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DRIVER SITUATION AWARENESS AND CARPHONE USE

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ABSTRACT

The driving performance of 15 subjects in a simulated road environment has been studied both with and without a hands-free telephone conversation. Previous research on the interference of the manual use of handsets while driving, or when looking at handsfree conversations, has tended to focus on the operational control performance of the driver. This study sought to extend those lines of research by taking a wider view of driving performance, and introduce the higher order concept of Situation Awareness (SA). The performance indicators used were choice reaction time, braking profile, lateral position, speed, and situation awareness.

The simulated driving task was a relatively undemanding motorway with low traffic volume. The young drivers studied were able to have a hands-free telephone conversation and perform well with respect to lateral position, the variation in lateral position of the car, and speed maintenance. However, significant differences were found in choice reaction time, especially in the beginning stages of the telephone conversation, and in situation awareness.

In this situation, subjects reacted significantly slower to an unexpected event in the first two minutes of the telephone conversation and were, for a large part of the telephone conversation, unaware of traffic movements around them. This paper presents those results in detail, and focuses in the discussion on the methodological issues involved in tapping into higher order cognitive functions of tactical and strategic decision making within the confines of current driving simulator capability.

INTRODUCTION

A survey in the United States has revealed that the vast majority (84%) of mobile phone users believes that using a phone is a distraction and increases the likelihood of an accident (*1*). The same respondents report however that 61% of them use their mobile phone while driving and around 30% use their phone frequently or fairly often. Since mobile phone use in cars is a relatively new phenomenon, and since the effects of mobile phone use on traffic safety are still unclear, laws regarding this subject vary between different countries. Some countries use a mixture of legislation and recommendation, but are not consistent about the difference in hands-free and hand-held phone use. For example, in Italy law allows only hands-free phones during driving. At the same time, however, the use of equipment that restricts the hearing senses, (which presumably includes all types of mobile phones) is prohibited.

The same situation exists in Spain, whereas in Portugal, Denmark, and Hungary law (2,3) prohibits only hand-held use of mobile phones. Outside Europe, a hand-held prohibition exists in Israel, Malaysia and some states of the U.S.A. (*2*). Germany, France, and Sweden are examples of countries in which no rules or jurisprudence are used to limit the usage of mobile phones during driving (*2*). Nevertheless, it is recommended in Finland and the UK to use hands-free phones only. The situation is confused and changing continually. Only recently, The Netherlands (June 2000)) have jurisprudence on using handheld mobiles during driving. A driver has been found guilty of causing an accident because she was having a phone conversation. It is likely that many other countries will develop case law in this way even if legislation does not exist.

At one point, it looked as though the problem for legislators would become easier. Research had highlighted the potential safety problems with driving and using handheld devices, and it seemed that the market was leading to the point at which car manufacturers would integrate well-designed hands-free telephones into their vehicles. Many interested experts claimed that driving and holding a carphone conversation was no more difficult than talking to passengers, and so, if the handset were removed, the problem would go as well. Unfortunately the market has gone in a different direction. Personal mobile phones are ubiquitous due to aggressive and cheap pricing regimes, but hands-free adapter kits for use in vehicles, as yet, are not popular. So the use of handheld devices is actually increasing. Added to this is growing concern that the act of holding a carphone conversation is fundamentally different to other in-vehicle conversations with passengers (*5,6,7*). So, we are not reducing the number of handsets, and even if we did, it is possible the problem will remain. This paper reports experimental work focused on an aspect of driving performance that has not been looked at in-depth in previous studies. In addition to measures of performance such as driver reaction time and steering ability, we consider higher-order functions that identify not just the ability to control the vehicle, but also to maintain a clear picture of the traffic situation around the driver during a carphone conversation.

METHOD

In the experiment, 15 volunteer subjects were used. The subjects were all (postgraduate) students at a UK university, aged 22 to 31 (average age = 24.0 years, SD = 2.27 years), with more than 3 years of driving experience, and little or no experience with using a mobile phone while driving.

A static driving simulator was used. A medium sized saloon car stood in front of a purpose-built, cylindrical projection screen. Three projectors produced a horizontal forward field of view of 120°. The vertical field of view was 40°. An additional projector, aimed towards the rear of the car gave a 50° horizontal x 40° vertical image, and provided normal view through the vehicle's interior and driver-side wing mirror. The images were produced with a frame rate of 20Hz and a screen resolution of 960 x 620 pixels per channel. The computer monitoring the car outputs also controlled various elements of feedback to the driver, such as the dashboard lights, engine, road and wind noise as well as the sound of other vehicles in the scene.

