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Comparing the Driving Performance of Average and Older Drivers: The Effect of Surrogate In-Vehicle Information Systems

Natasha Merat[1*], Virpi Anttila[2] and Juha Luoma[2]

[1]Institute for Transport Studies, University of Leeds, Leeds, LS2 9JT, U.K.

Tel: +44 113 343 5730, Fax: +44 113 343 5334, Email: N.Merat@its.leeds.ac.uk

[2]Communities and Infrastructure, Technical Research Centre of Finland (VTT), Finland.

*To whom all correspondence should be addressed

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Abstract

This paper outlines the results of a study conducted as part of the EU funded FP5 project HASTE (Human Machine Interface And the Safety of Traffic in Europe). Two Surrogate In-Vehicle Information Systems (S-IVIS) were developed for this study: a visual S-IVIS was designed to investigate the effect of increasing visual information on driving performance, whilst the effect of increasing cognitive demand was studied using a non-visual auditory memory task. The interaction between each of these tasks and driving was then observed in a field study using Finnish drivers, and in the Leeds Advanced Driving Simulator, using British subjects. For each site, drivers were allocated to one of two age groups: (i) average drivers aged between 25 and 50, with at least five years' driving experience and (ii) older participants over the age of 60 who drove an average of 10,000 miles per year.

Each secondary task was performed in isolation, and in combination with driving. As shown in previous research, compared to the older drivers, average drivers were more successful at performing the two S-IVIS tasks, both in isolation, and with driving. In the field, the effect of the two S-IVIS tasks was found to be more profound on older drivers, resulting in closer car following, more speed variation and less lane keeping compared to average drivers. The effect of the two secondary tasks on simulated driving was found to be slightly different to that of the field drives, with older drivers keeping longer distance headways and reducing their speed in the presence of the S-IVIS tasks. The implications of these findings are discussed.

1. Introduction

An increasing proportion of cars manufactured in the 21st century are equipped with an assortment of In-Vehicle Information Systems (IVIS), varying from simple warning sounds and lights, to more sophisticated navigation and telecommunication systems. Most of these systems are designed to assist with the driving task, and their main purpose is to increase road safety. However, the design of many of these systems is usually based on the 'average driver' and the requirements of drivers with special needs and psychophysiological limitations, such as the elderly, are not always taken into account.

The population of older people in the western world is on the increase, whilst changes in lifestyle and a desire to be more active and independent for longer in life means that the number of older drivers is growing continuously. For instance, in 2001, around two million licence holders were over the age of 70 in the UK (Holland, 2001). This number is estimated to rise to 4.5 million by 2015 (Noble, 2000). There is currently no age limit for British drivers within the UK, although drivers over the age of 70 are required to complete a self-assessment form detailing their medical health status, and this form must then be updated every three years. Across Europe, a number of different procedures are used for the renewal of older drivers' licence, and there are currently no uniform policies in place on this matter (RoSPA, 2001).

According to a recent report compiled by the European Conference of Ministers of Transport (2001), the road traffic accident pattern of the elderly can be summarised as follows:

a) Based on police reports, elderly drivers tend to be at fault in their collisions. The cause of the accident is seldom due to careless or aggressive behaviour but most of the time is due to their inability to handle complex traffic situations.

b) Elderly drivers are not as often involved in single vehicle accidents, but they are *over-represented* in multi-vehicle accidents.

c) Accidents involving older drivers typically occur at intersections, not on road sections. The dominant accident type is where the elderly driver is turning against oncoming traffic on the main road that has right-of-way. Obviously important factors are a slower reaction time, sometimes combined with an inability to correctly assess gaps in the oncoming traffic stream.

d) According to this report, elderly drivers' small share of accidents as non-responsible parties reflects their slower, conservative and cautious driving styles. Older drivers are less inclined to speeding, overtaking, zigzagging or not complying with police instructions.

e) Per person, the elderly are less often involved in accidents than young drivers (those under the age of 25), but their chance of getting involved in an accident per kilometre is relatively high, with the risk being just as high as for young drivers.

Despite these accident patterns, studies comparing the driving skills of older drivers with that of younger drivers have shown quite small differences between the two groups (e.g., Carr, Jackson, Madden & Cohen, 1992; Schlag, 1993). This small difference in the everyday driving performance of the young and old is contrasted with relatively larger differences in performance observed during laboratory experiments. Schlag argues that any impairments in the psychophysiological abilities of older drivers seen in the laboratory is unlikely to affect 'normal', low to medium levels of driving. On the other hand, large differences between young and older drivers start to occur when the driving task becomes more complicated, for instance due to an increase in traffic density or because of the necessity to perform other non-driving related tasks.

Of course, drivers "age" at different rates, and old age alone cannot be an indication of impaired driving ability per se. In addition, while the ageing process itself can result in some impairment of psychophysiological processes, old age is commonly accompanied by health problems that can exacerbate the situation. The range and severity of these health problems varies across an elderly population and the medication prescribed for such illnesses can itself affect performance and functioning. Therefore, results from studies on the older population have a tendency to show large variation between subjects, and it is more difficult to describe the performance of 'an average older driver'.

Nevertheless, ageing is usually associated with one or a series of psychophysiological changes that can contribute to a diminished driving ability. Common problems associated with ageing include impaired visual and auditory perception, as well as a decline in motor and cognitive abilities. Clearly, any deterioration in psychophysiological processes may also have an effect on older drivers' ability to interact with in-vehicle information systems, which can in itself be detrimental to the driving task.

For instance, from forty years of age, visual acuity (the ability to resolve fine detail) and our ability to focus on near objects starts to decline. Therefore, in the absence of bifocal or progressive lens glasses, any information presented on a visual IVIS in small fonts will be difficult to read. In fact, Hawthorn (2000) argues that even with bifocal glasses, screens providing information in the car are positioned at a distance that usually results in blurred vision. The *processing* of visual information is also shown to be a problem in older adults. For instance, compared to young participants, older adults tend to be worse at tasks which require detection of target objects amongst distracters, find it more difficult to identify fragmented or incomplete objects (Salthouse & Prill, 1988) and are poor at recognising objects which are imbedded in other objects (Capitani, et al, 1988). Therefore, visual information presented by systems in the car should use simple but large text formats, and the presence of overcomplicated and irrelevant visual items should either be reduced, or an option should exist for their exclusion. Indeed, the communication of complicated in-vehicle information by purely visual means is best avoided for the older driver.

The ageing process is also known to affect physical mobility and motor ability. As well as a general atrophy of muscle fibres, bone mass and nerve fibres with age; physical strength and speed of motor response can be impaired by age-related medical conditions such as arthritis. Examples of decline in motor ability include an increase in response time for more complex motor tasks (Spiriduso, 1995), impaired tracking abilities (Jagacinski, Liao and Fayyad, 1995) and a reduced ability to control repetitive speeds such as finger tapping (Krampe and Ericsson, 1996). However, ageing is not thought to affect simple discrete tasks or actions that are more familiar to subjects (Salthouse, 1996). Therefore, the physical limitations imposed by ageing are not likely to restrict older drivers' interaction with an IVIS, since it is not the movement per se that is impaired by ageing, but the requirement to plan, reprogramme and control the execution of a movement (e.g. Gottsdanker, 1980). Nevertheless, IVIS that require very accurate and minute motor movements are likely to be challenging for older drivers, and due to difficulties associated with switching between two tasks, older drivers are also likely to require longer periods of training before they are able to interact successfully with an in-vehicle system, whilst driving. Age-related physical problems also mean that driver-paced IVIS are probably more beneficial than system-paced machines for this group of drivers.

