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Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance

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Abstract

This paper presents the findings of a simulator study that examined the effects of distraction upon driving performance for drivers in three age groups. There were two in-vehicle distracter tasks: operating the vehicle entertainment system and conducting a simulated hands-free mobile phone conversation. The effect of visual clutter was examined by requiring participants to drive in simple and complex road environments.

Overall measures of driving performance were collected, together with responses to roadway hazards and subjective measures of driver perceived workload. The two in-vehicle distraction tasks degraded overall driving performance, degraded responses to hazards and increased subjective workload. The performance decrements that occurred as a result of in-vehicle distraction were observed in both the simple and complex highway environments and for drivers in different age groups. One key difference was that older drivers traveled at lower mean speeds in the complex highway environment compared with younger drivers.

The conclusions of the research are that both in-vehicle tasks impaired several aspects of driving performance, with the entertainment system distracter having the greatest negative impact on performance, and that these findings were relatively stable across different driver age groups and different environmental complexities.

Keywords: Driver distraction; In-vehicle distractions; Environmental complexity; Driving simulation; Driver age; Mobile phones

1. Introduction

Safely driving a vehicle on public roads requires a wide range of skills and abilities. Driving does not always take place in ideal conditions, in which a well-rested, well-trained and well behaving individual interacts with a simple, undemanding road environment. One issue that can make driving performance sub-optimal is distraction, both from within the vehicle and from within the highway environment.

Distraction occurs when a triggering event induces an attentional shift away from the task, in this case driving. The U.S. National Highway Traffic Safety Administration has identified driver distraction as a high priority area (Stutts et al., 2001). This is supported by an explosion of recent research and publications in the area. For example, Wang et al. (1996), using police accident data, found that up to 25% of crashes involved some degree of driver distraction. In an analysis of crashes caused by distraction, Stutts et al. (2001) identified outside people, objects or events as the source of distraction in 30% of driver distraction cases and adjusting the radio/cassette as the source in 11.4% of cases. These were the most frequently cited categories. Mobile phones were the source of the distraction in 1.5% of cases. However, it should be noted that the analyses performed by Stutts and colleagues were based on police reported variables, so the accuracy of the data is unknown.

1.1. Effects of in-vehicle distraction

There are many potential in-vehicle sources of distraction. One of the most frequently reported is the use of mobile phones. Reed and Green (1999) found that using hand-held mobile phones reduced driving precision, with the negative effects being worse for older drivers. Comparable age relationships were also found by McKnight and McKnight (1993) for both mobile phone use and for radio tuning. Burns et al.

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(2002) found that drivers using hand-held mobile phones were on average 50% slower to respond to hazards than when driving without using a phone. Similarly, in experimental research studies, hands-free mobile phones have also often revealed negative effects upon driving performance (e.g. Haigney et al., 2000).

Although mobile phone use has attracted the greatest media interest, other advanced electronic devices also have the potential to increase perceptual and cognitive demand when driving. Relatively simple 'low tech' tasks such as tuning the vehicle radio also have safety implications. Indeed, adjusting the radio, cassette or CD player was found to be one of the major causes of distraction-related crashes by Stutts et al. (2001). Adapting these devices to fit the cognitive, perceptual and even physical capabilities of drivers of all ages is an important research area worldwide.

It is likely that the concurrent performance of other tasks that compete for the same perceptual, cognitive and motor resources will have the greatest impact on the task of driving safely. There is some evidence that visual/psychomotor distracters affect driver safety more than auditory/cognitive distracters. Serafin et al. (1993) found, for example, that manually dialing on a mobile phone affected vehicle lateral position more than talking on the phone or dialing with a speech based interface. Hurwitz and Wheatley (2002) compared driving performance while completing a visual and an auditory monitoring task. Performance, as measured by steering wheel control and lane keeping, was worse with the visual task than with the auditory task, especially when the driving task was performed on a curved track compared to a straight track.

