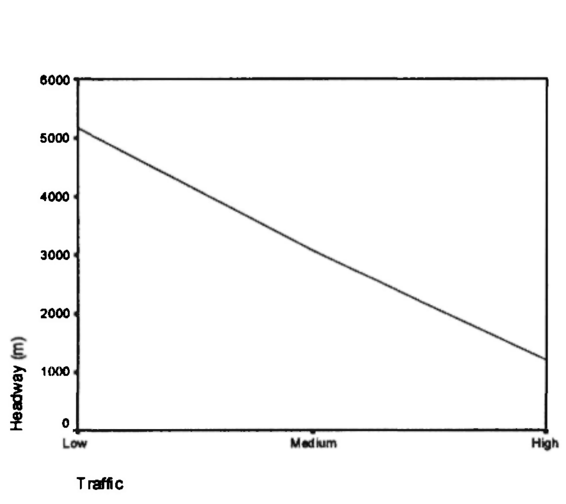
Graph 1
Mean speed for low, medium, and high traffic conditions.



Graph 2
Mean lateral road position for low, medium, and high traffic conditions

3.1 Driving Variables

A statistically significant main effect of traffic level was found for driving speed ($F_{2,109}$ = 21.2, $p < 0.001$), as shown in Graph 1. As traffic level increased, so the participants' speed decreased. A statistically significant main effect of traffic level was found for lateral road position ($F_{2\ 109}$ = 19.2, $p < 0.001$), as shown in Graph 2. As traffic level increased, so the lateral position of the participants moved to the right.



Graph 3
Mean headway for the low, medium, and high traffic conditions

A statistically significant main effect of automation was found for headway ($F_{2,109} = 5.3$, $p < 0.05$), with greater headway in the AICC condition. In addition, a statistically significant main effect of traffic level was found for headway ($F_{2,109} = 47.2$, $p < 0.001$), as shown in Graph 3. As traffic level increased, so the participants' headway decreased.

3.2 Locus of Control

Analysis of the responses recorded on Rotter's locus of control scale showed no statistical difference for either feedback ($F_{2,101} = 1.76$, ns[1]) or traffic level ($F_{2,101} = 1.01$, ns). In addition, the interaction between feedback and traffic was not significant for the LOCI scores ($F_{4,101} = 0.284$, ns).

Analysis of the MDIE scales revealed differences between participants on both the internality ($F_{2,101} = 3.29$, $p < 0.05$) and externality ($F_{2,101} = 4.08$, $p < 0.05$) scales in the pretrial measures. Post hoc t-tests showed that the participants in the medium-level traffic condition reported higher levels of internality than did those in the low-level ($p < 0.05$) and high-level ($p < 0.05$) conditions. The medium-level participants also reported lower levels of externality than did those in the low-level condition ($p < 0.05$).

[1] ns = not significant

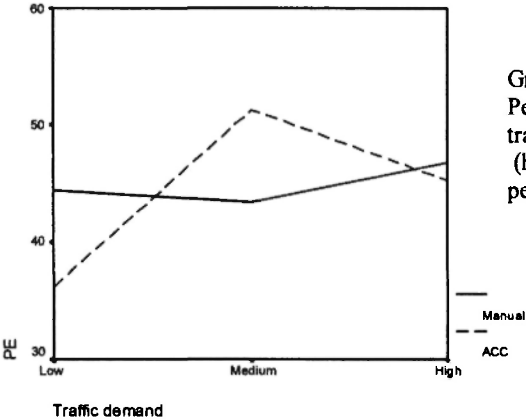
3.3 Workload

The NASA-TLX, as a multidimensional measure of workload, has six individual scales (mental demand, physical demand, temporal demand, performance, effort, and frustration; for details see Hart & Staveland, 1988). These scales contribute to an overall workload score, which is simply the arithmetic mean of the six individual scales.