Selective attention, or our ability to select important information from a background of irrelevant information, is shown to decline with age (e.g. Connelly and Hasher, 1993). This impaired ability to selectively attend to relevant information in the presence of distracters is shown to be highly correlated with the rate of driving accidents (Parasuraman & Nestor, 1991). On the other hand, tests of divided attention, where subjects are required to attend to more than one task at any one time, and sustained attention, which is required during vigilance tasks, are not found to be as highly correlated with the occurrence of accidents. Indeed, studies on the effect of age on divided and sustained attention have shown mixed results. For instance, if the tasks requiring division of attention are not too complex, their performance is shown to improve with practice, as these tasks become progressively more automated (e.g. Fisk & Rogers, 1991). Therefore, division of attention within driving (or between driving and in-vehicle systems) may be achievable under normal, low-level, driving conditions, but an increase in the difficulty of either task (e.g. driving through a heavy traffic junction) would reduce any residual cognitive resources available for the other task. If central resources are already limited, for instance due to ageing, then performance in one or both tasks is likely to deteriorate.

The experiments outlined in this paper were designed for the project HASTE (Human Machine Interface And the Safety of Traffic in Europe). One of the main objectives of this EU FP5 project was to develop methodologies and guidelines for the assessment of In-Vehicle Information Systems, and to assess the impact of increasing task load from an IVIS on driving performance and safety. Two surrogate IVIS (S-IVIS) tasks were designed for the HASTE project, and the interaction between these tasks and a variety of driving scenarios was considered. To examine the effect of age, a group of older adults (over the age of 60) were also recruited. The main reason for including this group of adults was to examine their interaction with the S-IVIS in a dynamic driving environment, and compare their performance with that of 'average' drivers. In particular, it was important to establish whether driving behaviour of the two age groups would be affected in the same way by the two S-IVIS tasks. The experiments also intended to establish whether older drivers were more likely to abandon the relatively less important S-IVIS task during more demanding driving conditions.

2. Method

The effect of age on S-IVIS and driving performance was examined using the Leeds Advanced Driving Simulator (LADS) in the UK, and the VTT Instrumented Vehicle in Finland. Forty eight participants were recruited at each test site, and in order to test the effects of age on performance, half of this group was aged between 25 and 50[1], whilst the other half were required to be over the age of 60. The Finnish studies

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[1] From this point on, these participants will be referred to as "average drivers".

examined the effect of ageing on driving with both the visual (Arrows) and cognitive (aCMT) surrogate IVIS tasks. Furthermore, in order to reduce variability in the field studies, all forty-eight Finnish subjects were required to perform both surrogate IVIS tasks. The design of the simulator studies was slightly different in that the S-IVIS task was used as a between-subject variable; with twenty four subjects completing each S-IVIS experiment. However, due to simulator sickness with the Arrows task, the older subjects in the Leeds study were only able to perform the cognitive task. For the purpose of clarity, the experiments from each test site will be reported separately.

2.1 The Leeds Advanced Driving Simulator Experiments

This study examined the effect of the auditory continuous memory task (aCMT) on driving performance in 'average aged' and older participants, using the Leeds Advanced Driving Simulator (LADS). For a full description of the surrogate IVIS and LADS see Jamson & Merat (this issue).

2.1.1 Participants

Twenty-four participants of average age (11 male, 13 female, mean age=31.7 years SD=7.17), and twenty-four older participants (13 male, 11 female, mean age=66.5 years, SD=5.32) were recruited for this study. All participants had at least five years' driving experience, and drove at least 10,000 km per annum. Following completion of a consent form and experiment information sheet, participants were briefed on the aCMT, and on the operation of the driving simulator. All participants received £15 on completion of the study.

2.1.2 Driving Environment

All participants drove two sections of rural road (roads A and B), on the Leeds Advanced Driving Simulator. Half of the participants drove road A as the baseline condition and road B as the 'experimental condition' i.e. driving plus S-IVIS. This order was reversed for the other half of participants. Roads A and B both consisted of three repetitions of three car-following scenarios, which were designed to vary in terms of workload and driving difficulty. These were: Scenario Level 1**:** Straight roads, requiring minimal workload compared to other scenarios, b) Scenario Level 2: Gentle s-shaped curves, which required some negotiation by the driver, c) Scenario Level 3: Discrete events, which lead to a major reduction of speed by the driver. As well as requiring a reasonable degree of interaction with the simulator and the lead car, this scenario was also thought to impose maximal driving difficulty and cognitive load, when compared to the other two scenario levels (see Figure 1 for an example).

Figure 1 about here

The individual scenarios described above were connected using 'filler' road sections, and the order of these scenarios was the same for roads A and B. However, to reduce learning, a different 'discrete event' (scenario level 3) was used for each of the two roads, although an attempt was made to keep these events as similar as possible within and across the two roads.

2.1.3 Design and Procedure

A mixed design was used for this experiment with a between-subject variable of age (25-50 and over 60 years old), and within-subject variables: road complexity (straight, s-shaped curve, discrete event) and S-IVIS level (aCMT: two, three and four target sounds). All participants practiced the S-IVIS task in isolation, followed by a short practice drive of the rural road. They then practiced driving the simulator whilst operating the S-IVIS. After these practice sessions, participants completed a baseline drive, a baseline run of the S-IVIS task and an experimental drive with S-IVIS in operation. The order of these events was counterbalanced across participants in each age group. Participants were asked to rate their driving performance at the same predetermined points of the experimental and baseline drives. Participants were prompted for this subjective rating by a recorded message, delivered immediately after completion of each driving scenario. Rating was on a scale of 1 (I drove very badly) to 10 (I drove very well).

2.2 The Finnish Field Studies

The test route for this study contained both urban and rural roads in and around the Helsinki capital area. However, in order to keep in line with the Leeds studies and due to space limitations, only results from the rural road will be reported in this article.

2.2.1 Test site

The instrumented vehicle used was a 1999 Toyota Corolla sedan with manual transmission. The vehicle was equipped with a hidden PC-based measuring system, differential GPS receiver and a video recording system with two cameras, one in front of the vehicle and one on the dashboard aimed towards the driver's face. The driver's eye movements were recorded with these cameras, as well as the general view of the front of the vehicle. Data collection frequency for speed and distance data and for steering wheel angle was 10 Hz. Data was transmitted to a videocassette recorder (VCR) and computer in the boot of the car.

The Arrows secondary task was presented via an LCD monitor (169 mm (W) x 127 mm (H)) located on the right side of the steering wheel, such that the eye-screen distance was approximately 65 cm for a driver about 180 cm tall.

2.2.2 Participants

Twenty-four participants of average age (19 male, 5 female, mean age=37.3 years, SD=6.58) and 24 older participants (19 male, 5 female, mean age=68.8 years, SD=2.43) took part in this study. Each subject had driven at least 10,000 km during the previous 12 months, and possessed their driving licence for at least 5 years. All drivers owned or regularly drove a vehicle of the same type as the one used in the study.

2.2.3 Driving Environment

The rural road section was 16 km long, and consisted of one-lane roads in the Helsinki capital area. The posted speed limit ranged from 60 km/h to 80 km/h. In addition to these test routes, drivers drove a practice route of 13.8 km to familiarise themselves with the car and the secondary task.