1.2. Effect of driving environment complexity

It must, however, be stressed that driver distraction is not just related to what is happening inside the vehicle. Distraction caused by aspects of the highway environment is also a major issue. In most advanced countries worldwide, the amount of visual information presented to drivers is increasing. New highway developments, a larger number of roadside advertisements and street-side vendors and an increased traffic flow all contribute to this issue. In a driving simulator and eye movement study, Horberry (1998) found that if an advertisement or other form of visual clutter (objects not relevant to the driving task, such as graffiti) is in a road scene then it is often looked at for a quite large proportion of the time (over 14% of the total driving time on average).

Cairney and Gunatillake (2000) conducted a literature review of the distracting effect of roadside advertisements. They concluded that regulation of roadside advertising was often justified on safety grounds. This problem may well be exacerbated in older drivers with decreased visual and cognitive capacities and lengthened reaction times (Ho et al., 2001). As this segment of the driving population is rapidly increasing, work to investigate these issues is clearly needed. Similarly the young novice driver, with less driving experience and hence less spare attentional capacity to devote to the driving task, may also be relatively more vulnerable to the effects of distraction.

Taken together, the above reported studies indicate that visual clutter (especially advertising) in the road environment almost certainly has negative safety implications, especially for older or younger drivers. Research to quantify more precisely the distracting effect and possible safety implications of increased highway complexity, and how this might be worsened by additional in-vehicle tasks is therefore needed.

1.3. Research aims

As discussed above, distraction is a significant and multifaceted road safety issue, and only recently has much research been devoted to it. This study aimed to build on previous distraction literature in several ways. First, it measured the relative effects of in-vehicle distraction and highway visual clutter, and how these two types of possible distraction might interact. Second, it measured the possible effects of distraction in a sophisticated driving simulator using an array of objective and subjective measures, including overall driving performance, responses to hazards and perceived mental workload. Finally, the relative effects of distraction upon the performance of young, mid-age and older drivers was investigated.

2. Method

2.1. Equipment

The experiment took place in the Monash University Advanced driving simulator in Melbourne, Australia. It comprises a fully instrumented car (for this experiment, a 1994 model Ford Falcon), two Silicon Graphics computers to display images and collect behavioral data, a 3D audio system, a motion platform and four advanced video projectors displaying images on a screen in front of the driver (with a lateral viewing angle of 180° forward).

2.2. Participants

Thirty one participants were employed, and each person was tested individually. Of these, 10 were younger drivers (aged under 25 years, mean age 21 years), 11 were mid-age drivers (aged 30–45, mean age 37 years) and 10 were older drivers (aged 60–75 years, mean age 66 years).

2.3. Distractions employed

The research was designed to assess both within-vehicle distraction and the possible distraction caused by environmental complexity (visual clutter) in the highway environment. For the in-vehicle distraction factor, two general distraction tasks were used:

1. *An auditory/vocal task: hands-free mobile phone conversation*. Participants answered a series of general knowledge questions presented by the experimenter over the simulator's audio system. The questions were followed by two alternative answers and participants had to choose the cor-

rect answer. Feedback of 'correct' or 'incorrect' was given after each answer. The pacing of the questions was such that there was continuous interaction between the experimenter and the participant. This secondary task allowed for measures of performance to be obtained in terms of number of correct answers, and number of questions attempted during the drive (although of course, such a quantifiable task made the phone conversation less realistic). There was a different series of matched questions for the two mobile phone distracter drives (in the simple and complex environments), appropriately counterbalanced.

2. *A visual/manual task: interacting with an in-vehicle entertainment/information system*. Participants were required to perform a series of tasks using the car radio and the cassette player; after one task was completed the subject was immediately required to perform a different task. As these tasks were partly self-paced, which different participants completed at slightly different speeds, it was impossible to conduct separate analyses on each individual task. The tasks were: tuning the radio to particular frequencies; changing the radio bass/treble balance; changing the speaker balance and inserting and ejecting music tapes. These functions were shown to participants prior to them commencing the experimental trials. There was a different set of tasks for the two in-car entertainment system distracter conditions (for the simple and complex environments), counterbalanced between participants.

In terms of the environmental complexity factor, participants were presented with a 'simple' and a 'complex' highway environment. Complexity was altered by modifying factors in the highway that previous research has found to be relevant (e.g. Horberry, 1998). Distracters were made up of objects that were not central to the driving task. These were:

- billboards and advertisements (either no advertisements in the simple highway environment, or approximately 14 advertisements km^{-1} in the complex condition);
- buildings, oncoming vehicles and other highway furniture.