Here, the NASA-TLX was analyzed as both the score of overall workload and at the level of individual scales. For overall workload (OWL), statistically significant differences were found between the experimental conditions. First, OWL was higher in the manual condition compared with the AICC condition ($F_{1,109} = 13.1$, $p < 0.001$). Second, the differences in the levels of OWL were associated with the levels of traffic ($F_{2,109} - 4.65$, $p < 0.05$). Post-hoc t-tests were used to explore these differences further. Specifically, OWL in the medium-traffic level condition was higher than that the in the low-traffic level condition ($p < 0.005$), and OWL in the high-traffic level condition was higher than that in the low-traffic level condition ($p < 0.01$). No statistical difference between the OWL scores in the medium-traffic and the high-traffic level conditions was found, suggesting a ceiling effect.

Statistically significant differences were found in mental demand (MD) for both automation ($F_{1,109} = 13.7$, $p < 0.001$), for which MD was higher in the manual condition compared with the AICC condition ($p < 0.001$) and for the level of traffic ($F_{2,109} = 5.31$, $p < 0.01$). These effects were further explored with post-hoc t-tests. Mental demand in the medium-traffic condition was higher than that in the low-traffic condition ($p < 0.005$); and MD in the high-traffic condition was higher than that in the low-traffic condition ($p < 0.01$). No statistical difference was found between MD in the medium-traffic and the high-traffic conditions, again suggesting a ceiling effect.

Statistically significant differences were found in physical demand (PD) for automation ($F_{1,109} = 11.2$, $p < 0.005$), for which PD was higher in the manual condition compared with the AICC condition ($p < 0.001$). There was also an interaction effect between automation and the traffic level ($F_{2,109} = 4.44$, $p < 0.05$), for which PD was higher for participants in the manual condition than in the AICC condition in low-traffic ($p < 0.005$) and high-traffic ($p < 0.05$) conditions.



GrGraph 4
PePerformance plotted against tratraffic levels and automation (h(high score relates to a poor pe performance rating)

A statistically significant difference was found in temporal demand (TD), with higher demand in the manual condition when compared with the AICC condition ($F_{1.109} = 5.6$, $p < 0.05$). No other statistical differences in temporal demand were found.

A statistical interaction for performance (PE) was found between automation and traffic level ($F_{2\,109} = 3.99$, $p < 0.05$), as shown in Graph 4. Post-hoc paired t-tests showed that PE was rated as higher (i.e., subjectively worse performance) in the manual condition under low-traffic levels ($p < 0.05$), and higher in the AICC condition under medium-traffic levels ($p < 0.05$). Independent t-tests revealed that PE within the AICC condition was rated as higher in the medium-traffic level condition compared with the low-traffic level condition ($p < 0.005$).

A statistically significant difference was found between the automation conditions for the level of perceived effort (EF; $F_{1.109} = 12.9$, $p < 0.001$), with greater levels of EF rated in the manual compared with the AICC condition ($p < 0.005$).

Finally, statistically significant differences were found between the traffic levels on frustration (FR; $F_{2,108} = 3.97$, $p < 0.05$), with higher levels of FR in the medium-traffic ($p < 0.05$) and high traffic conditions ($p < 0.005$) when compared with the low-traffic condition. No statistical differences were found between the high and medium-traffic demand conditions.

3.4 Situational Awareness

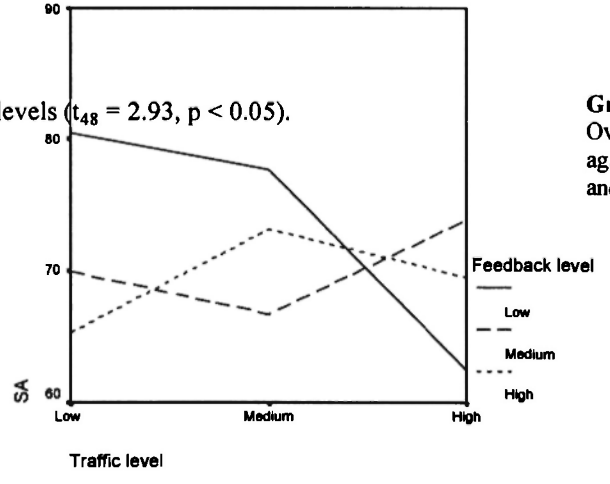
Situational awareness (SA) in the SART questionnaire is divided into overall SA and three main subscales:

1. demand on attentional resources (which is further subdivided into scales of: instability of situation, complexity of situation, variability of situation),
2. supply of attentional resources (which is further subdivided into scales of: arousal, concentration of attention, divided attention, spare mental capacity), and
3. understanding of situation (which is further subdivided into scales of: information quantity, information quality, familiarity with situation).