2.2.4 Design and Procedure

Drivers performed two repetitions of each secondary task, which were each presented at three levels of difficulty (for a description of these tasks, see Jamson and Merat, this issue). Pilot studies illustrated that the most difficult version of the Arrows task required a high level of visual attention from subjects, and might therefore be too hazardous to use with older subjects in the field. Therefore, the categorisation of the Arrows task in the field was altered, allowing a simpler version than that used in the HASTE simulator studies. Examples of displays used in the field are shown in Figure 2. Also, the categorisation of aCMT was altered in the field and the task included only one, two or three target sounds. Each secondary task was performed at link sections, where the speed limit was either 80 km/h or changed during the secondary task from 80 km/h to 60 km/h or vice versa.

Figure 2 about here

The test route was driven three times: (i) with the Arrows task, (ii) with the aCMT and (iii) as baseline. The order of tasks and task difficulty levels were balanced across subjects within each age group. The timing of each secondary task was determined and controlled by the distance travelled from fixed points (determined with a GPS receiver). Subjects were told that the aim of the study was to investigate what kind of task drivers can safely perform whilst driving. Subjects were instructed to drive safely through the test route and perform a secondary task when it was presented to them.

Experiments were carried out in good weather and road surface conditions between May 5 and July 2, 2003, and all data collection took place on weekdays between 9 a.m. and 3 p.m. Since the experiments were conducted in real traffic, an experimenter sat in the front passenger seat, which was equipped with an extra brake pedal. The experimenter was also responsible for giving directions to the driver, to ensure the maintenance of the correct route. An observer, whom the driver believed to be technical support staff, sat in the back seat of the car. At no time did the observer interfere with the driving.

3. Results

3.1 Auditory Continuous Memory Task – Leeds Driving Simulator

Performance on the S-IVIS task was analysed in terms of (i) percentage of correct responses (ii) percentage of missed responses and (iii) percentage of incorrect responses. Data were treated to a repeated measures ANOVA with between-subject factor age and within-subject factors: driving (none, straight, curve, discrete event) and S-IVIS level (two, three and four target sounds).

When aCMT was performed in isolation, older drivers achieved a smaller percentage of correct responses compared to average aged drivers (Mean: 51% and 74% respectively, $p < .001$). Concurrent driving was found to cause a reduction in percentage of correct responses for both age groups ($F(3,129) = 19.782$, $p < .001$), and when examining the effect of the three driving scenarios on aCMT performance, post hoc pairwise comparisons showed this effect was specific to the discrete event (see Figure 3), with a stronger effect seen in older drivers ($F(3,129) = 2.933$, $p < .05$).

Figure 3 about here

For both age groups, performance in aCMT was seen to deteriorate with an increase in the number of target sounds (averaged over driving events, F (2,86)=37.692, *p*< .001). However, the ANOVA failed to show an interaction between age group and number of target sounds (see Figure 4). Therefore, increasing the number of target sounds clearly increased the difficulty of aCMT for both age groups.

Figure 4 about here

Compared to average drivers, older drivers missed more responses and produced more incorrect answers when aCMT was performed as a single task (F (1,43)=4.771, *p*< .05 and (F (1,41)=16.445, *p*< .001) respectively.

Concurrent driving resulted in more missed responses for both age groups (F (3,123)=26.241, *p*< .001), and pairwise comparisons showed this to be restricted to the discrete driving event. Furthermore, a significant interaction between age group and driving revealed that the effect of the discrete driving event on missed responses was particularly strong in older drivers (F (3,123)=6.970, *p*< .001. see Figure 5). These results show clearly that the necessity to dedicate any available resources to the most difficult driving task meant that older drivers effectively abandoned the aCMT task.

Figure 5 about here

3.2 Lateral driving measures and steering control – Leeds Driving Simulator

Deviation in lateral position for the two age groups was treated to a 2 (Driving: straight, curve) x 4 (aCMT: none, two, three or four target sounds) analysis of variance. Results from the baseline drive showed that older drivers had less lateral control of the car than average drivers, during negotiation of the s-shaped curve ($F_{(1,46)}=250.189$, $p< .001$).

When assessing the affect of aCMT on lateral control, results showed less lateral deviation and thus apparently *better* control during concurrent performance of the continuous memory task, when the car was in straight sections of the road ($F_{(3,138)}=8.142$, $p< .001$, see Figure 6). This was true for both age groups.

Figure 6 about here

3.3 Longitudinal driving measures – Leeds Driving Simulator

Longitudinal control of the car was assessed using measures of speed and headway. Due to an interest in the safety effects of aCMT on driving, analysis of these measures was devoted to the third driving scenario level: *the critical events*.

Upon approach to the critical events in baseline driving, older drivers were found to maintain a lower mean speed than average drivers ($F_{(1,46)}=17.229$, $p< .001$, average drivers: 40.313 km/h, older drivers: 38.628 km/h). This adoption of a safer strategy by older drivers was also shown by measurements of mean time headway, which were found to be longer for older drivers than average drivers (5.036 and 3.621 seconds respectively). Therefore, as illustrated in previous research (e.g. Nishida, 1999), older drivers were perhaps aware of their limitations during the baseline simulation drive, and adopted a safe strategy to compensate for these limitations.

Concurrent performance on the S-IVIS task and driving was not found to affect mean speed in either age group. Moreover, a significant fall in safety-critical longitudinal measures such as minimum time to contact and minimum time and distance headway was observed. This failure to adjust speed and a rise in longitudinal risk margin was seen for both older and average aged drivers, with mean difference between the two age groups approaching significance for minimum distance headway ($F(1,46)=3.308$, $p=.075$). Therefore, although older drivers were trying to assume a safe distance with the lead car by reducing their speed in baseline conditions, the high workload imposed by the most difficult aCMT condition (four target sounds) clearly had some detrimental effect on this compensatory behaviour. On the other hand, as shown in Figure 7, all levels of aCMT were found to have quite a detrimental effect on longitudinal control of the car in average drivers. These results may suggest that average drivers were perhaps not aware of the detrimental effects of aCMT, and therefore failed (or chose not) to compensate their driving behaviour in its presence.

Figure 7

3.4 Subjective Measures – Leeds Driving Simulator

Overall, subjective rating of driving performance was found to be similar for average and older drivers. As shown in Figure 8 both groups believed their driving performance deteriorated from straight to curved to event scenarios (F (2,90)=11.488, *p* <.001), and both groups judged their driving performance to be worse in the presence of the S-IVIS task (F (3,135)=31.713, *p* <.001, see Figure 9).

Figure 8 about here

Figure 9 about here

<u>3.5 Measures and analysis method used in the VTT field trials</u>

Speed limit information and the driver's speed behaviour were recorded. Only free-flow traffic situations (in which drivers were able to choose their driving speed) were included in the speed analyses (77–80% of all cases). Two-degrees steering reversal rate were also computed. In addition to driver behaviour, the accompanying observer coded the driver's performance and the traffic situations, for example presence and interaction with any other vehicles, lane keeping behaviour and speed choice and adaptation.

The effects of S-IVIS difficulty and age group were analysed. However, only a few effects-based vehicle or observational data could be tested because the null hypothesis of Levene's test was usually rejected. Consequently, the obtained differences should be viewed only as possible trends.

