Shifting attention across near and far spaces: Implications for the use of hands-free cell phones while driving

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ABSTRACT

In three experiments, participants performed two tasks concurrently during driving. In the peripheral detection task, they responded manually to visual stimuli delivered through a LED placed on the internal rear mirror; in the conversation task, they were engaged in a conversation with a passenger, or through earphone-operated, loudspeaker-operated, or hand-held cell phones. Results showed that drivers were slower at responding to the visual stimuli when conversing through a hand-held cell phone or an earphone-operated cell phone than when conversing through a loudspeaker-operated cell phone or with a passenger. These results suggest that due to the brain coding the space into multiple representations, devices that make phone conversations taking place in the near, personal space make drivers slower at responding to visual stimuli, compared to devices that make the conversation occurring in a far space.

1. Introduction

Epidemiological surveys and empirical studies over the last two decades have shown the detrimental effects of cell phones upon driving performance (e.g., McEvoy et al., 2007). For instance, Redelmeier and Tibshirani (1997) argued that the use of cell phones determines a fourfold increase in the risk of vehicle accidents. Similarly, both on-road and simulator studies showed that using a phone affects a number of driving behaviours and measures. These include reduced sensitivity to road conditions (e.g., Haigney et al., 2000), increased mental workload (e.g., Brookhuis et al., 1991), reduction in headway (Lamble et al., 1999), and slower responses to events and stimuli (e.g., brake lights) (e.g., Hancock et al., 2003; Patten et al., 2004; Strayer et al., 2003; Strayer and Johnston, 2001). Though the negative effects of cell phones upon driving are agreed, the reasons why they occur are unfortunately still unclear. Results of a recent meta-analysis (Horrey and Wickens, 2006) suggest that acoustical-conversational factors or manual dexterity alone cannot explain the difficulty of driving while using a phone. Instead, the increased risk of accident is generally ascribed to attentional mechanisms: when engaged in a remote conversation, drivers are in a dual-task condition, so either the conversation or driving performance can suffer. However, such a very general account leaves those attentional mechanisms largely unspecified. Indeed, it is not clear why remote conversations through hand-held phones (which are banned in most Countries) interfere more with the driving task than remote conversations through hands-free phones (which are legal in most Countries), or why remote conversations require more attentional resources than conversations with a passenger. Studies that have directly addressed this issue are rare. For instance, Levy et al. (2006) reported that performance in a braking task was subject to dual-task interference, generalizing the central-bottleneck model (Pashler and Johnston, 1998). Spence and Read (2003), instead, investigated how the crossmodal links in spatial attention affect the performance of participants in a simulated driving task, and found that while participants’ performance in a speech shadowing task deteriorated while simultaneously performing a driving task, this dual-task cost was significantly reduced by presenting the auditory stream from directly ahead of the driver. These results suggest that people process auditory information more efficiently when relevant auditory and visual stimuli are presented from the same spatial locations, and have implications for the design of better cell phones devices.

