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Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes

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Abstract

This paper reports a simulator-based study of the effects of mobile phone use on driving performance. Changes in heart rate indicated that mobile phone use increases the cognitive demand experienced by drivers with, it is argued, consequent reduction in safety margins. However, experimental results also suggested that participants engaged in a process of risk compensation, with driving speed being slower at times of mobile phone conversation while the number of off-road excursions (OFFS) and collisions remained stable. There also was some evidence that the use of a hand-held mobile phone (when compared to a hands-free system) was associated with poorer driving performance. Implications for 'real world' driving are considered. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The effects of mobile (cellular) phone use on concurrent driving performance are the subject of continuing debate. Given that mobile phone use is rising in all countries for which connection data is available (Royal Society for the Prevention of Accidents, 1997a; Violanti & Marshall, 1996), establishing the nature of these effects is a matter of concern for all professionals with an interest in road safety. However, obtaining reliable evidence is difficult. Studies of 'real world'

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driving performance, that maximise ecological validity, are problematic for ethical and legal reasons (Haigney & Westerman, in press). Accident statistics provide an indication of the associated risks, but they lack precision (e.g. due to under-reporting), and this form of investigation does not enable specific factors that may influence driving performance to be manipulated. In this respect, driving simulator studies provide a useful, albeit a less ecologically valid, alternative. They also have the advantage that performance can be assessed accurately using a number of different measures (e.g. speed, off-road excursions (OFFS)) that may only relate to accident involvement as part of a complex pattern of events. This paper reports one such simulator study in which driving performance with and without concurrent mobile phone use was compared.

1.1. Compensatory processes

Concurrent mobile phone use increases the overall level of cognitive, and sometimes physical, demand experienced by drivers. This is consistent with the finding that, in this circumstance, both heart rate and self-report workload increase (Fairclough, Ashby, Ross, & Parkes, 1991). The implication of such changes is that safety margins are reduced when using a mobile phone, as drivers have less spare processing resources to allocate to sudden emergency situations (e.g. a child stepping off the pavement) or to increases in driving task demands (e.g. the road changing from straight to winding). Consequently, greater error can be predicted (see e.g. Reason, 1990). In support of this position, there is evidence that mobile phone use is associated with greater accident involvement (Goodman, Tijerina, Bents, & Wierwille, 1999). This model of resource allocation and competition could also be used explain why some driving studies found little, if any, effect of mobile phone use on performance (e.g. Drory, 1985; Stein, Parseghian, & Allen, 1987). It may be that, in these instances, the combined level of demand associated with the mobile phone task and the driving task was not sufficient to overload the system (see also Briem & Hedman, 1995).

It is important to note that not all mobile phone-related changes in driver performance equate with increased driving risk. There are some changes that may be indicative of the application of compensatory processes, through which drivers maintain what they perceive to be acceptable safety margins. For example, several studies have found that drivers reduce speed when using a mobile phone (Alm & Nilsson, 1990; Brookhuis, De Vries, & De Waard, 1991; Fairclough et al., 1991). In the context of attentional resource models (e.g. Wickens, 1991, see below) it is possible that driving at a slower speed is less resource demanding and thereby enables resource availability to be maintained at a level that equates with a perceived safety standard. A strong version of this hypothesis might refer to a process of risk homeostasis (see Wilde, 1982, 1988; although also see Adams, 1988, for counter-arguments).

In the study reported here, changes in the effort allocated to task performance under conditions of mobile phone use were investigated. In particular, the extent to which cognitive vs physical factors were responsible for changes in effort were considered (see below). Further, possible compensatory processes were examined. Mobile phone-induced changes that may promote safety (e.g. speed reductions) were considered in relation to changes that indicate increased risk (e.g. OFFS).

1.2. Task demand characteristics

It is apparent that different performance task elements (e.g. dialing, conversing), associated with mobile phone use, impose different cognitive and physical demands. Similarly, driving performance requires a range of cognitive and physical skills. Haigney and Westerman (in press) argue that prediction of levels of interference between these two tasks can only be achieved with reference to the specific demands of each. Although the probability of interference may be increased if concurrent demands are similar (e.g. both tasks require manual response), this is not a pre-requisite for interference (see e.g., Lamble, Kauranen, Laakso, & Summala, 1999). Goodman et al. (1999) refer to accident reports which indicate a driver has apparently left the carraigeway while conducting a conversation over a mobile phone (no physical or visual conflict). In this respect a hierarchical model of attentional resources (see Wickens, 1991) may provide a useful description, in that, if sufficient central processing demands of the different task components can lead to performance overload and to error.