3.6 The Auditory Continuous Memory Task – VTT field trials

When aCMT was performed in the static vehicle, older drivers achieved a smaller percentage of correct responses compared to average aged drivers (mean 68% and 89% respectively; F (1,143)=23.293 $p < 0.001$). The difference between age groups was also found when driving in the rural environment (mean=62% for older drivers and 87% for average drivers; F (1,47)=26.740, $p < 0.001$). However, neither the addition of driving nor the increase in number of target sounds were found to cause a significant reduction in percentage of correct responses for the two age groups (Figure 10).

Figure 10 about here

As seen in Figure 11, compared to average drivers, older drivers missed more responses both in the static vehicle and when driving in the rural area (F (1,143)=7.918, $p< .01$ and F (1,47)=15.260, $p< .001$ respectively). They also gave more incorrect answers in both conditions (static F (1,143)=16.362, $p< .001$ and rural F (1,47)=8.751, $p< .01$).

Figure 11 about here

3.7 The Arrows task – VTT field trials

Performance on the Arrows task was analysed in terms of reaction time. Reaction times were lower for the static situation compared to when drivers were in the rural environment. The difference between age groups was found to be significant when driving in the rural environment (mean reaction times 2.1s for average and 2.3s for older drivers, F (1,47)=4.374, $p < 0.05$). An increase in the difficulty level was found to cause a significant increase in reaction times for both age groups in the static condition (older drivers F (2,71)=122.373, $p < 0.001$ and average drivers F (2,71) =97.503, $p < 0.001$) and when driving in the rural environment (older drivers F(2,71) =47.366, $p < 0.001$ and average drivers F(2,71)=66.096, $p < 0.001$). No significant interactions were observed (Figure 12).

Figure 12 about here

<u>3.8 Longitudinal control – vehicle data VTT field trials</u>

Speed variation increased when subjects were required to complete the Arrows task, and older subjects were seen to vary their speed significantly more than average drivers (F (1,47) =26.769, p<0.00).

During performance of the Arrows task, minimum speed was significantly less for older drivers (77.4 km/h) compared to average drivers (78.7 km/h) (F(1,47)=3.94, p<0.05) and reduced by S-IVIS difficulty level for both age groups. Post hoc tests showed that the effect was significant between baseline (79.0 km/h) and the most difficult version of the task (76.2 km/h) (F(3,95)=2.855, p<0.05).

For both age groups, the aCMT task had practically no effect on mean speed. Minimum speed was found to be significantly less for the older drivers (77.2 km/h) compared to average drivers (79.2 km/h) (F(1,47)=5.165, p<0.05). However, older drivers were already driving more slowly in baseline conditions (77.2 km/h compared to 80.7 km/h for average drivers). Therefore, only average drivers reduced their minimum travelling speed in the presence of the aCMT.

Effects on mean speed, maximum speed and speed variation could not be tested because the null hypothesis of Levene's test was rejected.

3.9 Longitudinal control – observational data VTT field trials

In baseline conditions, the speed behaviour in free-flow traffic situations was assessed as appropriate (no change in speed behaviour) in 92% of the sections, compared to 68% in the Arrows task condition and 66% in the aCMT task condition. Compared to the baseline condition, variations in speed were more frequently observed when the driver was performing a secondary task. In addition, an extremely slow speed was frequently used in the Arrows task condition, while an increasing or extremely fast speed was typical in the aCMT task condition.

Compared to average drivers, older drivers were more often observed to have inappropriate (changes in their) speed behaviour. More specifically, the aCMT task had a somewhat greater influence than the Arrows task on the speed behaviour of average drivers, while there was no remarkable effect by secondary task type on the speed behaviour of older drivers. However, compared to average drivers, older drivers more frequently decreased or varied their speed when a secondary task was performed, especially with the Arrows task. In addition, for older drivers, both Arrows and aCMT tasks were also observed to increase the proportion of drivers who increased their speed (speeding up and extremely fast), whereas with average drivers increasing speed was observed mainly with the aCMT task.

In general, when increasing the secondary task difficulty, a greater proportion of drivers were rated to have inappropriate speed behaviour. While involved in the Arrows task, average drivers were observed to change their speed behaviour only at the most difficult level, whereas the speed of older drivers changed at all difficulty levels. While involved in the aCMT task, the number of inappropriate speed behaviours increased with the difficulty of the secondary task, except for older drivers for whom the number of inappropriate speed behaviours decreased between the two and three target sound condition.

In situations where the speed limit changed from 80 to 60 km/h, results showed that (overall) the Arrows task tended to decrease speeding of average drivers and increase that of older drivers, while the aCMT task increased speeding in both driver groups Therefore, the cognitive demand required by the non-visual aCMT was clearly taking drivers' attention away from important driving-related visual information in both age groups (Figure 13). Finally, the most difficult level of both secondary tasks was shown to cause a dramatic increase in the proportion of speeding average drivers. Therefore, once again, the high demand imposed by the most difficult version of each secondary task is shown to result in more hazardous behaviour, such as missing important speed-limit-related signage.

Figure 13 about here

Approximately 20% of the observation sections included a car-following situation (vehicles travelling in front). In the baseline runs, the drivers were observed to have appropriate headway in 90% of car following situations. The rate was 80% while engaged in the secondary task. Compared to average drivers, older drivers more frequently drove too close to the car in front. Older drivers had both momentary close-following situations (baseline 7%, Arrows 16%, aCMT 14%) and continuous close-following situations (baseline 14%, Arrows 21%, aCMT 14%) more often than average drivers did (continuous close-following situations 3% for Arrows and 12% for aCMT). However, one should bear in mind that the total number of car-following cases was quite small: only 21 to 30 drivers per secondary task condition.

3.10 Lateral control – vehicle data VTT field trials

Overall, the results showed that aCMT had hardly any effect on lateral control of the vehicle. However, the Arrows task tended to increase the reversal rate, especially with older drivers ($F(1,47)=34.121$, $p<0.0001$). When comparing the three difficulty levels of Arrows task, the results showed that for average drivers only the most difficult task level increased reversal rate. For older drivers, all task difficulty levels increased the reversal rate. Post hoc tests showed that effects were significant between baseline and all the difficulty levels ($F(3, 93)=7.969$, $p<0.00$) (Table 1).

Table 1 about here

3.11 Lateral control – observational data VTT field trials

In the baseline conditions, the observer coded the lateral control as inappropriate in 6% of observations, while the percentage was 59 for the Arrows task condition and 4 for the aCMT condition. While engaged in the Arrows task, drivers were most frequently observed to have lateral movement within their own lane (average 24%, older 38% of all cases) or even exceed the lane markings and make a correction (average 13%, older drivers 30% of all cases). Overall, older drivers showed inappropriate lane behaviour more frequently than average drivers and the task seemed to cause more severe problems for older drivers. For instance, all incidences of lane exceedence during approach of oncoming vehicle(s) occurred with older drivers (5% of all cases). The results by difficulty level of the Arrows task showed that the secondary task had a substantial affect on older drivers' lane behaviour for all levels, while the effects on average drivers' lane behaviour increased only with the most difficult level. …

3.12 Subjective measures – VTT field trials

The ratings were asked after each observation section, after secondary task blocks, or after a corresponding section on the baseline route when no secondary task was performed.

Overall, older drivers rated their driving performance lower than did average drivers for all conditions ($F(1,47)=66.020$, $p<0.005$). All drivers rated their driving performance to be better in baseline condition compared to driving with secondary task ($F(1,95)=37.376$, $p<0.000$). Ratings were somewhat higher for the aCMT task than for the Arrows task. However, the Post Hoc test indicated the difference to be between baseline and secondary task only. Drivers also rated their driving performance to be worse as the difficulty of the secondary task increased ($F(3,93)=30.655$, $p<0.005$).