In the complex condition there were on average over 12 times as many buildings, oncoming vehicles and other highway furniture compared to the simple condition. In the simple conditions, on average, 28 objects km^{-1} were encountered and for the complex conditions, 484 per km.

2.4. Conditions

There were two different environment conditions, simple and complex, and three in-vehicle distraction conditions (no distraction, mobile phone conversation distraction, and entertainment system interaction distraction), resulting in six experimental conditions. The study was a repeated measures design in which each participant drove in each of the six conditions. Each of the driving environments was approximately 6 km in length, with the same number of curves and hazards. The gradient was level, and the curves were gentle. Speed limit signs were placed in all the scenes, with the posted speed limit randomly changing between 60, 70, and 80 km/h every kilometer. The road was single carriageway in either direction.

2.5. Performance measures

The objective driving performance measures presented in this paper focus upon speed-related variables.

Two measures of driving performance were recorded in each drive: mean speed, and deviation from the posted speed limit. Data from both measures were recorded at 30 Hz during the drives. Additionally, a hazard detection task was employed whereby the effects of distraction were assessed in terms of drivers' reactions to hazards in the roadway. Data from three hazards were recorded: a pedestrian standing on the roadway near the edge, a car reversing down a driveway towards the road and a pedestrian crossing the road. The hazards were designed to be of differing severity. It was hypothesized that the pedestrian standing by the side of the road was least hazardous. The car reversing down the driveway would require more monitoring because drivers could not be sure that it would stop before entering the road. The pedestrian crossing the road was most hazardous and required the most active monitoring by the driver. These hazards were contained in each of the drives at predetermined (and counterbalanced) locations, and were designed so that drivers had to take some evasive action to avoid a collision. Minimum speed reached on approach to the hazards was used as the performance measure.

Finally, measures of perceived workload were recorded after each drive using a widely used multiple dimension subjective workload index, the NASA Task Load Index (NASA TLX).

2.6. Procedure

Participants were introduced to the driving simulator and shown the relevant functions of the vehicle. They then took part in a practice trial for approximately 5 min to familiarize them with the simulator vehicle and experimental tasks. Following this, they undertook the six experimental drives (as described in Section 2.4). Presentation order of these was counterbalanced across participants to control for order effects across conditions. Participants were instructed to drive as they normally would and obey the road rules. In addition, they were instructed to drive as closely as possible to the indicated speed limits, and to take any action that they judged necessary to avoid collisions with other vehicles or pedestrians.

After each condition participants were presented with the NASA TLX to assess perceived workload for the previous drive. Each drive consisted of 6 min of driving, with approximately a 3 min rest between each drive.

3. Results

The experiment yielded both objective measures of driving performance and subjective measures of workload. Unless otherwise indicated, analyses were performed using a mixed factorial ANOVA with the repeated measures factors of environment

Table 1
Mean speed (km/h) for each distraction condition

Distracter condition	Mean speed
No distracter	58.48
Entertainment system distracter	54.33
Phone conversation distracter	58.94

(simple and complex) and in-vehicle distracter (no distracter, entertainment system distracter and phone conversation distracter). Age was a between-subjects factor. Tukey's post hoc test was employed to compare means for the between subjects factor. Paired sample *t*-tests were used to compare means for the within subjects factor with more than two levels. The significance level was adjusted for the number of comparisons being performed to preserve an alpha level of .05. For the in-vehicle distraction factor three comparisons were performed and the test value for significance was therefore $p = .017$.

3.1. Objective measures: overall driving performance

Data were analyzed for the two measures of mean speed and deviation from the posted speed limit.

3.1.1. Mean speed

Driving performance in the complex environment was worse (lower mean speed) than in the simple environment ($F(1,22) = 9.082$, $p = .006$). A significant main effect was also found for the in-vehicle distracter ($F(2,22) = 7.072$, $p = .004$), but there was no main effect for age ($F(2,22) = 1.49$, $p = .246$). Paired samples *t*-tests indicated that the entertainment system distracter produced a significantly lower mean speed than both the no distracter condition, $t(28) = 3.111$, $p = .004$, and the phone distracter, $t(28) = 3.557$, $p = .001$. As such, the entertainment system was more distracting to participants than the telephone conversation. The phone distracter and the no distracter conditions were not significantly different from each other, $t(28) = 0.480$, $p = .635$. The mean speed for each distracter condition is shown in Table 1.