Very often studies of mobile phone use and driving performance have failed to consider task demand characteristics (Royal Society for the Prevention of Accidents, 1997a). For example, the existing 'mobile phone' research literature gives very little indication of the impact of a potentially important source of physical conflict, the process of gear changing in a manual transmission vehicle. Differences in driver workload have been noted between transmission types (Zeier, 1979). However, the authors were able to locate only one study of drivers' phone use that explicitly described the use of a vehicle fitted with manual gearshift (Brown, Tickner, & Simmonds, 1969). A number of studies do not state the form of transmission fitted in their test vehicles (e.g. Wikman, Nieminen, & Summala, 1998; Fairclough, 1991), while other studies – the majority of the research literature – specify using automatic transmission vehicles or driving simulators or scenarios which mimic the operating conditions within an automatic vehicle (Royal Society for the Prevention of Accidents, 1997a).

Another factor that will influence task demand characteristics is the type of mobile phone unit that is used. Differences in driver workload have been noted between hand-held and hands-free phone types (Royal Society for the Prevention of Accidents, 1997a; Brookhuis et al., 1991), with the former being relatively more demanding. Moreover, it can be hypothesised that phone type will interact with transmission type, and that physical interference will be maximal when driving a manual transmission vehicle while concurrently using a hand held phone unit – a scenario particularly relevant to the existing situation in UK (see Royal Society for the Prevention of Accidents, 1997a,b). Therefore, the study reported here examined the possible influence of vehicle transmission type (automatic vs manual) and phone type (hand-held vs hands-free), on the effects of mobile phone use while driving.

2. Method

2.1. Participants

Thirty participants (13 male, 17 female) were recruited for this study (mean age = 26.93 years, S.D. = 3.06). Each had held a UK manual transmission driving license for private and light goods vehicles (PLG) for at least one year (*M* 4.37 years, S.D. 1.73). UK, drivers holding a full PLG manual transmission license are qualified to drive PLG automatic transmission and so this was deemed an adequate gauge of basic driving skill for this experimental design (Zeier, 1979). Sixty-three percent of the sample had previous experience of using a mobile phone; 13% of the sample had experience of using a hands-free phone; and 20% of the sample used a mobile phone while driving with a frequency of once per week or greater.

2.2. The Aston Driving Simulator

The Aston Driving Simulator (ADS) comprises an adjustable car seat, steering wheel and pedal controls. The 'windscreen' view, the car 'dashboard' (including a speedometer), and rearview mirror (a real-time representation of objects and events occurring behind the users 'vehicle') are displayed on a 21in. monitor, placed in front of the participant. The 'forward' view is a computer-generated image of a carriageway and car bonnet with perspective incorporated. Participants 'drive' along the carriageway through the manipulation of appropriate vehicle controls in a closed loop simulated environment. The road is also populated with 'intelligent' vehicles on either side of the carriageway, capable of overtaking the participant's vehicle and each other.

As the ADS only shows a carriageway with no intersections, this version of the programme included 'pop-ups' intended to mimic vehicles pulling out suddenly onto the carraigeway (Stein et al., 1987; Nilsson & Alm, 1991). The pop-ups took the form of another vehicle that spontaneously appeared at a distance between 50 and 80 m in front of the user's vehicle on the left-hand carriageway. Pop-ups then traveled along the carriageway as an 'intelligent other' (see above). Their appearance could, depending on the user's speed, require the user to brake or steer around the pop-up.

For this experiment, mean speed, standard deviation of accelerator pedal travel, brake pedal travel, and number of gear changes were logged every 0.5 s. In addition, number of overtakes, number of off-road excursions (OFFS), and number of collisions were recorded as dependent measures.

To maximise face validity, 'off-the-shelf' cellular phone equipment was used for this experiment (Zwahlen, Adams, & Schwartz, 1988). The model (a Nokia 1611 GSM) was a single unit with the keypad on the same face as the output speaker and microphone. To receive a call it was necessary for participants briefly to depress a specific button on the keypad. No action was required to end a call. The phone was placed upright in a 'holster' to the right of the steering wheel, on a level with the dashboard readout dials.