4. General Discussion and Conclusions

Two studies were conducted to compare the performance of average and older drivers on the HASTE surrogate IVIS tasks. The effect of these tasks on driving performance was also studied in the Leeds Advanced Driving Simulator, and the VTT instrumented vehicle.

In general, single task performance of the two S-IVIS was found to be worse in the older participants than that of the average group. For instance, as well as producing a lower number of correct answers to the aCMT, older participants in the Leeds study missed a large number of responses to this task. This may have been because satisfactory performance of the aCMT involved production of the correct response at the correct time, i.e. at a system-paced rate. Therefore, during analysis, any response produced after the 2-second inter-stimulus interval was considered a missed response. This large number of missed responses by this age group is not wholly unusual, since ageing is known to reduce the speed of motor responses such as speech production (e.g. Balota & Duchek, 1988), whilst also increasing the production of false starts, hesitations and filled pauses such as ‘ums’ and ‘errs’ (see Kemper, 1992).

The effect of Arrows and aCMT on the driving behaviour of the two age groups was generally similar in situations that required relatively simple driving manoeuvres, such as the straight and curved sections. However, differences between the two groups became more obvious when a high workload was imposed by the driving task, for instance during the discrete events in the simulated drive. This difference was particularly obvious if the secondary task also imposed a high workload. For example, in the Leeds study, older drivers provided the least number of correct responses to aCMT during the discrete driving event, presumably because dealing with this event was in itself associated with a high workload. Older drivers were also seen to miss a large number of responses to the aCMT during the discrete events. This is likely to be linked to limited cognitive resources, but could also be because, aware of their limitations, these participants abandoned the secondary task to try and concentrate on their performance in driving. Unfortunately, this attempt by the older drivers to devote all available cognitive resources to the primary driving task was not entirely successful, as driving performance was still seen to be affected. For instance, when aCMT was presented, older drivers were found to miss important driving-related signage in the field study, whilst in both the simulator and the field their distance to the car in front was found to be significantly reduced, despite a reduction in mean speed.

Some erratic driving behaviour was also seen by older drivers during performance of the Arrows task in the field, especially for the most difficult level of this task. These included a significantly higher degree of speed variation and more incidences of markedly reduced speed, compared to that of average drivers. Also, all levels of the Arrows task were shown to cause marked variation in lane position for the older drivers, as well as an increase in the number of steering corrections, as shown by reversal rate. This is an interesting and rather worrying observation, as it is clear that despite their limitations, older drivers were either unable or failed to abandon the Arrows task, even though they were in a real-world driving situation, in the presence of other road users.

The effect of these secondary tasks on the driving performance of older participants is clearly of some concern, but not entirely surprising. For instance, research has shown that age-related impairments in executive resources can result in problems with appropriate planning and scheduling of tasks, as well as difficulties with feedback-contingent switching between tasks, and problems with inhibition of inappropriate information and appropriate response selection (e.g. Raz, 2001). Clearly then, research is required to establish the best methods by which information can be relayed to the older driver in a dynamic environment, without any adverse effects on the driving task. As shown in our experiments, this kind of research becomes more difficult for visually presented information, due to the simulator sickness experienced by older drivers.

In the simulator, aCMT was seen to *improve* lateral control of the car for both age groups. This reduction in lateral deviation as a result of a cognitively demanding secondary task has been seen in other experiments of the HASTE project (see Östlund et al. 2004), and is thought to be due to an allocation of central resources and attention to the road ahead, perhaps at the expense of peripheral vision (e.g. Brookhuis, De Vries, & de Ward, 1991; Ball and Owsley, 2000). Indeed, glance-based measures obtained during performance of the aCMT and driving show increased concentration of gaze fixations towards the centre of the road for average aged drivers (see Victor et al., this issue).

A slightly more worrying finding from these studies was that, compared to older drivers, average drivers assumed rather more risky driving behaviour in the presence of the aCMT task, such as maintaining shorter headways with the car in front, or failing to reduce their speed during aCMT presentation. This fall in longitudinal safety margins as a result of the cognitive load imposed by aCMT is obviously of some concern. Neither age group thought it necessary to reduce their speed when performing the aCMT, perhaps because the non-visual nature of the task meant that drivers were able to continue paying visual attention to their driving and the road ahead. However, the average drivers in particular were clearly not aware that this failure to reduce speed and simultaneous attention to the secondary task made them more susceptible to a collision with the lead car. At this stage, it is difficult to establish if average drivers were oblivious to the effect of this secondary task on their driving behaviour, or if they made a conscious decision not to be concerned with its effect in an experimental driving environment.

What is clear for both age groups is that, even in the field, drivers continued to perform both secondary tasks at least 50% of the time. Thus, even average drivers, whom, in theory, do not suffer from the executive problems associated with inhibition of inappropriate information, failed to abandon the secondary task in order to promote safe driving behaviour. It is hard to ascertain whether participants believed that completion of the secondary task was an essential obligation of the experiment itself. In addition to making an attempt to complete the secondary tasks during driving, both age groups performed reasonably well on both tasks, with accuracy averaging around 50% or more. Future experiments hope to establish whether increasing the difficulty of these tasks even further will eventually encourage participants to abandon the task completely, in favour of safe driving.

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Figure 1 – Example of a rural road discrete event - Figure shows the lead car coming to a stop, due to the presence of a crossing lorry in its path

Figure 2 – The three levels of difficulty used in the field version of the Arrows

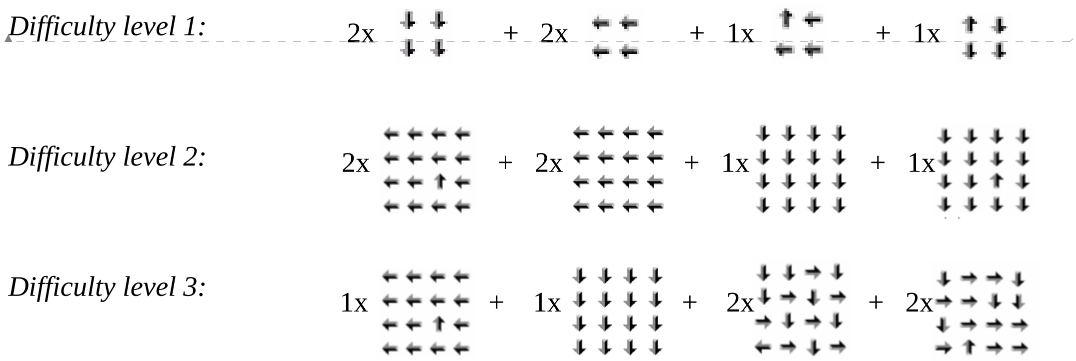

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Figure 3 – The percentage of correct responses in aCMT for each driving event in each subject group (averaged over target sounds)

