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EFFECTS OF HANDHELD MOBILE CONVERSATIONS ON EXPERIENCED PHONE USERS' SIMULATED DRIVING PERFORMANCE

Abstract

Recently, controversy has arisen regarding phone use while driving, as some studies indicate that the likelihood of being involved in crashes or near crashes may not increase due to a conversation - it may even decrease (Olson et al., 2009; Young, 2012). The current study examines the effects of handheld mobile phone conversations on driving performance of drivers who report to use their phone at least once a week during driving. A total of 20 participants, in a fixed-base driving simulator, drove a simulated route twice, once while having a handheld phone conversation, and once to record baseline driving, in a counterbalanced repeated measures design. The route included several speed limit sections (50, 70, 80, 100 km/h), and seven traffic lights.

Driving performance results are assessed on the strategic (traffic light wait time, trip duration and speed limit exceeding), tactical (acceleration, deceleration and lane choice) and operational levels (indicator use, steering wheel movements and braking). Results regarding visual performance, mental workload, lateral performance, and speed are reported elsewhere (Knapper et al., under review)

The results show that mere handheld mobile phone conversation while driving leads to more conservative driving, in terms of speeding, waiting time and decelerating. These potentially positive effects may, however, be countered to some extent by the absence of indicating, and the fact that exposition to other traffic remains larger, due to the trips taking more time. However, the results also show that even experienced mobile phone users' driving performance is influenced by handheld conversations. Thus we cannot exclude phoning as a cause for road crashes, as its distraction does affect driving. However, considering the overt effects, it seems unlikely that its contribution is large.

1. INTRODUCTION

Driving is a complex task that many of us perform, together with many other traffic participants, all at the same time. We all want to get from A to B, and do so safely. The complexity of the driving task lies in the many factors that may influence it, for instance, children on the street, the route, shifting gears, traffic rules, traffic signs and other drivers performing the strangest manoeuvres. One issue in dealing with that task is the fact we like to perform it alongside other tasks, such as Facebooking, dealing with children, tuning the radio, and daydreaming. We may then be driving distracted by a secondary task, that is, a task that is not necessary for driving. Distracted driving has been identified to be involved in almost 80% of all crashes (Dingus et al., 2006).

Until recently, common thinking was that mobile phone conversations in general while driving increase the risk of being involved in a crash (Redelmeier and Tibshirani, 1997). However, large scale naturalistic driving studies have shown that this risk is in fact smaller than baseline driving for handsfree mobile phone conversations, and about equal in case of handheld mobile phone conversations (Olson et al., 2009). Hence, some controversy has arisen about whether earlier studies have adopted a positive bias towards the negative effects of mobile phone use while driving (Young, 2012). On the other hand, it may be that the effects on driving performance are real, but that drivers compensate for these effects by either slowing down or by selecting traffic conditions that allow for secondary task performance as they are very low risk in nature their selves.

According to a meta-analysis by Caird, Willness, Steel, & Scialfa (2008), the majority of research up until 2007 focused on handsfree mobile phone use (37 papers included), and only few on handheld (5 papers). Estimates are that 1 up to 12% of drivers at any given moment are using their mobile phone (WHO, 2011; Kircher et al., 2011). In a roadside observation study in England, Sullman (2012) reports observation of about 2% of drivers holding a phone to their ear.

Comparing effects on driving of having handheld and handsfree phone conversations, Strayer et al. (2011) found no differences. Both phone conditions did however differ from baseline driving in longer reaction times and, more careful driving (longer headway distance and somewhat slower driving). Furthermore, the effects of the difficulty of the conversation itself (simple or complex) were found to be larger than the effects of handheld versus handsfree conversations (Patten et al., 2004). This is in concordance with Horrey & Wickens' (2006) meta-analysis results. Although participants in the study by Törnros & Bolling (2005) rated their own driving performance during handsfree driving better than during handheld driving, results regarding lateral performance showed mild positive effects in both modes, and similar increases in driver mental workload. Likewise, handheld versus handsfree phoning did not cause differently heightened effects regarding mental workload, in a study by Haigney et al. (2000). That study did however find a slightly higher number of off-road excursions during handheld as opposed to handsfree phoning.