2.3. The mobile phone task

The task used to simulate a mobile phone conversation was developed from the 'grammatical reasoning test' detailed by Baddeley (1968) and used previously to replicate the demands of a conversation held over a mobile phone whilst driving (Brown et al., 1969). The original task comprised a series of trials for which two letters are presented to the participant, either aurally or visually, followed by a statement concerning their order. Participants are required to respond 'true' or 'false' to this statement. Given that mobile phone conversations may be considerably more 'intense' and 'complex' than other conversations (Fairclough et al., 1991), the task was adapted for this experiment to increase the associated cognitive demands. In this study, participants were presented with five stimulus letters, followed by a statement regarding the relative ordering of two pseudo-randomly selected letters. As for the original task, participants were required to indicate whether this statement was true or false.

2.4. Procedure

Participants initially completed a short questionnaire comprising items relating to age, gender, driving experience, and experience of hands-free and hand-held mobile phones. Then, seated in the ADS, they were fitted with the heart rate sensor, and the phone earpiece and microphone.

Participants' resting heart rate was assessed using a Pulse Coach-3, with an earlobe sensor. This was used as a baseline, against which changes associated with driving and mobile phone use, were considered. A 150 s practice period then followed in which participants were allowed to familiarise themselves with the simulator.

Participants then completed four simulated drives. Two of these were performed using a manual transmission setup, the other two used an automatic transmission setup. Each simulated drive comprised three 150 s periods: (i) 'pre-call', (ii) 'during call', and (iii) 'post-call'. In the during call period participants received, and were required to deal with, an incoming phone call. Two of these (one for each transmission type) required the use of a hand-held phone unit, and two required the use of hands-free mobile phone equipment. The order in which participants experienced each combination of 'transmission type' and 'phone type' conditions was counterbalanced.

When performing in the 'automatic transmission' condition participants were required only to use the brake pedal, the accelerator pedal and the steering wheel in order to maneuver the vehicle in the ADS environment. When performing in the 'manual transmission' condition participants were required to use the brake, accelerator, clutch, gear lever (arranged as a 'straight H', 4 geared box) and steering wheel in order to maneuver the vehicle in the ADS environment. Auditory feedback was available, to assist the timing of gear changes, through the inclusion of simulated engine noise that rose in pitch as engine revolutions increased.

In the 'hand-held' phone conditions, participants were required to remove the phone from, and return the phone to, the holster following each 'conversation'. It was also necessary for them to hold the phone to their ear for the duration of the conversation. A Vodaphone 'hands-free conversion kit' was used for the hands-free conditions. This comprised an earpiece and microphone that was attached to the participants' clothing. In hands-free conditions participants were still required to 'receive' calls, as described above. However, the phone unit did not need to be removed from its holster.

3. Results

A series of 2 (manual vs automatic transmission) $\times$ 2 (hands-free vs hand-held phone type: PHONE) $\times$ 3 (pre-call vs during call vs post-call time periods: PERIOD) repeated measures ANOVAs was used to analyse the performance for each dependent measure. When the frequencies of gear changes were examined it became apparent that, in the manual condition, participants had not changed gear in either the during call or post-call time periods. It would seem that, because there was no penalty for using the wrong gear (the car did not stall if a high gear was selected at low speed, it just pulled away more slowly) participants were, in effect, using the manual simulation as an automatic vehicle. Probably for this reason, significant effects of the transmission manipulation were limited to differences in standard deviation of accelerator pedal travel and are not reported here.

3.1. Driving performance

There was a main effect of PERIOD on speed, $F(2,58) = 5.98, P < .005$, and standard deviation of accelerator pedal travel, $F(2,58) = 20.34, P < .001$. The mean value for each of these dependent measures was lower during the mobile phone call, relative to either pre- or post-call values (see Table 1). The effects of PERIOD on brake pedal travel, $F(2,58) = 1.39$, number of overtakes, $F(2,58) = 1.88$, number of OFFS, $F(2,58) = 1.35$, and number of collisions, $F(2,58) = 1.07$, were not significant.

There was a significant effect of PHONE on the number of OFFS, $F(1,29) = 4.22, P < .05$, with more OFFS when using the hand-held unit than the hands-free condition (see Table 2). The interaction between PHONE and PERIOD for OFFS was not significant, $F(2,58) = 1.92$. However, there was a tendency for the difference between phone types to greatest before and during the phone call. The main effect of PHONE on speed, $F(1,29) = .06$, variability of accelerator pedal travel, $F(1,29) = .03$, brake pedal travel, $F(1,29) = .27$, number of overtakes, $F(1,29) = .15$, and number of collisions, $F(1,29) = .03$, were not significant. Similarly, there were no other significant interactive effects, $F(2,58) = 2.25$; $F(2,58) = .46$; $F(2,58) = 1.47$; $F(2,58) = .71$; and $F(2,58) = .04$, respectively.