This framework will be used to structure the analyses.

Analysis of overall SA revealed an interaction between the traffic levels and the level of feedback ($F_{4.109} = 3.04$, $p < 0.05$), as shown in Graph 5. Post-hoc t-tests show that for the low traffic levels, low feedback resulted in higher SA than did medium feedback ($t_{46} = 2.49$, $p < 0.05$) and high feedback ($t_{46} = 3.02$, $p < 0.005$). In the high traffic level, medium feedback resulted in higher SA than did low feedback ($t_{46} = -2.22$, $p < 0.05$). In the low-feedback condition, SA was higher in low-traffic levels when compared with high-traffic levels ($t_{46} = 3.52$, $p < 0.005$) and in medium-traffic levels compared with high-traffic levels.

levels ($t_{48} = 2.93$, $p < 0.05$).



Graph 5
Overall SA plotted against traffic levels and feedback.

Analysis of the main subscale of demand on attentional resources revealed a main effect for automation, with higher demand in the manual condition ($F_{1,109} = 12.2$, $p < 0.005$). An automation main effect was also found for the subscale of instability ($F_{1,109} = 12.2$, $p < 0.005$). The traffic main effect revealed differences between traffic levels and reported instability ($F_{2,109} = 6.38$, $p < 0.005$). Further analyses revealed that the levels of instability were lower in the low-traffic level when compared with medium- ($t_{162} = -3.77$, $p < 0.001$) and high-traffic levels ($t_{142} = -2.59$, $p < 0.05$). Some of these effects might be due the higher proportion of 'internals' in the medium-traffic-level condition. An interaction also occurred between traffic levels and automation ($F_{2,109} = 5.4$, $p < 0.001$). Post hoc t-tests revealed that in the AICC condition, the medium-traffic-level condition was rated higher on instability than were the low=- ($t_{80} = -5.06$, $p < 0.001$) and high- ($t_{80} = 2.16$, $p < 0.05$) traffic levels. Additionally, the high-traffic level was rated higher on instability than was the low-traffic level ($t_{70} = -2.52$, $p < 0.05$). The manual condition was rated higher on instability when compared with the AICC condition in low-traffic-level ($t_{35} = 3.94$, $p < 0.001$) and high-traffic-level ($t_{35} = -2.6$, $p < 0.05$) conditions.

A main effect for traffic level was found for the rating of complexity ($F_{2,109} = 3.65$, $p < 0.05$). Complexity was rated significantly lower in the low-traffic-level condition compared with medium- ($t_{162} = -3.21$, $p < 0.005$) and high-traffic levels ($t_{142} = -2.18$, $p < 0.05$). An interaction effect between automation and traffic level was also found for the rating of complexity ($F_{2,109} = 3.49$, $p < 0.05$). For the AICC condition, complexity was rated significantly lower in the low-traffic-level condition when compared with medium- ($t_{80} = -4.17$, $p < 0.005$) and high-traffic levels ($t_{70} = -2.12$, $p < 0.05$). Complexity was also rated lower in the AICC condition when compared with the manual condition ($t_{135} = -2.35$, $p < 0.05$).

Analysis of the main subscale of supply of attentional resources revealed a main effect for automation, with higher supply in the manual condition ($F_{1,109} = 13.9$, $p < 0.001$). Arousal also showed a statistically significant difference between the levels of automation ($F_{1,109} = 7.12$, $p < 0.001$), for which the arousal was higher in the manual condition. Concentration shows a statistically significant difference between the levels of automation ($F_{1,109} = 12.7$, $p < 0.005$), for which the concentration was higher in the manual condition.