Thus, based on the literature, we may conclude that effects of mobile phone conversations (both handheld and handsfree) while driving include deteriorated reaction time, leading to intensified braking, less awareness of the situation, increased risk taking and compensatory behaviour (Dragutinovic and Twisk, 2005). Still, a lot of potential variables have not been

mentioned in papers, possibly due to the file drawer problem (cf Horrey and Wickens, 2006; Elvik, 2011), in that non-significant results are not reported. Thus, despite the fact that phones have been present in cars for over 20 years (i.e., Brookhuis et al., 1991), still a lot remains unknown regarding the effects of phone conversations while driving.

The current study describes the results of a closer look at the mobile phone data gathered in the study as described in Knapper et al. (under review). Regarding mobile phone effects, that study looked merely at mean speed and speed variability, lateral performance, and eye glances. It assessed driver distraction in a more general sense; way finding using either a navigation system or a paper map, programming destinations, texting, and having an handheld mobile phone conversation. Here, in order to gain more in depth knowledge regarding the effects on driving performance as caused by cognitive distraction induced by a handheld mobile phone conversation, we will study other driving performance related measures, including trip duration, traffic light wait time, speed limit exceeding, acceleration and deceleration, lance choice, indicator use, steering wheel reversals and braking.

Therefore the research questions addressed here is: *Which measures show differences between normal driving and driving during a handheld phone conversation?* The results are discussed regarding the relevant measures known or potential impact on road safety, specifically in order to gain insight in why and how they do so. Hence, in this paper, we deal with to what extent drivers who are distracted by a phone conversation are impaired at performing their driving task. The measures, or dependent variables, are addressed in the next chapter.

2. METHOD

PARTICIPANTS

Of 21 initial participants, one was excluded from the study for being simulator sick. Therefore, 20 persons including six females and 14 males eventually participated in the study. They had been recruited at Delft University of Technology using elevator posters and digital newsletters. They applied via e-mail, and first were requested fill in a small questionnaire regarding their driving behaviour, including a question on how often they used a mobile phone while driving. Included in the study were persons answering they used phone at least once a week, i.e., frequent users, who reported driving at least 10,000 kilometres annually. The thus obtained sample drove an average of 23,638 kilometres per year (SD=6,893), was aged 27 to 59 (M=37.7, SD=9.8), and had possessed their drivers' licence for at least two years (M=15.6, SD=9.3). All participants filled in a written consent, and were paid a 30€ gift voucher for each visit to the driving simulator.

MATERIALS

The employed driving simulator comprises a fully adjustable real car seat including seat belt, and a real steering wheel, including controls, installed in a mock-up cockpit with a fixed base. The three flat screen monitors consisted of one forward screen including projected dashboard with speedometer and rear view mirror, and two side screens that included the side mirrors, placed at an 120 degree angle from the centre screen. The screens could produce a lot of heat, therefore the driving simulator was situated in a small room provided with air conditioning, that enabled the room to be kept at a comfortable 20 degrees Celsius, which was helpful in reducing simulator sickness (Stoner et al., 2011). Other measures against sickness included ensuring the screens were aligned correctly, avoiding overly sharp bends, and breaks between sessions.

The simulator was controlled by two connected personal computers, equipped with software developed by StSoftware © (Van Wolffelaar and Van Winsum, 1992). This includes a module designed for developing road environments that was used to replicate a real road south of Delft, the N470, also known as the Kruithuisweg, from the A4 exit to the village of Pijnacker-Nootdorp. The first part of the simulated road consisted of about two kilometres of fictitious road, that was not used for any analyses, but purely for participants to become familiarised to driving in the simulator. Furthermore, it had four different speed limits (50, 70, 80, and 100 km/h) which changed rather often during the route due to the seven signalised intersections. Figure 1 provides a simplified picture of the route.