The route used in the simulation was designed to keep the attention of the driver on the road. A single carriageway in a countryside environment was used, with smooth horizontal and vertical curves equally spread along the track length. Other traffic on the simulated road did not disrupt the movement of the subject car. In this way, the subjects could always drive at their desired speed. However, to make the driving environment as natural as possible a fairly high level of oncoming traffic was simulated. Cars also appeared in the rear-view mirror and far ahead of the subject car. The route had a total length of 15.5 miles. Measurement of the performance indicators for each subject took place between the 4^{th} and the 11^{th} mile. Each subject drove the route twice, once while engaging in the carphone task, and once without. The order of routes was balanced across subjects to minimise carry-over effects

Subjects were instructed to keep the vehicle in the middle of the lane and to keep close to the mandatory speed limit, indicated by regular roadside speed limit signs, at all times. The subjects were also told that other normal road environment conditions applied, that other traffic would be present and that some severe weather conditions (like wind gusts) were likely to occur.

Subjects were asked a series of questions via the hands-free carphone, and were required to make a verbal response when they felt able to do so. A hybrid test was developed (*8,9*) that incorporated numerical and verbal memory, arithmetic and verbal reasoning. The test was extensively piloted and was aimed to be demanding for the subject group. The subjects were not under time pressure, and they were told that their scores would not be used in any part of the analysis of the trial.

Two different kinds of ‘unexpected events’ requiring choice reactions were simulated. The first one was a green square (presented on two occasions) that appeared on the road in front of the car for approximately 2 seconds. Subjects had to flash the lights of the car as quickly as possible in response to the green square. The second event was a red square that represented a danger on the road, and the subjects were expected to make an emergency stop immediately. A further indication of the driver performance was given by the braking distance of the car after the appearance of the red square. This is of course directly related to the reaction time of the driver and the speed of the car, but gives extra information about the performances of the driver. Choice reaction time measurements were taken at 5 miles (1st green square appearance), 6 miles (red square appearance) and 8 miles (2nd green square appearance). Wind gusts were simulated at 5.5 miles and at 10 miles, from the left side of the road at an angle of 90°. Both gusts had a speed that gradually increased from zero to 15mph and then decreased again gradually to 0mph. In total, each wind gust lasted over a distance of around 500m.

Lateral position and variability were measured, both on straight sections and when there were simulated wind gusts from the side of the vehicle. Speed maintenance was recorded during sections not involving other measures. Another indicator of performance with respect to speed is the adjustment to a change in the mandatory speed limit. Along the test route the mandatory speed limit changed once from 80 to 50km/h (at 4.5 miles) and once from 50 to 80km/h (at 7 miles)

Situation awareness (SA) has been defined as *'a person's perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future'* (*10*). The relation between poor situation awareness and poor performance has been found in several studies (*11*). There are three different levels of Situation Awareness (*10*):

Level 1 SA: Perception of the elements in the environment.

Level 2 SA: Comprehension of the current situation.

Level 3 SA: Projection of future status.

All three levels of SA were measured in this research by questions directed to the subject at two fixed locations at 6.5 miles and 9 miles after the start of the test. The screen went blank and the simulation was stopped. The subject was then asked SA probe questions. At the moment the screen went blank, one car was in the rear-view mirror and three or four cars were approaching on the opposite lane. After asking the questions, the simulation was resumed at the same position as when the simulation was stopped.

Every subject got a chance to get used to the simulator car on a practice route. This route was simple, with low levels of traffic and road curvature and change in mandatory speed limit. During the practice one green and one red stimulus was presented to acquaint the subject with the choice reaction task. After the practice each subject drove the test route twice, once with and once without the carphone conversation. Since both routes were identical in curvature, amount of traffic and performance measures, it was important to counter balance the sequence in which the phone/no-phone trials were held. Between the practice run and the first trial, and between the two trial runs, a break was included. The total experiment took around 80 minutes for each subject and had the following structure:

- Introduction (5 min)
- Practice (15 min)
- Break (5 min)
- Trial 1 (20 min)
- Break (5 min)
- Trial 2 (20 min)

RESULTS

A one-sample t-test, was used to determine if there was a difference between the reaction time of the subjects in both situations. The result showed for the first green square a significant decrease in reaction time associated with the carphone conversation ($t(1,14) = 2.576$, $p<.05$).