Finally, an interaction effect was found between automation and feedback for spare capacity ($F_{2,109} = 3.69$, $p < 0.05$), for which spare capacity was greater in the AICC condition than in the manual condition under medium-traffic levels ($t_{43} = 2.3$, $p < 0.05$).

Analysis of the main subscale of understanding of situation revealed an interaction effect between automation and traffic levels ($F_{2,109} = 3.48$, $p < 0.05$). In the manual condition, understanding is rated higher in the medium-traffic level than in low-traffic ($t_{80} = -2.23$, $p < 0.05$) or high-traffic ($t_{80} = 2.06$, $p < 0.05$) levels. Understanding in the AICC condition is also rated lower than in the manual condition ($t_{35} = 2.6$, $p < 0.05$).

A main effect for traffic levels was found for information quantity ($F_{2,109} = 3.72$, $p < 0.05$). Information quantity was rated higher in high-traffic level than in low-traffic ($t_{142} = 2.00$, $p < 0.05$) or medium-traffic ($t_{162} = 2.94$, $p < 0.005$) levels.

An interaction effect between automation and traffic levels was found for information quality ($F_{2,109} = 5.76$, $p < 0.005$). In the manual condition, information quality is rated higher in the high-traffic level than in the medium-traffic level ($t_{79} = -2.12$, $p < 0.05$). Information quality was also rated higher in the AICC condition compared with the manual condition ($t_{43} = 2.98$, $p < 0.01$). A main effect for automation was also found for familiarity ($F_{1,109} = 21.5$, $p < 0.001$).

3.5 Trust

No statistically significant results were found for levels of overall trust on either the feedback ($F_{2,109} = 0.311$, $p = ns$) or traffic conditions ($F_{2,109} = 0.305$, $p = ns$), nor did a significant interaction occur between these parameters ($F_{4,109} = 1.55$, $p = ns$).

3.6 Mental Models

No statistically significant results were found for any of the measures of mental representations between the experimental conditions. The statistics are summarized in Table 2 below.

TABLE 2

Statistics for mental models questionnaires according to experimental condition

	Feedback	Traffic	Interaction
Multiple-choice	$F_{2,101} = 1.22$, p = ns	$F_{2,101} = 0.551$, p = n	$F_{4,101} = 1.03$, p = ns
What happens next	$F_{2,101} = 1.65$, p = ns	$F_{2,101} = 1.13$, p = ns	$F_{4,101} = 0.485$, p = n
Verbal protocol	$F_{2,101} = 1.24$, p = ns	$F_{2,101} = 1.67$, p = ns	$F_{4,101} = 2.30$, p = ns

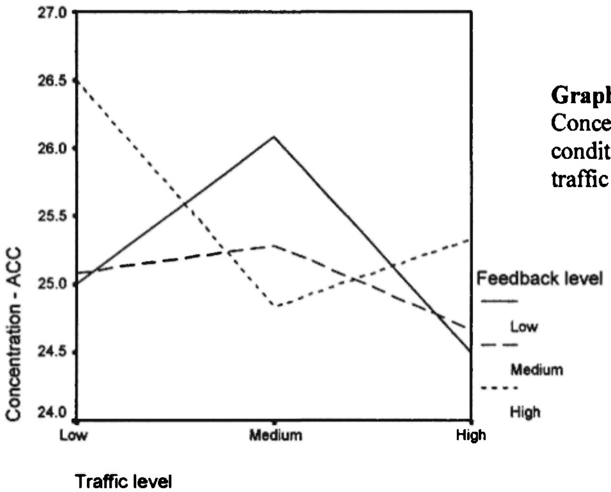
3.7 Stress

The DSSQ is subdivided into scales of: anger, concentration, control and confidence, hedonic tone, motivation, self-esteem, self-focused attention, task-irrelevant interference, task-related interference, and tense arousal. This list of scales will serve as a means of ordering the sequence of analyses.