Other traffic that was programmed in the route was meant to resemble off-peak traffic as much as possible, i.e., some light traffic, so that participants could choose their own preferred speed.

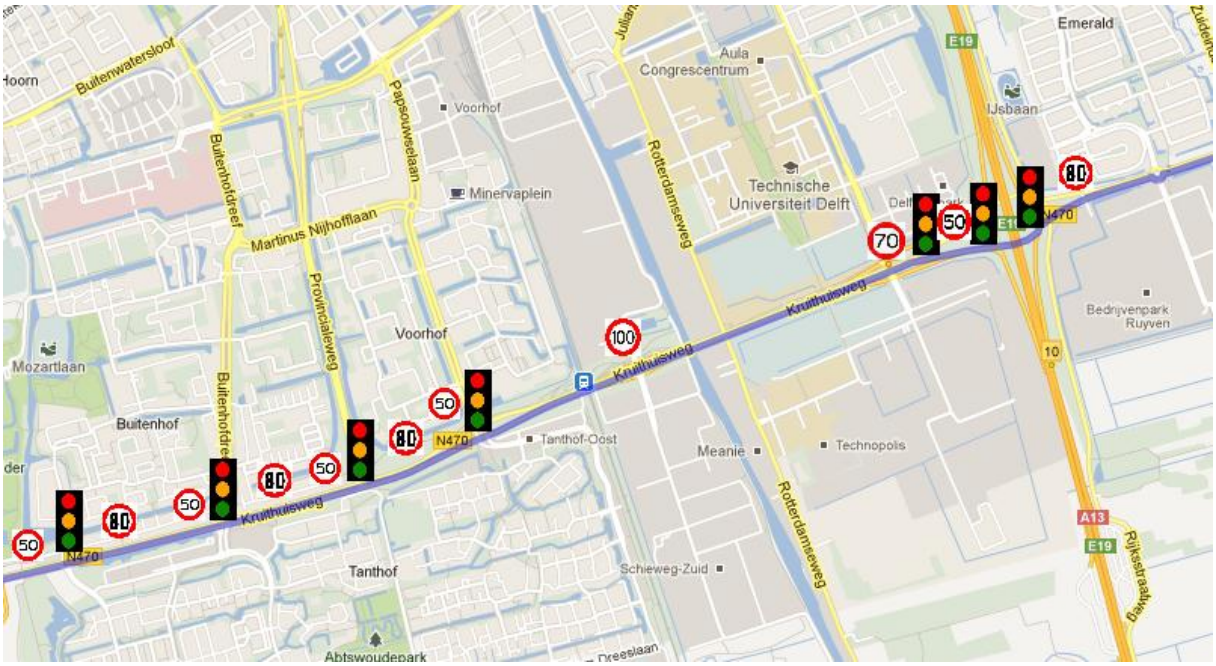


Figure 1: Overview of the select part of the route, including indications of speed limits and traffic lights.

PROCEDURE AND DESIGN

Each participant joined two driving simulator sessions, one in which the phone conversation while driving was performed, one for recording baseline driving. The current study was part of a larger study, in which another drive was performed in the simulator. Therefore, each participant, on arrival, was informed that he would be driving twice, with a break in between the two drives. Furthermore, all participants drove the real route too, in order to validate the driving simulator speed (report in preparation). Over these two experiments, five participants first drove the simulator, the others first drove in the field test, in order to avoid carryover effects. None actively recognised this part of the route as being an existing road, in spite of the fact that some used it for their commute. This may be due to the fact that the start of this route did not compare to the real road.