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Table 1. The mean reaction time to the various stimuli in the phone and no-phone situation

Stimulus	Mean reaction time (sec)	
	Without phone conversation	***With phone conversation***
1st green square	1.008	1.131
2nd green square	1.115	1.187
Red square	1.370	1.421

The second green square showed however a non-significant t-value of 1.169 (df=14 and α=0.05 and t_{crit}=1.761). The reaction time to the red square gave a similar non-significant result.

The mean lateral position was calculated for each subject from the lateral position of the car between the 4^{th} and 5.5^{th} mile and the 7^{th} and 8.5^{th} mile of track. A one-sample t-test showed no significant difference in the mean lateral position between the phone and no-phone situation (df=14, α=0.05, t_{crit}=1.761, t1=-1.390, t2=0.879).

A further indication of the performances of the subjects is given by the variability in lateral position, estimated by the standard deviation of the lateral position. The more the subject varies the lateral position, the more implications this might have on traffic safety. The standard deviation for each subject was also calculated for the same two sections as above. A one-sample t-test showed no significant difference between the phone and no-phone situation in each section. The variance in lateral position was also used to measure the influences of mobile phone usage on the unexpected event of a wind gust. The standard deviation of the lateral position of each subject was calculated from the lateral position of the car, from the triggering of the wind gust, until 500 metres after. A single-sample t-test gave non-significant values of -0.48 and 0.73 for wind gust 1 and 2 respectively (with df=14, α=0.05, t_{crit}=1.761).

Speed was also used to measure driver performance. The speed of the car in each trial was measured along part of the route. To avoid influences from the emergency stop (red squares) and the wind gusts, the speed of the car was measured in sections without these features. There was no significant difference between trials.

It was also of interest to see if there was a difference in speed adjustment between the two situations, once the mandatory speed limit changes. During the (possible) phone conversation the mandatory speed limit changed once from 80mph to 50km/h and once from 50 to 80km/h. For each subject the speed was recorded every 100 metres from 500 metres before the mandatory speed limit sign until 500 metres after the speed limit sign. Analysis showed no difference in mean speeds around the 50-80 km/h change (df=14, α=0.05, t_{crit}=1.761, t=1.13), but a significant difference was found when the speed changed from 80 to 50km/h (df=14, α=0.05, t_{crit}=1.761, t=3.42).

However, although the mean speeds of the subjects around the speed limit change differed significantly, this does not say anything about how quickly the subjects reacted to the speed change. Therefore, the mean speeds of the subjects were calculated at 100 metre intervals in both the phone and the no-phone situation. These mean speeds are plotted for the 80-50 km/h and the 50-80 km/h speed changes respectively. This shows that there is no observable difference between the mean reaction to the change in speed limit from 50 to 80 km/h in the phone and no-phone situation: both lines show approximately the same pattern. The change from 80 to 50 km/h however seems to be slower in the phone situation: the mean speed of the subjects in the no-phone situation was below the speed limit after almost 100 metres.

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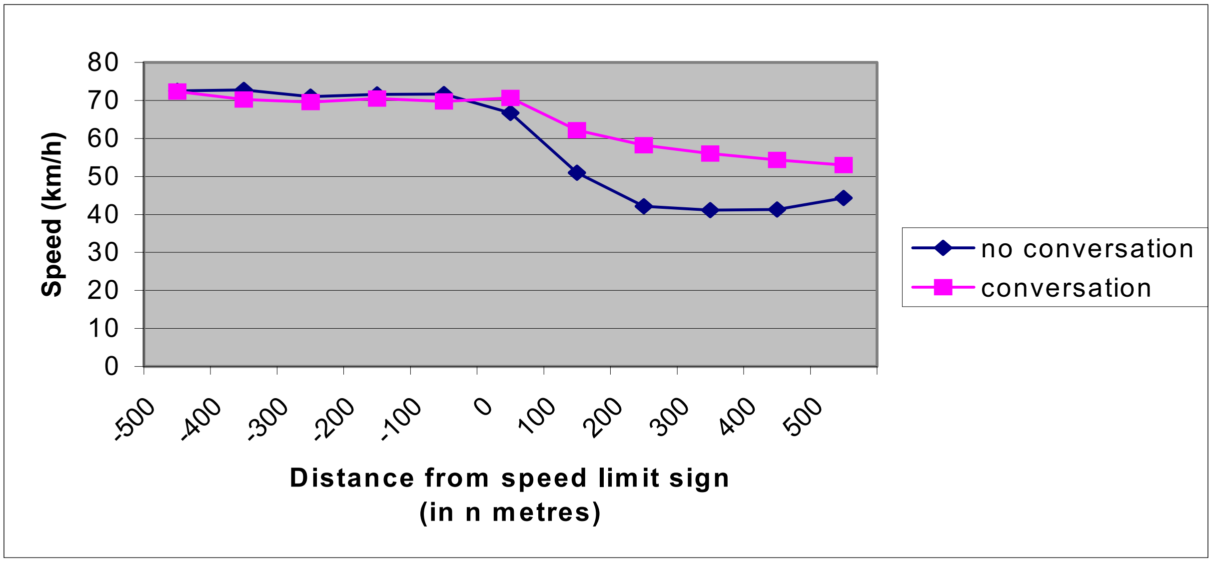