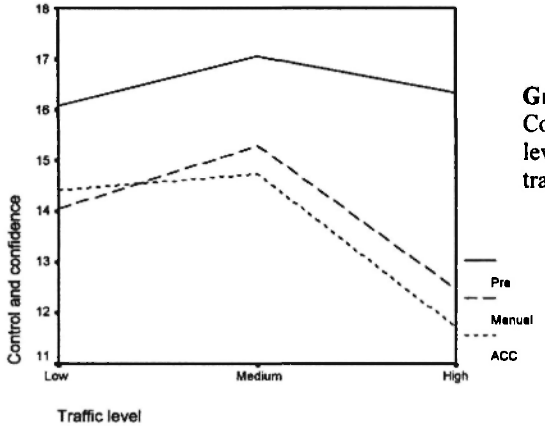
The analysis of the anger scales revealed a main effect of automation ($F_{2,202} = 6.12$, $p < 0.005$). Anger scores were higher in the manual condition than in the pre-driving condition ($t_{109} = -3.34$, $p < 0.005$) or the AICC condition ($t_{109} = 2.13$, $p < 0.05$).

A main effect of automation for the concentration scores ($F_{2\ 202} = 3.75$, $p < 0.05$) was also found. Concentration scores were higher in the AICC condition than in the pre-driving condition ($t_{109} = 2.45$, $p < 0.05$). A complicated three-way interaction effect also occurred between automation, feedback, and traffic levels ($F_{8,202} = 2.20$, $p < 0.05$). As Graph 6 shows, the reported concentration levels for medium feedback were more consistent across traffic levels than for low or high feedback in the AICC condition. High feedback appears to have required more concentration in the low-traffic-demand condition, and low feedback appears to have required more concentration in the medium-traffic-demand condition.

Analysis of the control and confidence scale revealed a main effect for automation ($F_{2\ 202} = 41.6$, $p < 0.001$). Control and confidence was higher in the pre-driving condition than in the manual condition ($t_{109} = -6.89$, $p < 0.001$) or the AICC condition ($t_{109} = -7.46$, $p < 0.001$). A traffic level-main effect was found for control and confidence ($F_{2,101} = 4.14$, $p < 0.05$), as illustrated in Graph 7. Control and confidence was higher in the medium-traffic



Graph 6
Concentrationin the AICC condition for feedback against traffic levels.



Graph 7
Control and confidence for the levels of automation against traffic levels.

level condition than in the high-traffic-level condition (t_{220} = 4.00, $p < 0.001$) and higher in the low-traffic-level condition than in the high-traffic-level condition (t_{214} = 2.51, $p < 0.05$). An interaction also took place between automation and the traffic level ($F_{4.202}$ = 3.83, $p < 0.01$), as shown in Graph 7.

Analysis of the hedonic tone scale revealed a main effect for automation ($F_{2.202}$ = 34.3, $p < 0.001$). Hedonic tone was higher in the pre-driving condition than in the manual condition (t_{109} = –7.75, $p < 0.001$) and higher in the pre-driving condition than in the AICC condition (t_{109} = –6.21, $p < 0.001$). A traffic level main effect was also found for hedonic tone ($F_{2.101}$ = 3.20, $p < 0.05$). Hedonic tone was higher in the medium-traffic-level condition than in the high-traffic-level condition (t_{220} = 2.63, $p < 0.01$) and higher in the low-traffic-level condition than in the high-traffic-level condition (t_{214} = 2.87, $p < 0.005$).

An automation main effect was found for the motivation scale ($F_{2\,202}$ = 14.4, $p < 0.001$). Motivation was higher in the pre-driving condition than in the AICC condition (t_{109} = –4.58, $p < 0.001$) and higher in the pre-driving condition than in the manual condition (t_{109} = –4.18, $p < 0.001$).

An automation main effect was found for the self-esteem scale ($F_{2.202}$ = 47.6, $p < 0.001$). Self-esteem was higher in the pre-driving condition than in the AICC condition (t_{109} = 7.26, $p < 0.001$) and higher in the pre-driving condition than in the manual condition (t_{109} = 8.33, $p < 0.001$).