In case of the phoning condition, participants were asked to drive as they normally drove, and to have a handheld phone conversation with an experimenter calling from a remote location, on the participant's private mobile phone, while driving. When the participant would reach a certain point, the experimenter would phone the remote experimenter that he or she could start phoning. In case of the baseline condition, the participant was asked to drive as normally as possible. Participants were randomly assigned to starting in either experimental condition in the simulator, in order to avoid any carryover or learning effects.

MOBILE PHONE TASK

The conversation always started by the remote experimenter welcoming the participant and asking him if he was ready to answer some questions. If he was, the remote experimenter would remind the participant to keep watching the road and traffic during the conversation. The phone conversation itself was developed in another study (see Knapper et al., in review,

for more details). It was based on the Rosenbaum Verbal Cognitive Test Battery, as used in Waugh et al. (2000) and on questions used by Pereira et al. (2008). In the current study, four blocks of five questions were used. Each of the five questions was based on a different category, including listing questions (i.e., list as many places starting with an A as possible) and answering questions (i.e., which woman is taller if Jane is shorter than Kim?). The remote experimenter recorded the answers provided by the participant, thank him, and consequently terminate the phone call. After the conversation had finished, the simulator experimenter recorded the road segment on which it had stopped, and tell the participant to stop driving.

DEPENDENT VARIABLES

The driving simulator recordings allow for a great deal comparisons, given the large number of variables that can easily be recorded. For the current study, a distinction was made between three hierarchical levels of skill: (1) Strategic, (2), tactical and (3) operational level (Michon, 1985).

On the strategic level, drivers plan and define their strategies regarding speed and route. Here, this includes traffic light waiting time (all data rows where speed was zero), speed limit exceeding, and the time they allow themselves to drive. The latter duration was analysed in order to assess, on a more aggregate level, whether the phone conversation would influence driving efficiency in terms of time, which to some extent may reflect patience. It probably consists of a combination effects, including traffic light waiting time and speed. Considering duration, two fixed points were selected, one at the third traffic lights and one just before the start of the roundabout (see figure 1).

Next, the tactical level involves manoeuvring, including lane choice and longitudinal acceleration and deceleration. Regarding accelerations, only those that followed traffic light stops were selected. Thus, in case a participant met green lights, being able to cross the interaction without stopping, this event was not taken into account here. The mean acceleration in a 10 second interval after the stop was calculated.

On the operational level, drivers carry out automatic tasks, i.e., the tasks they usually do not need to think about, basic skills. Incorporated here are indicator use, steering wheel movements, and braking force. Indicator use was measured for by the time the handle was engaged, either left or right. In order to compare the extent to which participants corrected their course, the standard deviation of steering wheel reversals was calculated. Braking force was defined in percentage of the brake pedal position, i.e., fully depressed is 100, not touched is 0.

Measures regarding forward speed, lateral performance, mental workload, and secondary task performance have already been reported in Knapper et al. (being reviewed).

The phone conversation was targeted to start at the second traffic light (see figure 1), but to ensure including only data in which the participant was phoning, only data from the third traffic lights onwards was used. Although we did not record traffic light changes, we do know they had fixed timers. Therefore we could safely assume that overall, differences would be balanced, and effects could be attributed to the experimental conditions.

3. RESULTS

In case variable pairs violated statistical test assumptions (i.e., normally distributed, judged by Shapiro-Wilk), they were analysed using the more robust Wilcoxon's Signed-Rank test. Other variables were analysed using the paired samples t-test, all in IBM SPSS Statistics, version 20. Significance level was set at $\alpha = .05$.

STRATEGIC LEVEL

Traffic light waiting time

The results show that during the phone conversation conditions, participants had an average total time standing still before lights of 52.6 seconds (SD=26.2), whereas in the baseline drive the stopping time was 39.4 seconds (SD=20.8), which amounts to a substantial difference ($t=2.48$, $p<.05$).