Figure 1. Mean change in speed as a result of a mandatory speed limit change from 80-50 km/h

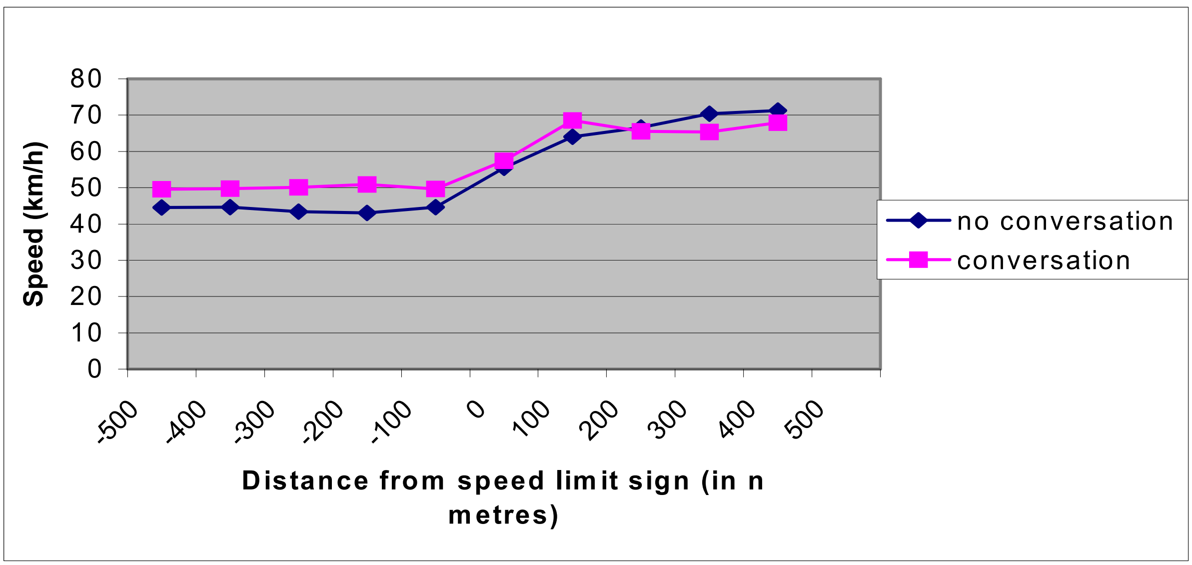

Figure 2. Mean change in speed because of a mandatory speed limit change from 50-80 km/*h*

Situation awareness of the subjects was measured by asking the subjects three questions at two fixed locations during the simulation. The questions asked at each location were:

1. *Can you tell me what other traffic was surrounding you just before I stopped the simulation?*

2. *Can you tell me the colour of the car that was in your rear-view mirror?*

3. *Was the car in your rear-view mirror driving faster than you, or not?*

Table 2. Performances on the situation awareness task with and without phone conversation (location 1)

No. of correct answers; Location 1	**Without phone conversation**	**With phone conversation**	χ^2	*Critical value*	*p-value*
Question 1	14	4	13.89	12.12	<.0005
Question 2	14	6	9.60	9.14	<.0025
Question 3	13	6	7.03	6.63	<.0100

Table 3. Performances on the situation awareness task with and without phone conversation (location 2)

No. of correct answers; Location 2	**Without phone conversation**	**With phone conversation**	χ^2	*Critical value*	*p-value*
Question 1	12	5	6.65	6.63	<.01
Question 2	12	4	8.57	7.88	<.005
Question 3	12	5	6.65	6.63	<.01

There were significantly more correct answers to the situation awareness questions in the no-phone situation at both locations.