A significant age by environment interaction was also found, $F(1,22) = 5.45$, $p = .011$; Fig. 1 shows that older drivers had a lower mean speed in the complex conditions than the other two age groups.

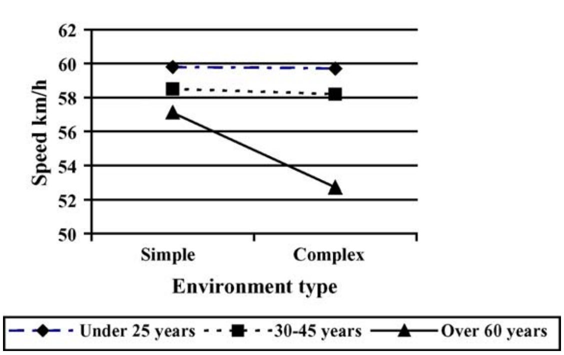

Fig. 1. Mean speed: environment type by age.

3.1.2. Deviation from the posted speed limit

The speed limit changed several times during each drive and participants were instructed to drive as closely as possible to the current speed limit without exceeding it. In a repeated measures ANOVA with deviation from the speed limit as the dependent variable, there was a significant main effect for in-vehicle distracter $F(2,21) = 3.867$, $p = .037$ and a main effect for age, $F(2,22) = 7.649$, $p = .003$, but no significant interaction. The younger group deviated less from the posted speed limit than the two older groups; the Tukey post hoc test found that the under-25 age group was significantly different to both the 30–45 age group ($p = .010$), and the over-60 age group ($p = .006$), but there was no significant difference between the 30–45 age group and the over-60 age group ($p = .910$).

Paired sample *t*-tests were used to compare means for the three levels of the in-vehicle distracter condition; the highest deviation from the posted speed limit occurred in the entertainment system distraction conditions. Significant differences were found between the no distracter condition and both the entertainment system distracter ($t(30) = 4.707$, $p < .0001$) and the phone conversation distracter condition ($t(30) = 4.0688$, $p < .0001$), and between the phone distracter condition and the entertainment system distracter ($t(30) = 6.564$, $p < .0001$).

3.2. Objective measures: responses to hazards

For each of the hazards that were encountered during each scenario, driver behavior was measured by the minimum speed reached when encountering the hazard. The result for the hazard that was designed to be least severe is described first in this paper, and the most severe hazard is described last.

Hazard: pedestrian standing on the roadway. There were no significant main effects for speed, or interactions, for this hazard.

Hazard: car reversing down driveway. There was a significant main effect of age $F(2,24) = 3.405$, $p = .050$, but no significant effect due to in-vehicle distracter $F(2,23) = 1.538$, $p = .236$. Tukey's post hoc test showed that the under-25 age group differed significantly from the over 60 age group with lower minimum speeds for the older age group ($p = .040$).

Hazard: pedestrian crossing the road. There was a significant main effect of in-vehicle distracter, $F(2,22) = 4.984$, $p = .016$, and of age $F(2,23) = 15.325$, $p < .0001$. Tukey's post hoc test showed a significant difference between the under-25 age group and both the 30–45 age group ($p = .002$) and the over-60 age group ($p < .0001$), with the older groups reaching a lower minimum speed than the under-25 year olds. There was no significant difference between the 30 and 45 age group and the over 60 age group ($p = .191$). The mean minimum speeds for each age group for this hazard are shown in Table 2.

Paired sample *t*-tests showed that the no distracter condition did not differ from the entertainment system distracter ($t(27) = 2.456$, $p = .021$). There was, however, a significant difference between the no distracter condition and the phone conversation distracter ($t(27) = 2.883$, $p = .008$), with lower minimum speeds reached for the no in-vehicle distraction

Table 2
Mean minimum speed (km/h) reached during hazard

Age group	Minimum speed
Under 25 years	32.46
30–45 years	17.23
Over 60 years	11.76

conditions, as compared with the two distraction conditions. There was no significant difference between the entertainment system distracter and the phone distracter in terms of minimum speeds $t(26) = 0.256$, $p = .800$.