Duration

On average, the time it took participants to get from the third traffic light to the start of the roundabout was 233.4 seconds in the baseline condition, and 270.3 in the phoning condition, which was significantly longer ($t=4.34$, $P<.05$). Controlling for traffic light waiting time renders a baseline duration of 194 seconds versus a phoning condition duration of 218 seconds ($t=3.37$, $P<.05$).

Speed limit exceeding

Exceeding the speed limit by 20% or more was done at some time by all participants. The highest percentage of exceeding the speed limit was found on the 70 km/h speed limit segment, which is not surprising considering the fact that segment is preceded by a 100 km/h limit section, so it apparently took participants a while to slow down. In that section, during baseline driving, 54% of time, participants showed more than 20% exceeding, during the conversation, this was 32% ($z=-2.2$, $p<.05$).
Overall, participants exceeded the speed limit by more than 20% for about 7.5% of the time during baseline driving, while during the phone conversation this was 4.9% ($Z=-2.2$, $p<.05$).

TACTICAL LEVEL

Acceleration

The mean acceleration in a 10 second interval after the stop was calculated. Participants in the mobile phone condition did not accelerate in a different fashion than during baseline driving

(.88 versus 1.16 m/s^2, respectively, tested not significant). Selecting only five second intervals showed a similar direction (1.18 versus 1.56 m/s^2, respectively, also non-significant).

Deceleration

Where accelerations showed no different effects from conditions, deceleration before stopping for a red light did neither. Calculating mean (negative) accelerations from 10 seconds before the stop before a traffic light (where speed is 0), rendered -.85 m/s^2 for the phoning condition, and -.89 m/s^2 for baseline driving. For the five second interval, it was -1.06 and -1.11 m/s^2, respectively. Neither of these differences tested to be significantly different.

Lane choice

On most of the trip, participants were able to choose which driving lane they preferred, sometimes it was blocked, or they should give way to merging robot cars. We did not find a difference between percentages of time spent on either the left or the right lane. In both conditions, about 83% - 84% of the time was spent on the right lane, versus 16% to 17% on the left lane, which are not substantial differences.

OPERATIONAL LEVEL

Indicator use

During the phone conversation participants had their indicator engaged for 1.3% of the time, while in baseline driving this was 3.5%, a significant difference ($z=-3.92$, $p<.05$).

Steering wheel movements

Steering wheel movement was recorded in degrees, and showed a substantially higher standard deviation in the baseline condition than in the phoning condition (11.9 versus 7.6, respectively, $z=-2.09$, $p<.05$).

Braking

In 10 seconds before the full stop, averages were not different (10.7 for the phoning condition, 12.1 for baseline, not significant), but regarding the five second interval, braking was somewhat fiercer in baseline driving (13.3 for the phoning versus 16.2 for the baseline condition, $t=-2.21$, $p<.05$). This may also be due to speed while approaching the traffic lights. In the phoning condition, in the 10 second interval, this was 18.4 km/h, in the baseline 19.8 km/h. Five seconds before the stop, this was 11.5 and 12.3, respectively, showing that in both conditions, drivers chose about the same speeds for approaching traffic lights, but the slight difference in braking force may partly be attributed to the somewhat higher speed.

4. DISCUSSION

This paper had a closer look at several measures that were recorded in a driving simulator study to see whether these measures had effects on driving performance of persons having a (handheld) mobile phone conversation while driving. The measures were classified according to Michon (1985), and included duration, traffic light wait time, speed limit exceeding (on the strategic level), acceleration and deceleration, lance choice (on the tactical level), and indicator use, steering wheel reversals and braking (on the operational level).