DISCUSSION

The reaction time to the first choice reaction event, the responsiveness to a lower speed limit and the situation awareness of the drivers showed a significant difference in favour of the no-phone situation. However, before drawing any conclusions it is important to interpret the outcome of the analysis within the context of the particular limitations of this study. A main limitation is that the measurements took place in a safe, simulated environment. In addition to this, the simulated road was a countryside environment, with a reasonable amount of surrounding traffic, but no direct conflicts with other cars. The road driven did not have sharp curves or large junctions and the subjects were asked to keep to the maximum speed limit, which was either 80 or 50km/h. As a result, the driving task was rather easy. The phone task on the other hand consisted of a selection of verbal and numerical questions and was rather difficult to perform. The results may therefore only apply directly to a situation of a relatively easy driving task combined with a relatively difficult telephone task.

The reaction time to both the second and third choice-reaction events was not significantly longer in the phone situation, which questions the difference in reaction time to the first event. A reason for this difference might be that the first square appeared rather soon after the start of the conversation (after approximately 2 minutes), whilst the other squares appeared later (at approximately 5-7 minutes after the start of the phone conversation). This would imply that drivers are slower in their reactions when a phone conversation just has started, but the effect reduces over time. This result finds some support in real road studies (*7*) that showed a pronounced dip in speed at the onset of a carphone call. The carphone task seems to occupy the subject more in the beginning stages, resulting in a reaction time, which is on average 0.13 seconds longer. This means that (at a speed of 80 km/h) on average an extra 3 metres is covered before a reaction to an event on the road is triggered. The second significant difference in performance was found in the responsiveness to a change in speed limit from 80 to 50km/h. It took drivers in the phone situation on average 200 metres more to adapt to the new speed limit than in the no-phone situation.

The third difference may be more important. Significant deterioration was found in situation awareness between the phone and the no-phone situation. Many subjects in the phone situation had very little idea about what was going on around them at the two points the simulation was stopped and were not able to report on the presence or actions of traffic around them. Whilst it is clear that a small set of questions relating to the presence, colour and speed of following cars is not a comprehensive analysis of driver SA, but rather a sub-set measuring the attention given to traffic approaching to the rear; the results are clear-cut and quite dramatic. Future research in this area should broaden the interpretation of SA to include knowledge of the status of the vehicle, relevant roadsigns and infrastructure and a greater insight into the immediate traffic environment. Given the technical limitations of the particular simulator used in this study, these options were not available, and a very simple approach had to be developed. However, the results clearly show that the demands of the carphone conversation were such as to disrupt the mirror sampling pattern and a narrowing of the focus of attention in the driving scene.

The results have shown that a young well-educated group of drivers were able to engage in a difficult carphone conversation and cope with basic control elements of driving reasonably well. However even this group showed a dramatic fall off in traffic awareness due to the level of concentration demanded by the carphone conversation.

It is clear that more research is required into the nature and duration of typical carphone conversations, and into the behavioural and performance consequences for a wider group of drivers, in both simulated and real world environments. Until then it is likely that legislation will continue to focus solely on the use of hand held devices. Whilst this is important, it does not address the full extent of the problem.

This study can serve as one of the preliminary steps towards building up a rich picture of the effects of carphone conversations on vehicle safety; but it is only one step. The simulated traffic scenario was simplistic, and the choice reaction tasks somewhat abstract. The measures of vehicle speed and lane position are objective, yet caution must be used in the generalisation of the results, as we have used a static driving simulator with a reasonably crude vehicle performance model. This begs the question of whether we could have greater confidence in the results if a much more sophisticated simulation was employed.

At one level one can argue that what is of real interest here is the relative difference in the observations of the two groups of data, with and without carphone conversation. If we are interested in the direction of change, and the relative difference in sample distributions, then this form of simulation, which has high face validity for subjects, is sufficient. Alternatively, if we wish to say something absolute about vehicle speeds, stopping distances and so on, then a simulation with higher content validity (greater realism in the scenarios and vehicle performance characteristics) would be required. However, even then we would only have part of the overall picture. Ideally, we should capture data relating to long term experience with carphones, discriminate between different types of conversation (some are clearly more demanding and stressful than others), describe the mediating influence of the complexity of the concurrent driving task, and also gauge performance in relation to realistic risk of accidents. Given current simulation technology, great strides can be made towards increasing the fidelity and realism of the driving experience, yet ultimately there are limits to the verisimilitude of the experiment.

This experiment has attempted to focus on those elements that can reasonably be addressed in a medium fidelity simulator: speed choice, lane tracking, reaction times and situation awareness. All of these measures have shown that the concurrent engagement in a hands-free carphone task directly influence performance in a direction associated with a decrease in safety.

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