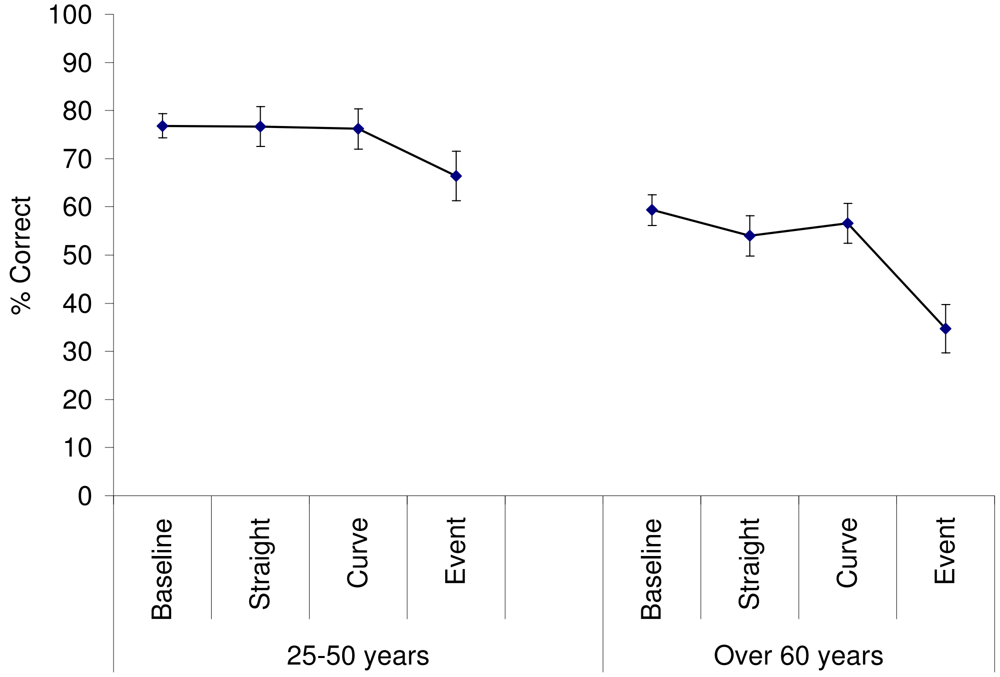


Figure 4 –The effect of increasing target sounds on percentage of correct responses.