3.3. Objective measures: analysis of trade-offs during the in-vehicle phone distraction condition

To analyze whether participants in the three different age groups adopted different performance strategies when undertaking the in-vehicle distraction tasks, a metric of in-vehicle distraction task performance was obtained. Performance on the mobile phone conversation was obtained by calculating participants' performance with regard to answering the general knowledge questions presented. Of particular interest was whether participants adopted the strategy of preserving driving performance by allowing secondary task performance to decline when increased demand was placed on their cognitive resources.

Paired sample *t*-tests found no difference between the simple and complex environments on the three dependent variables of number of questions answered correctly ($t(30) = 0.070$, $p = .945$), number of questions attempted ($t(30) = 0.404$, $p = .689$) and percentage of correct answers ($t(30) = 0.594$, $p = .557$), indicating no difference in performance levels due to environment. An analysis of variance found no significant differences between the age groups on the number of questions answered correctly, $F(2,28) = 0.506$, $p = .608$, the number of questions attempted $F(2,28) = 0.112$, $p = .895$, or the percentage of correct answers $F(2,28) = 2.408$, $p = .108$. This shows that the three age groups performed to a similar level during the phone conversation general knowledge questions, suggesting that different aged participants did not differentially trade-off their performance in the mobile phone conversation whilst driving. Although performance on the entertainment system task was unable to be formally quantified, the experimenter noted a similar pattern of performance, with participants seemingly following the experimental instructions of both driving safely and attending to the in-vehicle distraction task.

3.4. Subjective measures: NASA TLX data

To obtain an overall measure of workload, scores were averaged across the six TLX sub-scales. Perceived workload differed across scenarios, with the two in-vehicle distraction conditions (phone and entertainment tasks) resulting in increased subjective workload compared to the no distraction condition. A significant main effect for in-vehicle distracter was found, $F(2,27) = 63.819$, $p < .0001$; paired sample *t*-tests showed that workload was significantly different for all three levels of the in-vehicle distracter condition. Workload in the no distracter condition ($M = 5.9$) was significantly lower than in the entertainment system distracter ($M = 10.3$) ($t(30) = 11.140$, $p < .0001$) and the phone conversation distracter ($M = 8.1$) ($t(30) = 4.871$, $p < .0001$) conditions. Subjective workload was higher for the entertainment task compared to the phone conversation distracter condition ($t(30) = 4.978$, $p < .0001$).

A similar pattern of results was found when the six NASA TLX subscales were examined separately. There was a significant main effect for distracter for all the subscales, with highest ratings for the entertainment system distracter and lowest ratings for the no distracter condition.

Workload did not significantly differ between the simple and complex environment conditions, indicating that distraction coming from outside the vehicle did not, as perceived by participants, increase workload.

4. Discussion and conclusions

4.1. Effects of in-vehicle distraction

The lower mean speeds adopted by drivers for the in-vehicle distraction conditions were presumably a compensatory mechanism adopted by participants to increase their margin for error when they were distracted. This was more pronounced for older drivers and for the entertainment system distracter. For the entertainment system the main source of interference could be attributed to the requirement for the driver to take their eyes off the road (i.e. visual distraction). For the telephone conversation task the main source of interference appeared to be the cognitive demand associated with answering the questions, as visual attention could still be focused on the road. In addition, timesharing between driving and the telephone conversation task may have been easier (visual/manual and auditory/vocal) than between driving and performing the entertainment task (both visual/manual).

4.2. Effects of external complexity

Generally in this experiment, participants drove more slowly when they were under load. It could be argued, therefore, that participants found the complex drive more demanding than the simple drive (despite not reporting subjectively higher workload in the complex drive) and slowed down as a compensatory measure which gave them more time to process information in the richer environment. The fact that older drivers drove more slowly in this condition than other drivers supports this proposition.

4.3. Responses to hazards

The findings suggest that minimum speeds were higher in the presence of the two most severe hazards when participants were distracted. Given that mean baseline speeds were generally lower when people were distracted, this suggests that people were less responsive to these hazards when distracted. While it may seem that older drivers were more responsive to these hazards because they slowed to lower minimum speeds this is probably because their *mean* speeds were lower and so it is likely that their speed when encountering these hazards was lower than that of younger drivers.