Here we hypothesize that the shift of spatial attention between near and far positions is one the mechanisms that determine the dual performance cost of driving while conversing, and that it affects differently the cost of conversing through hand-held- and earphone- versus loudspeaker-operated phones. Indeed, research on the effects of remote conversations on driving has largely ignored that the three-dimensional space around us is not unitarily represented in the brain. Several authors have indeed proposed that our brain codes different representations of space, and different
neural systems have been identified that subserve the interaction of individuals with different regions of the 3D space around them (Cutting and Vishton, 1995; Grusser, 1983; Previc, 1998; Rizzolatti and Camarda, 1987; Rizzolatti et al., 1985; Ortigue et al., 2006; Vaishnavi et al., 2001). For instance, Rizzolatti and coworkers (Rizzolatti and Camarda, 1987; Rizzolatti et al., 1985) on the basis of their findings in brain-damaged subhuman primates identified separate representations of the personal space, mainly characterized by oral and tactile interactions between the individual and the world, of the peripersonal space, where reaching movements occur, and of the extrapersonal space, where oculomotor activity prevails. Although there is still disagreement about the number of representations and the location of the boundaries between them, the distinction among the representations of the personal, peripersonal, and extrapersonal spaces is widely accepted. More importantly, it has been shown that shifting attention across these different spaces entails larger behavioural costs, in terms of both speed and accuracy, than shifting attention within the same space (Couyoumdjian et al., 2003; Losier and Klein, 2004; Di Nocera et al., 2006). Furthermore, it has been demonstrated that it is more difficult to disengage attention from spatial locations within the personal space, and to engage it on farther spatial locations (i.e., within the peripersonal or extrapersonal spaces), than the other way round (e.g., Andersen and Kramer, 1993; Marienelli et al., 2001). This is especially interesting because this condition occurs when drivers are engaged in a conversation through hand-held and earphone-operated hands-free phones. In these cases, drivers have to shift continuously their attention from the near, personal space wherein the conversation takes place to the peripersonal and extrapersonal spaces (e.g., the dashboard, the road) where most of the driving related information are deployed. Instead, such shifting of attention between the personal and the farther spaces does not occur when drivers use loudspeaker-operated phones or talk with a passenger. This leads to the prediction that remote conversations through hand-held or earphone-operated cell phones should interfere more with driving than remote conversations through loudspeaker-operated phones. Interestingly, the few studies that compared the effects of different phone devices gave unclear results. In some cases (e.g., Consiglio et al., 2003) hand-held and hands-free phone conversations have been reported to yield the same effects upon driving, but the hands-free devices were earphone-operated phones. In other cases, loudspeakers-operated phones and hand-held devices have been reported to yield the same effects upon driving (Tornros and Bolling, 2005; Patten et al., 2004). However, in both studies participants reduced significantly their driving speed only when engaged in a conversation through the hand-held phone, leaving the possibility of a trade-off effect between driving and conversational tasks open.

The issue of whether remote conversations through different phone devices have the same effects is relevant from a road safety perspective, as usually hands-free phones are allowed while driving. Thus, we aimed at investigating whether the cost associated with shifting attention away from the personal space contributes to the negative effects of remote conversations upon responses to stimuli and events that occur while driving.

2. Experiment 1

The performance on a visual peripheral detection task (PDT, e.g., Patten et al., 2004) was investigated while drivers were engaged in an in-vehicle conversation, or in remote conversations using an earphone-operated phone or a loudspeaker-operated phone. According to our hypothesis, drivers should be slower at responding to the visual stimuli while using the earphone-operated phone than while using the loudspeaker-operated phone or when conversing with a passenger. This is expected on the basis of the hypothesis that the former condition requires to shift attention between different spatial representations, while in the latter condition the attentional shift occurs within the same spatial representation.

3. Method

3.1. Participants

Twelve healthy, right-handed undergraduate students (4 women) volunteered for the study. Their mean age was 26 years (from 23 to 30 years). All reported normal vision and no hearing deficit, and were naïve as to the purposes of the experiment. They held a valid driver’s license for a minimum of four years, and reported driving regularly (i.e., every day) their own car on both highways and urban roads.

3.2. Apparatus and stimuli

All the participants drove an instrumented, manual gearbox car. The same GSM cell phone was used over the entire experiment. It was operated through a personal single right earphone, or through an external speaker mounted centrally on the dashboard, at about 51° of visual angle horizontally (from 49° to 52°), relative to the line of sight of the driver fixating straight ahead. Signal strength was 3/4 to full strength over the entire driving route, as indicated by the signal strength indicator on the cell phone. The conversation participants were involved into was based on a list of 120 questions concerning their daily life, requiring short sentences in reply (e.g., “What kind of music do you appreciate and why?”). All the conversations occurred at about 65 dB SpL (sound pressure level, B&K 2236 sound meter). The environmental noise level was on average about 58 dB SpL.

The visual stimuli (100 ms) were presented with an average interval of 4 s through a high intensity, red LED placed on a corner of the internal rear mirror, at about 51° of visual angle horizontally (from 49° to 52°), relative to the line of sight of the driver fixating straight ahead. The spatial location of the LED was chosen because the internal rear mirror is normally used while driving.