An automation main effect was found for the self-focused attention scale ($F_{2,202}$ = 125.6 $p < 0.001$). Self-focused attention was higher in the pre-driving condition than in the AICC condition (t_{109} = 12.2, $p < 0.001$) and higher in the pre-driving condition than in the manual condition (t_{109} = 13.2, $p < 0.001$).

An automation main effect was found for the task-irrelevant interference scale ($F_{2.202}$ = 46.2 $p < 0.001$). Task-irrelevant interference was higher in the pre-driving condition than in the AICC condition (t_{109} = –7.04, $p < 0.001$) and higher in the pre-driving condition than in the manual condition (t_{109} = –7.38, $p < 0.001$). Task-irrelevant interference was also higher in the AICC condition than in the manual condition (t_{109} = 2.42, $p < 0.05$).

An automation main effect was found for the task-related interference scale ($F_{2.202}$ = 5.52 $p < 0.01$). Task-related interference was higher in the AICC condition than in the pre-driving condition (t_{109} = 2.38, $p < 0.05$) and higher in the manual condition than in the pre-driving condition (t_{109} = 3.38, $p < 0.05$). An interaction effect between automation and traffic levels was found for task-related interference ($F_{4.202}$ = 2.62, $p < 0.05$). In the medium traffic level, task-related interference was higher in the manual condition than in the pre-driving condition (t_{37} = 2.68, $p < 0.05$) and higher in the AICC condition than in the pre-driving condition (t_{37} = 3.07, $p < 0.05$). In the high traffic level, task-related interference was higher in the manual condition than in the pre-driving condition (t_{35} = 2.41, $p < 0.05$) and higher in the AICC condition than in the pre-driving condition (t_{35} = 2,79, $p < 0.05$)

An automation main effect was found for the tense arousal scale ($F_{2.202}$ = 4.39 $p < 0.05$). Tense arousal was higher in the manual condition than in the pre-driving condition (t_{109} = 2.89, $p < 0.01$). An interaction effect between automation and traffic levels was found for tense arousal ($F_{4,202} = 4.28$, $p < 0.005$). In the pre-driving condition, tense arousal was higher in the medium traffic level than in the low traffic level ($t_{72} = 2.43$, $p < 0.05$) and higher in the high traffic level than in the low traffic level ($t_{70} = 2.03$, $p < 0.05$). In the medium traffic level, tense arousal was higher in the AICC condition than in the pre-driving condition ($t_{37} = 2.20$, $p < 0.005$). In the high traffic level condition, tense arousal was higher in the manual condition than in the pre-driving condition ($t_{35} = 3.62$, $p < 0.005$) and higher in the AICC condition than in the pre-driving condition ($t_{35} = 2.68$, $p < 0.05$).

3.8 Summary of Results

The results of the ANOVA study are summarized in Table 3, together with the implications for the experimental hypothesizes.

4. DISCUSSION AND CONCLUSIONS

In summary, the ANOVA study shows six main findings.

- First, increases in traffic density are associated with slower speeds, traffic moving into the right-hand (overtaking) lane, and shorter headways. Although this is an obvious result, it does give some credibility for the accuracy of the simulation.
- Second, the locus-of-control scales are highly stable, which means that control loci are not affected by automation.
- Third, the higher workload experienced by participants in the manual condition confirms that automation by invoking AICC is associated with reduced workload in normal operation.
- Fourth, workload is higher in higher traffic levels.
- Fifth, greater stress is also associated with higher traffic. These two points might lead us to suppose that AICC might be of greatest benefit at higher traffic levels.
- Finally, higher situational awareness (SA) was associated with the medium feedback condition (i.e., where information on the status of the AICC system was presented on the instrument cluster in the car).