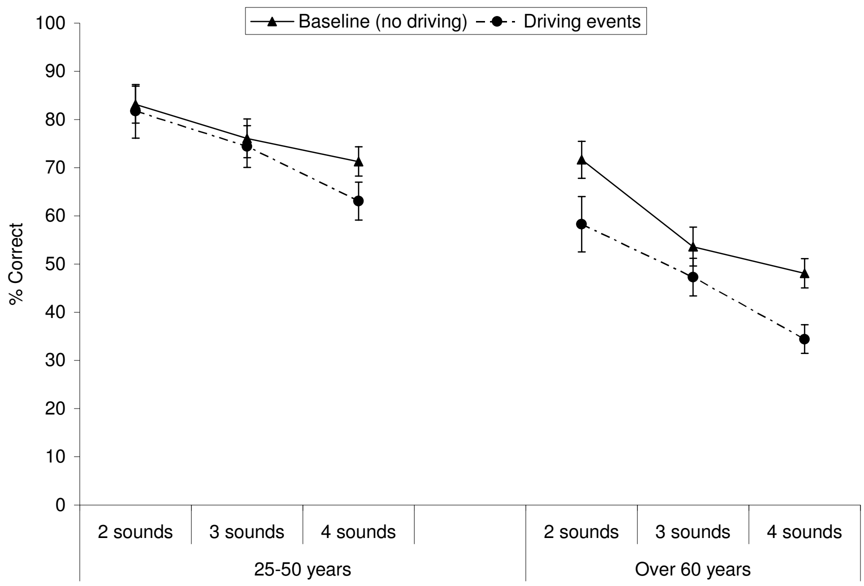


Figure 5 – The percentage of missed responses for each driving event

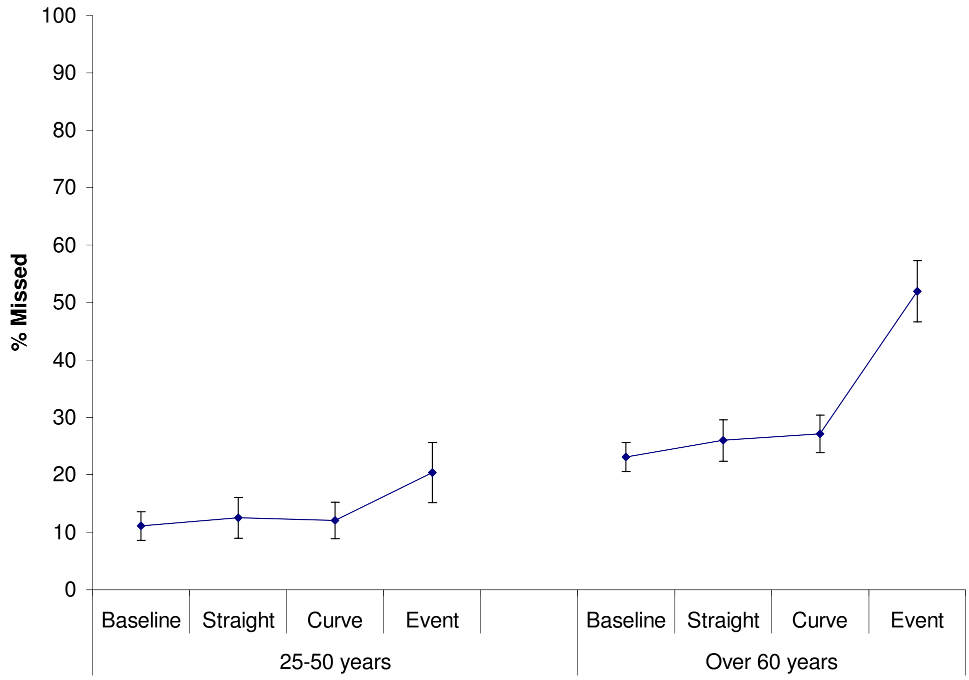


Figure 6 – Effect of concurrent aCMT on lateral driving control

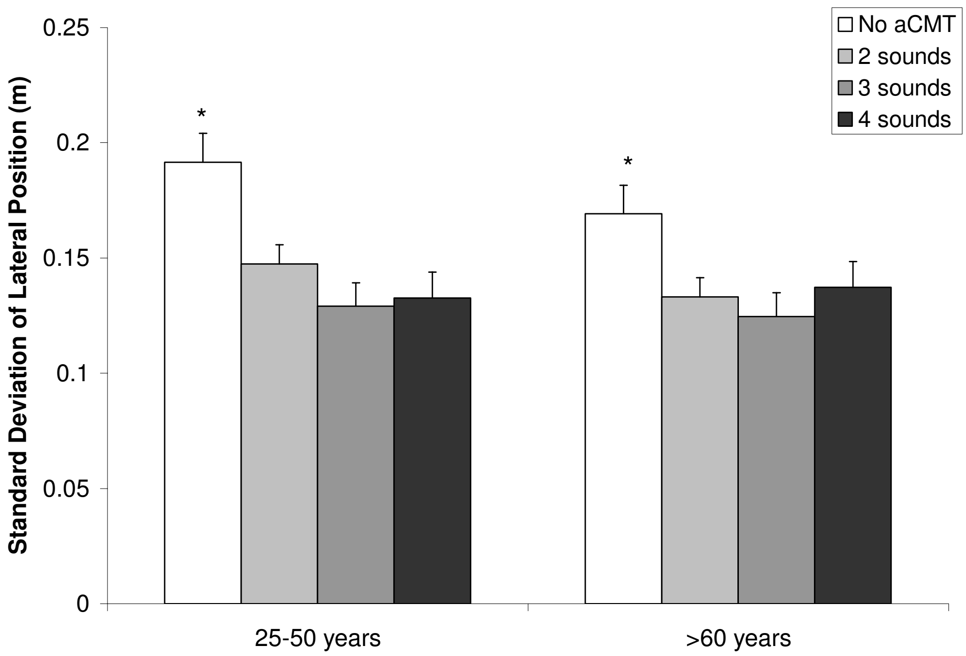
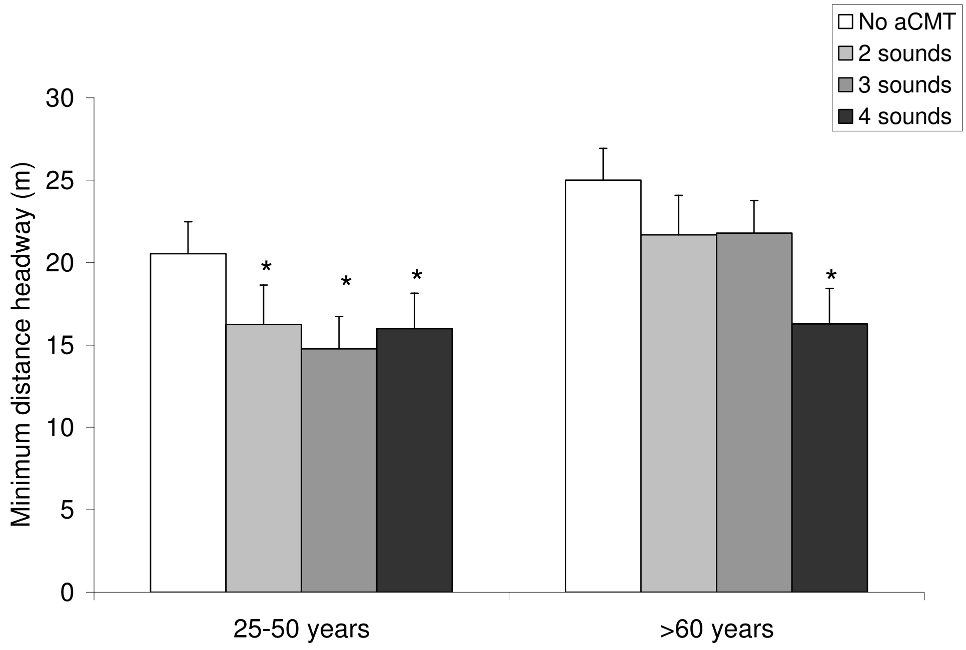
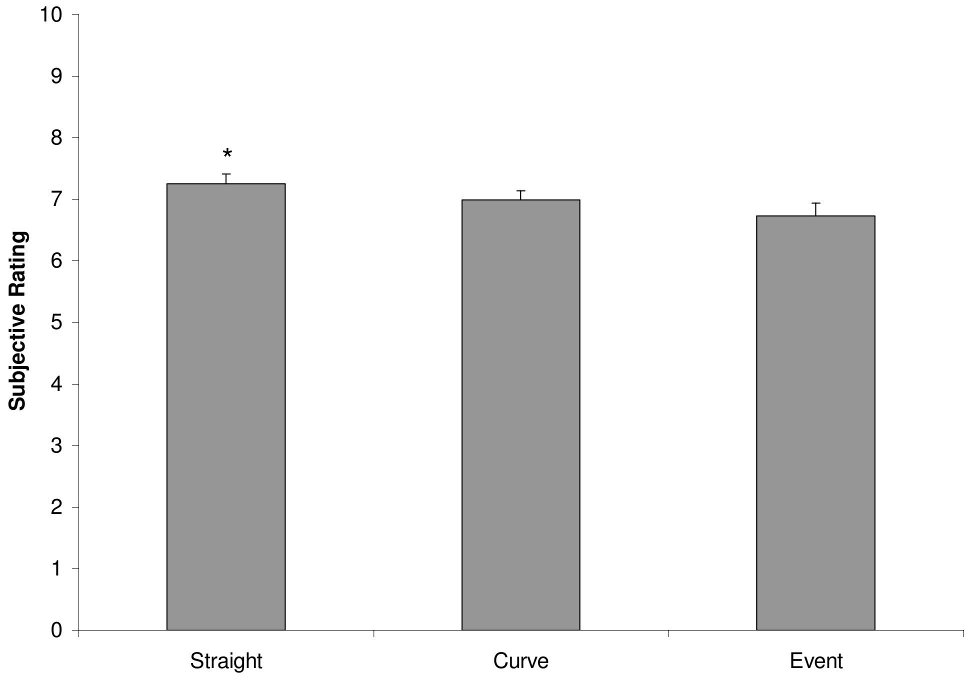


Figure 7 – Comparison of minimum distance headway in average and older drivers



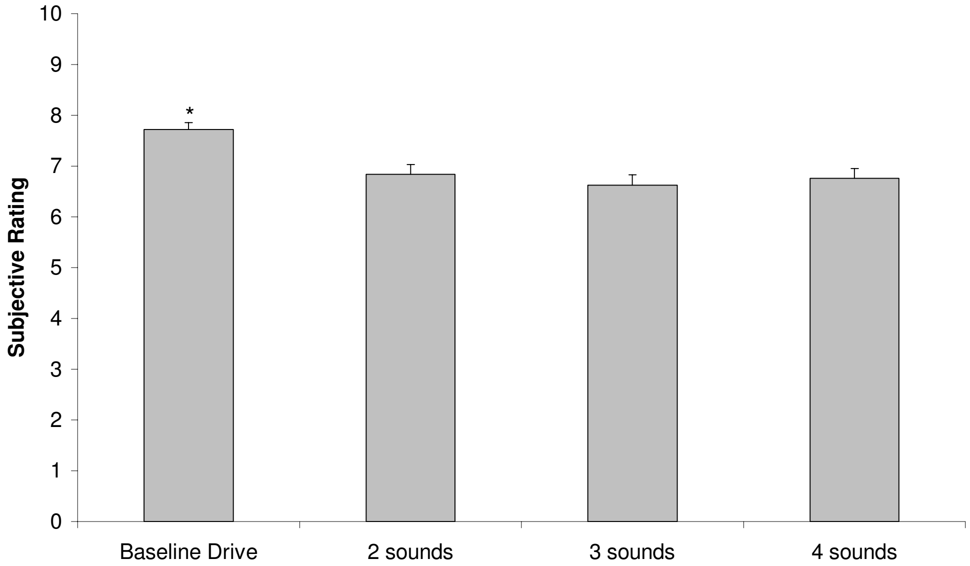
*Value reliably lower than baseline, p< .05)

Figure 8 – Subjective rating for each driving scenario (averaged across the two age groups)



*Rating reliably higher than curve and event sections $p < .05$.

Figure 9 – The effect of aCMT on subjective rating (averaged across the two age groups)



*Rating reliably higher than all other ratings $p < .05$.