3.3. Procedure

Before the experimental session, participants drove for about 30 min along an urban and a highway route in order to practice with the car. During the experimental session, participants drove along a six-lane highway (three lanes in each direction) with a very low traffic load (level of service A (Mannering et al., 2004), no need to change lane or speed). The legal speed limit was 130 km/h. While driving, participants were engaged in a conversation in four conditions: through a hands-free speaker (loudspeaker) cell phone, with an external loudspeaker placed on the dashboard, through a personal hands-free (earphone) cell phone, with a personal single earphone, and with one experimenter sitting in the same vehicle (passenger). In a control condition (control), participants were not engaged in any conversation. In the loudspeaker and earphone conditions, the conversation was with one experimenter sitting in another vehicle following at distance.

On average, each conversational turn (i.e., one question and the corresponding answer) lasted about 30 s. Conversations flowed uninterrupted during the experimental conditions. The conversation task was performed concurrently with a peripheral visual detection task. Participants had to respond as fast as possible to the visual stimuli by pressing a micro switch located on the steering wheel with their right thumb finger. During each experimental...
condition, 80 visual stimuli were presented. Each experimental condition lasted about 5 min.

Participants had to drive in their usual manner (within the bounds of the law), and were told to use the central lane as long as possible in order to avoid possible manoeuvres or changes of speed due to slower vehicles. Experimental trials were run out of rush hour traffic between 10:00 and 15:00 h. Weather conditions were fine with unlimited visibility, and the road surface was dry. Traffic and road conditions were consistent during all the trials. All the phone related operations (e.g., answering the call) were performed by the experimenter who traveled with the participants. The order of the experimental conditions was randomized across participants.

4. Results and discussion

A one-way repeated-measure ANOVA on the reaction times to the visual stimuli showed a significant effect of the experimental conditions ($F_{3,33} = 5.17, p = .005, \eta^2 = .39$). Specifically, participants were significantly slower in all the conditions involving a conversation (mean = 270 ms, overall), compared to the control condition (237 ms, $F_{1,11} = 7.31, p = .02$). Crucially to our hypothesis, conversing through a device that requires to shift attention between the peri/extrapersonal and the personal spaces (earphone condition, mean = 270.30 ms, S.E. = 10.05 ms) made participants slower than conversing through a device that does not (loudspeaker condition, mean = 259.71 ms, S.E. = 9.86 ms) ($F_{1,11} = 10.71, p = .007$) (Fig. 1a). No difference between reaction times in the passenger and earphone conditions was found instead ($F<1$). This result was likely due to the passenger being the senior researcher and the participants being students attending his class. This confounding has been removed in the following experiments. An identical ANOVA on the proportions of missed stimuli gave similar results. Participants missed more stimuli when involved in a conversation than in the control condition (35% vs 27% respectively, $F_{3,33} = 3.41, p = .03, \eta^2 = .24$), and more stimuli in the Earphone condition than in the Loudspeaker condition (41% vs 25% respectively, $F_{1,11} = 6.39, p = .03$). No difference in the proportion of missed stimuli was found between the passenger and earphone conditions ($F<1$). A final ANOVA on the participants’ driving speed gave no significant effect of the experimental conditions ($F_{3,33} = 1.05, p = .38$). Participants maintained about the same speed across the experimental conditions, slightly below the legal limit.

These findings indicate that devices that make phone conversations taking place in the personal space make drivers slower at responding to visual stimuli, compared to devices that make the conversation occurring in a far space. Thus they are in fair agreement with the hypothesis that the interference of phone conversations upon driving is partly due to the brain coding the space into multiple representations. Indeed, other alternative explanations seem unfeasible. For instance, it may be argued that even though sound level was equated across devices, signal-to-noise ratio was not, as it was dependent on the variable environmental noise. However, the signal-to-noise ratio was obviously better for the earphone-operated device than for the loudspeaker-operated device, and thus this cannot explain why the Earphone condition yielded the slower reaction times. Also, shifts of attention on a 2-dimensional plane (i.e., horizontal and vertical) were equally required in all the conditions, thus this factor cannot explain the pattern of results we found.

Nevertheless, an alternative interpretation is that the favourable traffic conditions made participants devoting less attention to the driving task. This hypothesis has been addressed in the Experiment 2, wherein drivers were required to drive along an urban route.