TABLE 3

Summary of results

Variable	**Summary finding**	**Hypothesis**
Speed	Lower speeds with higher traffic levels	
Lateral position	Medium and high traffic level more likely to be in the overtaking lane	
Headway	Shorter headways with higher traffic levels AICC led to greater headways	
Locus of control	Medium traffic level condition has higher internality scores and lower externality scores than the low or high conditions	H1 = false
Trust	No statistical differences	H2 = false
Situational awareness (SA)	For overall SA, under low traffic levels, low feedback leads to greater SA For overall SA, under high traffic levels, medium feedback leads to greater SA Greater demand on attentional resources in manual driving compared with AICC Greater supply of attentional resources in manual driving compared with AICC Greater understanding of the situation in manual driving compared with AICC	H3 = true
Mental models	No statistical differences	H4 = false
Workload	Greater overall workload in manual driving compared with AICC Greater overall workload in medium and high traffic levels compared with low traffic levels Greater mental demand in manual driving compared with AICC Greater mental demand in medium and high traffic levels compared with low traffic levels Greater physical demand in manual driving compared with AICC Greater temporal demand in manual driving compared to AICC In manual condition, performance is rated as worse in the high traffic level than medium traffic level In AICC condition, performance is worse in the medium traffic level than low traffic level Greater effort in manual driving compared with AICC Greater frustration in medium and high traffic levels compared with low traffic levels	H5 = false
Stress	Driving leads to greater stress than not driving Driving in higher traffic levels leads to more stress than in lower traffic levels Greater anger in manual driving than AICC Greater task-irrelevant interference in AICC than manual driving	H6 = false H7 = true

The stability of locus of control is consistent with the results of previous research. Prior research into manual driving has shown that 'externals' are less cautious, less attentive, and more likely to be involved in accidents than are 'internals' (Montag & Comrey, 1987; Holland, 1993; Lajunen & Summala, 1995). This position might be exacerbated though automation. One possible solution to this problem might be to investigate driver-training programs that emphasize the development of an internal locus of control.

The reduction of workload in the AICC condition might be a cause for concern in very low-traffic levels, whereas it could be a welcome relief under very high-traffic levels. Workload research argues for an optimal level, neither underloading nor overloading the individual (Parasuraman & Riley, 1997). It is difficult to imagine how a seamless transition between manual and automatic headway control could be designed so that it would respond to changes in the level of road traffic. At present, the decision to transfer control to AICC remains with the driver. Getting control back from AICC is fairly seamless as this task requires only that the driver brake or accelerate. As the AICC system has the potential to monitor the amount of braking and accelerating that both the AICC and the driver are performing, the system could prompt the driver to take back control under conditions of very low workload and suggest that AICC take over under in conditions of high workload. Exactly how this program might be realized could be the subject of further research.

Increasing the driver's SA is a key to successful automation. In this study, we found that provision of a head-up display (HUD) mirroring the AICC status from the instrument cluster display actually reduces the reported SA. Perhaps one reason for this finding is that with the instrument cluster display, drivers could have discretion over when they want to sample the information, whereas with the HUD, the data are displayed all the time. Therefore, the HUD might have made the driving task more visually complex (e.g., by adding clutter to the visual scene, and even the process of blocking out the information requires some processing effort) and might have reduced overall SA. Under low workload (i.e., low traffic conditions), the low feedback system (comprising the auditory warning only and no visual display) was found to lead to the highest reported SA. Under these conditions, the simplest interface is likely to be the most appropriate because it reduces driver distraction. Under medium and high traffic levels associated with higher workloads, the medium feedback system (comprising the auditory warning and the LCD message display embedded in the instrument cluster) led to the highest level of reported SA. The irony here is that the design considerations that optimize SA may well have a negative effect on workload and vice versa. For instance, if an interface is simplified to improve SA, this change can also have the effect of reducing workload. Depending upon the context of performance, reductions in workload may not be desirable.