Figure 10 - Percentage of correct responses by age group, environment and number of target sounds

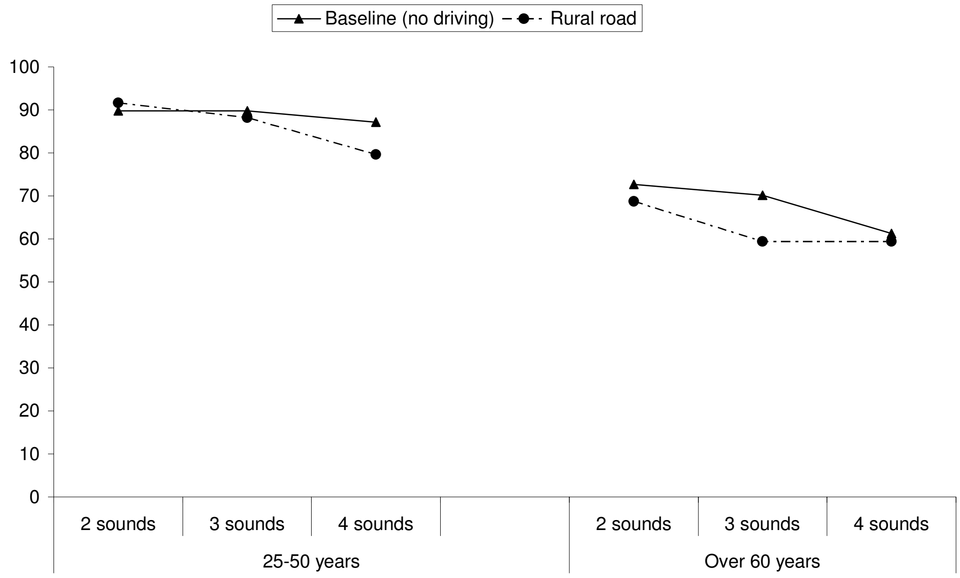


Figure 11 - Response type by age group and environment

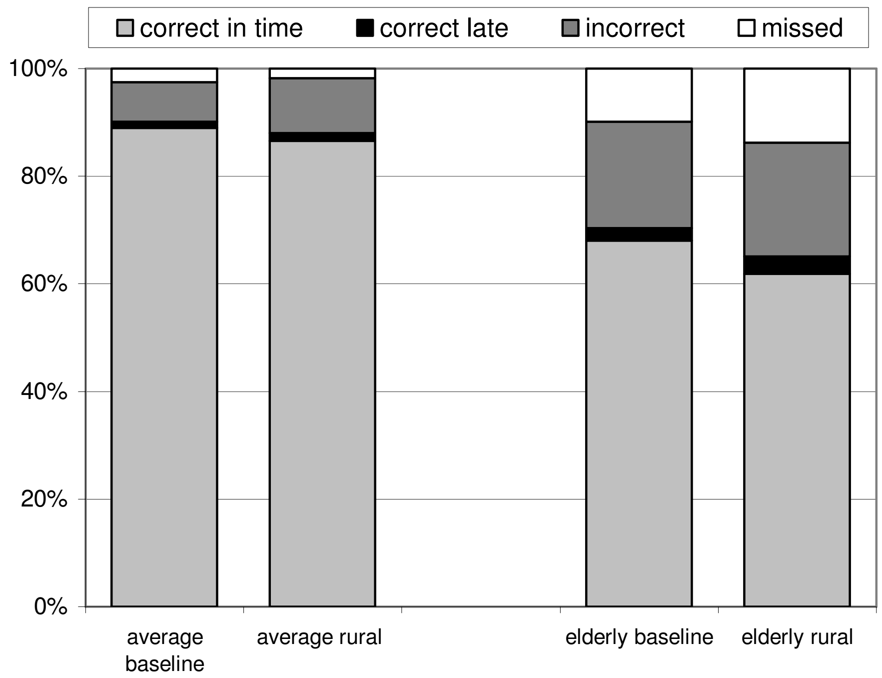


Figure 12 - Mean reaction time in Arrows, by age group, environment and task difficulty level

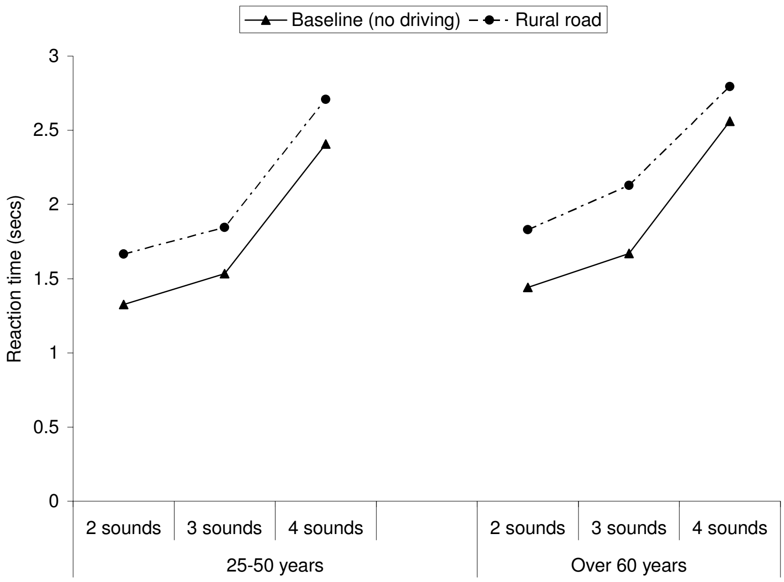


Figure 13 - Percentage of drivers driving too fast by age group and secondary task.

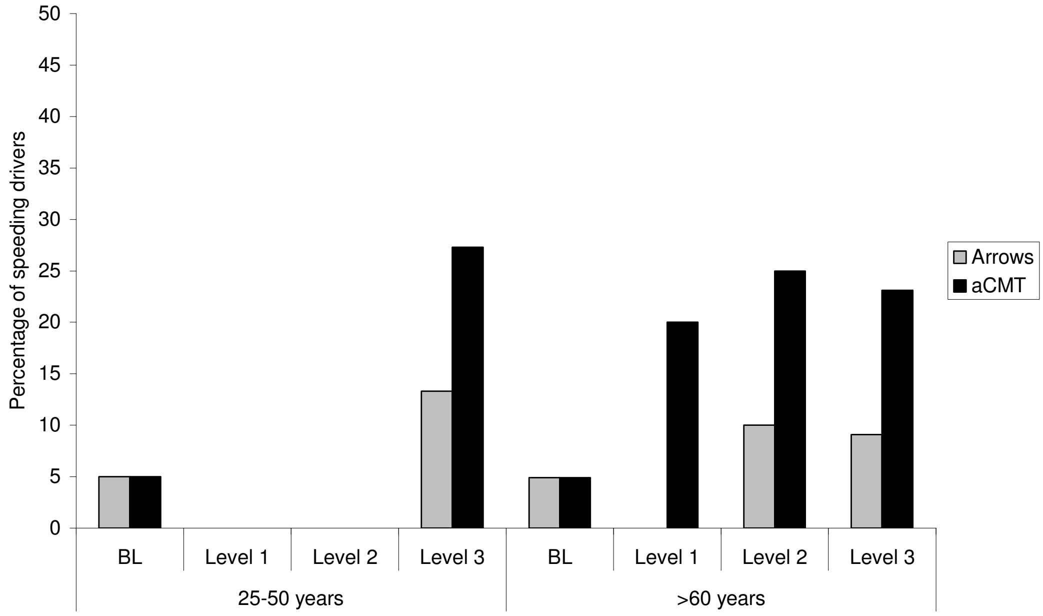


Table 1 - Reversal rate (2 degrees minimum change) by secondary task condition, difficulty level and age group.

Reversal Rate (1/minute)	**Average**	**Older**
Baseline	0.28	0.32
Level 1	0.29	0.40
Level 2	0.31	0.39
Level 3	0.35	0.42