4.4. Age-related effects

Even though the experimental instructions were to maintain a target speed (the posted speed limit), older drivers drove slower than younger drivers. This implies they had difficulty performing when there was distraction and compensated by slowing their speed. But it is interesting to note that generally few age-related differences were found for performance in the in-vehicle distraction conditions.

The overall findings of this study generally fit in well with previous research. In terms of in-vehicle tasks causing distraction and worsening driving performance, our results support much of the previous literature (e.g. Reed and Green, 1999; Stutts et al., 2001). Our finding that the entertainment task was more distracting than the mobile phone task supports the results of some studies (e.g. Briem and Hedman, 1995). The finding of no significant decline in driving performance due to the complexity of the external highway environment is at odds with some studies (Horberry, 1998; Ho et al., 2001) that found decrements due to increasing environmental complexity. Differences in the saliency of the displayed advertising messages in the various studies may explain the different results. Our results do, however, concur with those of Lee et al. (2001), who found that increasing environmental complexity did not affect all measures of driving performance. Further work on the topic of the safety implications of increased environmental complexity (for example, the number of advertisements around highways) is therefore recommended, even though making the information in the environment salient to all participants will surely challenge the ingenuity of researchers.

Finally, the findings that older people achieved a lower minimum speed with respect to the hazards, drove at overall lower mean speeds in complex environments and had higher speed standard deviation fits in well with much previous research. Although it appears that older drivers regulate their driving behavior, they performed as well as the younger drivers on the mobile phone conversation task, indicating that they did not trade-off mobile phone performance to enable them to drive safely. They slow down and give themselves an increased margin for error because they know they cannot respond to hazards as quickly.

The range of distraction tasks or environmental complexities used in this study of course cannot capture all cases of distractions. However the study adds to the weight of scientific evidence suggesting that performing in-vehicle tasks whilst driving has a detrimental effect on driving performance, and that these effects are relatively stable across different driver age groups and different environments. In particular, a distracter task that requires the same perceptual/motor resources as the driving task would appear to impair driving performance more than a distracter task that uses different resources (the results showing poorer performance for the entertainment system task support this).

4.5. Conclusions

Performing an additional in-vehicle task (such as tuning the radio or conducting a conversation) whilst driving can degrade driving performance in some driving situations. This study has shown that the in-vehicle task of interacting with the entertainment system (and to a lesser extent holding a simulated hands-free mobile phone conversation) can affect measures of driving performance such as maintaining speed, and preparedness to react to unexpected hazards (e.g. to slow down when a pedestrian suddenly crosses the road in front of the vehicle). These in-vehicle distraction driving performance decrements were evident in the simple and complex highway environments and for drivers in different age groups. Whilst driving more slowly may not of itself compromise driver safety, reduced preparedness to respond to hazards will almost certainly compromise the safety of drivers and other road users. In addition, there was a difference in mean speed between the simple and complex environments, with lower mean speeds in the complex environment, implying that the complex highway environment distracted drivers. Drivers over the age of 60 appear to attempt to compensate for the effects of distraction by driving more cautiously than younger drivers in the complex environment. The results for the objective and subjective measures largely agreed, both showing that the in-vehicle distracter tasks had a greater detrimental effect on driving performance and perceived workload than the complexity of the road environment.

Whilst there has been much preoccupation by the media in alerting the public to the dangers of using mobile telephones whilst driving, the findings of the present study suggest that there is a need to inform the public of the potential dangers of performing everyday tasks whilst driving that may have a greater detrimental effect on safety than engaging in a mobile telephone discussion. The degree to which such tasks compromise road user safety, however, depends on the degree of exposure a driver has to them, which can be measured by how frequently they are performed whilst driving, as well as whether or not the task is under the driver's direct control (for example, tuning the radio is under their direct control, whereas receiving a phone call is not). It is possible that tasks found to be relatively more distracting in the laboratory may not compromise safety in the real world if they are performed infrequently, or in low demand situations. The role of exposure to distraction in defining overall crash risk is an important area for future research.

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