On the strategic level of driving, the results show that drivers may obtain a more patient driving style while having a mobile phone conversation compared to baseline driving, judging from the longer waiting time at traffic lights (perhaps because of a lower inclination to pass through yellow lights), and the longer time they took to drive the same distance. The longer trip duration in the mobile phone conditions was not only caused by the longer traffic light waiting time, but also by slower driving speed. As reported in Knapper et al. (being reviewed), participants showed a lower mean speed in the mobile phone condition, as compared to baseline driving. Here, it appeared that also fewer speeding instances were recorded during the phone conversation. Thus, it seems that through a more patient or careful driving style, participants compensated to some extent for the secondary task they were asked to perform, which compares to other studies reporting driver to slow down due to the phone conversation (i.e., Haigney et al., 2000). Moreover, this relates to Wildes (1982) Risk Homeostasis Theory, that states that people try to maintain a preferred level of risk by compensating for increased risk on the one hand (having a phone conversation) by decreasing a risk on the other hand (here: decrease speed, adopt a defensive driving style). In addition, Fullers (2005) Task-Capability Interface model explains that drivers may not so much strive for a certain level of risk, but for a level of task difficulty, which is to be kept between certain limits, based both the driver's capability, and the task demands. Thus, capability may be decreased by adding a phoning task to the driving task, which may be compensated for by slowing down, which decreases task demands.

On the tactical level, participants did not seem to change their accelerating nor their decelerating behaviours too much. The slightly slower acceleration in the mobile phone condition may also account for some of the extended time it took to drive the distance, but for only a small amount. Decelerations were practically the same. Also, dealing with other traffic by overtaking or choosing not to overtake were no different in both conditions.

Related, the indicator was used substantially less often in the phoning condition than in baseline driving. Most probably this is due to the fact that participants needed one hand to hold the mobile phone, which left only one hand for steering. And as they also needed to shift gears (manual driving is most normal in the Netherlands), it may have been more practical to hold the phone in the left hand. One other noticeable operational effect is the reduction in steering variation. Apparently, in the mobile phone condition, participants were less inclined to correct steering very often. In the Knapper et al. (being reviewed) study, standard deviations of lateral position did not differ, but in that study, all lane changes were removed from the data in order to obtain a valid lateral performance measure. Rakauskas et al. (2004) report no significant differences between steering variability in their phoning conditions (easy or difficult), compared to baseline driving, whereas Shinar et al. (2005) did find greater steering deviations in baseline driving, compared to driving while having a phone conversation.

Also braking force showed a small effect for the last five seconds before the stop, which to some extent resembles findings by Strayer et al. (2006), who report mildly fiercer braking in baseline driving. However, in that study, braking was measured in response to braking lights coming from a pace car.

Taken together, it seems that the largest effects of handheld phoning while driving may be found in the area of speed, including traffic light waiting time, trip duration and speed limit exceeding. Other effects that have been found before, but that were not incorporated in the current study, relate to increased reaction time (Brookhuis et al., 1995, Strayer et al., 2011) and glancing behaviour. The latter has been shown to change in the sense that while phoning, fewer glances off the forward road were observed (Knapper et al., being reviewed), but also that drivers show fewer mirror checks (Brookhuis et al., 1991) and fewer searches for other traffic (Harbluk et al., 2007).

LIMITATIONS

In spite of the strong experimental control, driving simulators may cause drivers to behave differently than they do in their own car. The absence of risk, vehicular movement and the mere fact that they are being studied may change participants' behaviour to a certain extent. Moreover, these drivers may in real driving not have selected this road section for engaging in a phone conversation. Furthermore, and perhaps (partly) due to the absence of real movement, some participants after driving reported mild dizziness and light nausea, which may have influenced their driving, too.

CONCLUSION

From the current results, the mere handheld mobile phone conversation while driving shows to lead to more conservative driving, in terms of speeding, waiting time and decelerating. These potentially positive effects may, however, be countered to some extent by the absence of indicating, and the fact that exposition to other traffic remains larger, due to the trips taking more time. However, it also shows that even experienced mobile phone users' driving performance is influenced by handheld conversations. Thus, based on the evidence, we cannot exclude phoning as a cause for road crashes, as its distraction does affect driving. However, considering the overt effects, it seems unlikely that its contribution is large.

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