5. Experiment 2

5.1. Method

5.1.1. Participants

Twelve healthy, right-handed individuals (4 women) volunteered for the study. Their mean age was 24 years (from 23 to
27 years). They had the same driving experience as participants involved in the previous experiment. None of the participants took part in the previous experiment.

5.1.2. Stimuli and procedure
Stimuli, procedure, apparatuses, and experimental conditions were the same as those used in Experiment 1. The only difference concerned the experimental route, which was an urban road with high traffic load (more than 10 vehicles/min, intersections, pedestrians), but without queuing or light stops. The legal speed limit was 50 km/h. In the present experiment, driving speed was not analysed, as the variable traffic conditions determined a corresponding large variability in the driving speed.

6. Results and discussion
The ANOVA showed again a significant effect of the experimental conditions on the reaction times to the visual stimuli \(F_{3,33} = 28.53, p < .001, \eta^2 = .72\). Being involved in a conversation made participants slower compared to the control condition (298 ms vs 248 ms respectively, \(F_{1,11} = 52.02, p < .001\)). More importantly, when participants conversed through an earphone-operated cell phone they were slower than when they conversed through a loudspeaker-operated phone \(F_{1,11} = 18.65, p = .001\), mean = 306.15 ms, S.E. = 9.38 ms and mean = 293.33 ms, S.E. = 11.04 ms, respectively), or with the passenger \(F_{1,11} = 5.14, p = .04\), mean = 306.15 ms, S.E. = 9.38 ms and mean = 295.80 ms, S.E. = 9.13 ms, respectively) (Fig. 1b). Due to the higher traffic load, participants missed more stimuli than those in experiment 1. Participants missed more stimuli when involved in a conversation than in the control condition (56% vs 38% respectively, \(F_{1,11} = 42.97, p = .001\)), but there was no difference among the other conditions \(F < 1\).

Also the present findings clearly indicate that conversations occurring in the personal space (using an earphone-operated phone) have a larger interference effect than conversations occurring in a far space (using a loudspeaker-operated phone or with the passenger). Furthermore, results of this experiment confirm that conversing with a passenger gives the same effect as conversing through a loudspeaker-operated device. Though, a stronger case was made by showing that earphone-operated and hand-held phones have the same interference effects on the PDT task, and by taking into account the difficulty of the conversation. Thus, in the next experiment we added a hand-held phone conversation condition (hand-held). Also, a new set of 120 questions requiring single word answers (e.g., "What’s your mother’s name?") was added to the previous set.

9. General discussion
A first one-way ANOVA on the reaction times to the visual stimuli showed again that participants were slower when involved in a conversation than in the control condition (390 ms vs 281 ms, \(F_{1,11} = 29.48, p < .001\)). A two-way repeated-measure ANOVA on the reaction times to visual stimuli with conditions (hand-held, earphone, loudspeaker, passenger) and conversation (single-word replies, longer replies) as within-subject variables showed a significant effect of the experimental conditions \(F_{3,33} = 3.66, p = .02, \eta^2 = .33\), but no effect of the conversation type \(F < 1\), nor a condition by conversation type interaction \(F < 1\). Crucially to our hypothesis, we found that conversations through devices that require to shift attention between the near and the far space (hand-held and earphone-operated cell phones, mean = 404.9 ms, S.E. = 13.68 ms and 406.16 ms, S.E. = 20.12 ms, respectively) made participants’ reaction times slower than conversing through a device that does not (loudspeaker-operated cell phone, mean = 379.25 ms, S.E. = 10.76 ms) or with a passenger (mean = 3381.65 ms, S.E. = 16.41 ms) \(F_{1,11} = 13.00, p = .004\) (Fig. 1c).

Coherently with our hypothesis, no difference between reaction times in the passenger and loudspeaker conditions was found \(F < 1\), nor between reaction times in the hand-held and earphone conditions \(F < 1\). The same analysis on the proportions of missed stimuli failed to show any significant effect \(F < 1\).

7. Experiment 3
7.1. Method
7.1.1. Participants
Twelve healthy, right-handed individuals (8 women) volunteered for the study. Their mean age was 26 years (from 24 to 30 years). They had the same driving experience as participants involved in the previous experiments. None of the participants took part in the previous experiments.