Table 1
The effects of time period (pre-, during- or post-mobile phone call) on speed and variability (S.D.) of accelerator pedal travel

Time period	Speed		S.D. Accelerator pedal travel	
	Mean	S.D.	Mean	S.D.
Pre-call	46.04	(10.67)	19.36	(5.91)
During call	43.78	(15.97)	14.92	(5.73)
Post-call	48.31	(16.59)	17.68	(6.52)

Table 2
Breakdown of the frequency of driving off the carraigeway by time period (pre-call, during call or post-call) and phone type (hand-held or hands-free)

Time period	Hand-held		Hands-free	
	Mean	S.D.	Mean	S.D.
Pre-call	0.18	(0.54)	0.12	(0.33)
During call	0.32	(1.06)	0.13	(0.50)
Post-call	0.10	(0.30)	0.10	(0.41)

Table 3
The effects of time period (pre-call, during call or post-call) on deviation from baseline heart rate

Time period	Mean	S.D.
Pre-call	2.34	(4.37)
During call	5.66	(7.61)
Post-call	0.87	(7.13)

3.2. Heart rate

There was a main effect of PERIOD on mean heart rate, $F(2,58) = 19.10, P < .001$, with heart rate being greatest in the during call period (see Table 3). Relatively low scores in the post condition may be attributable to participants getting used to the experimental environment and because there was no gear changing requirement (see above).

There was no significant effect of PHONE on heart rate, $F(1,29) = 1.70$, and no significant interaction between PERIOD and PHONE, $F(2,58) = 2.03$.

3.3. Secondary task performance

Secondary (mobile phone) task performance was analysed using a repeated measures 2 (manual vs automatic transmission) $\times$ 2 (PHONE) analysis of variance. This only applied to the 'during' phone call time period. There were no significant main or interactive effects.

4. Discussion

Consistent with the prediction that using a mobile phone while driving imposes additional load relative to driving without concurrent phone use, mean heart rate was higher in the during call period of this experiment than either the pre-call or post-call periods. The fact that there was no interaction with phone type (hand-held vs hands-free) indicates that this increase was not related to the physical demands associated with holding the phone. Instead, it would seem that participants were finding task performance cognitively more effortful in the during call period, and were having to invest greater attentional resources in task performance. As mentioned above, this may not translate directly to poorer driving performance, but has implications for associated safety margins, and therefore accident risk. These findings also indicate the utility of heart rate as a measure, in this context. Although there are difficulties associated with the use of heart rate as an index of workload (Kramer, 1991), it is a relatively non-intrusive measure that can be sensitive to cognitive demand (see e.g. Wilson & Eggemeier, 1991).

The results of this study also supported the hypothesis that drivers engage in compensatory behaviour and attempt to reduce workload when using a mobile phone to enable perceived required safety margins to be achieved. Consistent with the findings of previous studies (Alm & Nilsson, 1990; Brookhuis et al., 1991; Fairclough et al., 1991), participants drove more slowly in the during call period than they did either prior to or after the call. Given that the frequency of collisions or OFFS did not increase in the during call period, this supports the notion that participants were engaging in a process of risk compensation. Though increased workload in the during call period would lead to a reduction in safety margins, drivers seemed to apply a compensatory strategy to minimise these effects and avoid major incidents (collisions or OFFS).

Reduced variability of accelerator pedal travel in the during call period is consistent with changes noted by Bailey (1994) and Nilsson and Alm (1991) that may be indicative of a reduction in driver reactivity to road/traffic conditions at times of concurrent mobile phone conversation. There was also a main effect of phone type with respect to the number of OFFS in the predicted direction, with participants having more OFFS when using the hand-held phone. This is consistent with this phone type placing greater demands on the driver. Although PHONE did not interact with PERIOD, differences were pre-call and during call. Some difference in the pre-call period might be due to anticipation of the call, i.e. preparation for answering the call. As would be expected, the mean number of OFFS was the same for both types of phone unit in the post-call period.

5. Conclusions

The results of the reported study suggest that using a mobile phone while driving may have implications for safety margins that will not be immediately apparent. Although it seemed that drivers attempted to compensate (by reducing speed), increased cognitive workload resulted from mobile phone use. It can be predicted that this will render drivers less able to cope with emergency situations or other abrupt increases in driving task demands. Negative effects were particularly apparent when participants were using a hand-held phone unit. However, on the basis of these results, the position stated by Royal Society for the Prevention of Accidents (1997a) is maintained – it is recommended that drivers do not engage in concurrent phone use.

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