The AICC system certainly seems to fulfill its role as a comfort and convenience device because it reduces both driver workload and anger when compared with manual driving. The stress-reducing aspects of AICC are likely to be of most benefit at higher traffic levels, when driver stress is reported to be at its highest. This benefit comes at a price, however, because reduced 'understanding' of the situation has been reported in the AICC condition. The reasons for a greater 'understanding' by drivers in the manual condition can be explained by arguments of 'in-the-loop' and 'out-of-the-loop' behavior. On the face of it, reducing the drivers' workload might plausibly be associated with increased SA because they have potentially greater opportunities to seek information and process it. This opportunity is counteracted by the removal of the driver from the task of longitudinal control, which in classic ergonomics research is referred to as "out-of-the-loop control". There is no longer any requirement for the driver to attend to the feedback because s/he does not need it to control the vehicle. Bainbridge (1983) argued that the passive role of monitoring an automatic system is less satisfactory from a human performance perspective than is the active role of controlling it. In this respect, Young & Stanton (2001) draw a parallel between automation and skilled performance, or *automaticity*.

Driving, as a classic example of an automatic skill, is marked by an unconscious processing of information and responding appropriately. Automation, too, removes the driver from conscious control of the driving task. If task demands change—perhaps because of some critical event on the road—then both automaticity and automation require the driver to resume conscious control. Young & Stanton (2001), however, argue that the driver using automation is at a disadvantage, due to the lack of a relevant knowledge base to draw upon to cope with the change in demands. The implication is that automation provides a kind of 'false expertise', whereby automation lulls drivers into a false sense of security. This false sense can extend to their metacognitive abilities, in particular to their own perceptions of SA. Experienced drivers, under manual control, are attending to numerous stimuli without really being aware of it. Hence, although one might reasonably argue that drivers have a greater opportunity to sample the world when they are not involved in longitudinal control, they may not know what they should be attending to.

Ideally, we would like to design the AICC system so that it leads to the benefits of reduced workload and stress under high traffic density, but without reducing the driver's understanding. To understand how this goal might be achieved, we turn to the research on SA. Concerns have been expressed for the reductions in pilot's SA with the advent of the glass cockpit (Jenson, 1997). As with pilots, drivers have to track events in the world if they are to maintain adequate SA. The SA concept seems to be particularly appropriate for driving because the driving task shares many of the same elements as do the other domains in which SA has been used—multiple goals, multiple tasks, performance under time stress, and negative consequences associated with poor performance (Kaber & Endsley, 1997).

In terms of Endsley's (1995) three-level model, we would argue that the AICC interface should be designed in a manner that identifies features in the world to which the driver should attend, to promote perception of the elements, comprehension of the current situation, and projection of future status. The current design of AICC is largely centered on parsing messages about the status of the AICC system (e.g., messages on the mode AICC is in, such as: 'cruising', 'following', standby', or 'driver intervene'). The driver is required to integrate this information with what is happening outside the vehicle. Endsley (1995) argues that an interface design should ideally provide an overview of the situation and support pro-jection of future events, as well as providing cues of current mode awareness. To translate these guide- lines into the design of AICC would require a radical departure from traditional in-car interface design. Typically, systems report only on their own status; they do not integrate the data with the status of other systems, nor do they offer any predictive information. This is not to say that it cannot be achieved, however, as the AICC system readily processes much of this information already, it just doesn't display it to the driver yet.

Therefore, the AICC system of the future may require a new kind of display to help the driver identify cues in the world that he should attend to and to offer predictions about their future trajectory in relation to the driver's own vehicle. We imagine that this information could be presented to identify potential conflicts between the driver's own vehicle and other vehicles based upon the trajectory of both vehicles. For example, the speed of the leading vehicle could be presented, and/or the difference in the two vehicles relative speed, and/or a recommended separation. Ideally, the design of the interface would have to reduce the reliance on drivers to make calculations and to make comprehension and prediction easier (Endsley, 1995).

To conclude, this study has shown that there are benefits associated with AICC as a comfort and convenience device. We should point out that despite the morbid fascination with AICC in critical situations, in the study undertaken here, none of the drivers encountered life-threatening situations. AICC is likely to be of most use to the driver in high demand situations as a potential means of alleviating driver stress and workload. At present, the use of an HUD to present textual information on AICC mode status is not recommended because it appears to be associated with lower levels of reported SA. Future research should address this issue, using objective measures of SA and designing interfaces that support SA acquisition with the minimum of cognitive effort.

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