7.1.2. Stimuli and procedure
The visual stimuli and general procedure were identical to those used in the previous experiment. The only exception was that we made participants driving along an urban route on a desktop driving simulator in order to introduce the hand-held phone conversation condition (hand-held). Also, a new set of 120 questions requiring single word answers (e.g., "What’s your mother’s name?") was added to the previous set.
obvious reasons, and was higher for the earphone-operated and hand-held phones than for the loudspeaker-operated phone. This means that monaural conversations were actually easier than binaural conversations. Furthermore, when the signal-to-noise ratio is equated across the binaural and monaural conditions, the binaural advantage has been found to correspond to about 1 dB reduction of the auditory threshold (e.g., Wilson, 2003), which is below the advantage has been found to correspond to about 1 dB reduction of the auditory threshold (e.g., Wilson, 2003), which is below the

Also, shifts of attention on a 2-dimensional plane (i.e., horizontal and vertical) were equally required in all the conditions, thus this factor cannot explain the pattern of results we found. Finally, it should be noted that whereas findings from the passenger condition in the experiment 1 were not as expected, those of experiments 2 and 3 were in the expected direction and support our hypothesis that the slow reaction times found in experiment 1 were due to the senior researcher acting the passenger role.

It is worth to note that we did not measure responses to traffic hazards of the kind a driver can face while driving. This would have been difficult on a methodological ground (hazards have to be rare and unpredictable) and questionable on the ethical ground, especially in the real driving conditions we used. Admittedly, this is a limit of the present study, and will be addressed in future studies, in simulated driving conditions. However, having used a very simple PVT task actually works in favour of our conclusions. Indeed, the stimuli were rare and less expected, the effect on reaction times would have been probably amplified, not diminished.

Findings of the present study are relevant for several reasons. First, they shed some light upon the largely unknown mechanisms that make remote conversations dangerous while driving. Indeed, it appears that the mechanism responsible for shifting attention across different spaces contributes to the cost drivers pay when they converse over a phone. It is worth noting that only relatively few studies have compared hand-held and hands-free phone conversations, usually without reporting any difference in their effects upon driving (e.g., Strayer and Johnston, 2001; Consiglio et al., 2003; Strayer et al., 2006). However, in most of these studies earphone-operated phones were used, so that the lack of a differential effect may be accounted for by both hand-held and hands-free earphone-operated phones making the conversation occurring in the personal space. The few studies that did compare hand-held and loudspeaker-operated phones gave unclear results.

For instance, Patten and coworkers (2004) and Tornros and Bolling (2005) reported that the performance on a PVT task did not vary as a function of whether drivers use hand-held or loudspeaker-operated phones. However, their participants maintained comparable performance when using the two devices but their driving speed was slower when using the hand-held phone, suggesting a trade-off effect between conversation and driving. Notably, this confounding does not affect the results, as participants in experiment 1 maintained the same driving speed independently of the device they used. Also, Matthews and coworkers (2003) reported that the total mental workload, measured through the NASA-TLX, was lowest for the earphone-operated phone and highest for the loudspeaker-operated phone. However, the effect was due to the higher frustration produced by the lower intelligibility of the messages conveyed through the loudspeaker-operated phone. Whereas results of previous comparisons involving loudspeaker-operated phones are not conclusive, results of the present experiment suggest that these devices interfere less with driving because they do not require drivers to shift their attention away from the personal space.

Second, findings of the present study generalize the cost of shifting attention across different representations of the space to a highly practiced, real-world task. Thus, it appears that such a cost is far more pervasive than previously suspected on the basis of the evidence from clinical studies of brain-damaged patients, and from highly controlled, not ecological, experimental studies.

Third, results of the present study might have practical implications: many Countries adopt legal restrictions for using hand-held phones while driving but allow for using earphone-operated and loudspeaker-operated hands-free phones. Our results instead suggest that how individuals shift attentions across the spaces should be taken into account, and that earphone-operated devices may not be safer than hand-held devices. Of course, further designs and procedures are needed to obtain a reliable estimate of the effect of shifting attention across different representations of the space. Particularly, real driving-related variables such as lane keeping and braking reaction times should be taken into consideration in future research.

References


