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Effects of Cognitive Distraction on Driver's Stopping Behaviour: A Virtual Car Driving Simulator Study

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Abstract. Drivers are prone to distractions while driving, due to conversations they have with passengers on board, processing their thoughts or using their mobile phones. These distractions result in a mental workload that compromises driving safety and requires the implementation of risk compensatory behaviours. This study examines the effects of hands-free mobile phone conversations on young drivers' stopping manoeuvres when a pedestrian enters a zebra crossing. A cohort of seventy-eight university students, aged 20-30 years old, performed a driving task in a virtual urban environment, by means of a virtual car driving simulator. They formed a control and an experimental group, balanced on age and IQ level. The control group was left free to drive without any imposed cognitive task. The experimental group was asked to drive while making a phone call that was planned to diminish the amount of cognitive resources allocated to the driving experience. For both groups, the analyses focused on a specific moment, i.e., while a child suddenly entered a zebra crossing from a sidewalk. Throughout the simulation, the intensity of the participants' actions on the brake pedal, accelerator, and steering wheel were recorded with a time step of 250 ms. Before the virtual driving experiment, each participant completed a questionnaire on his/her daily driving style, involvement in road accidents, and general mobile phone usage even while driving. A mixed two-way ANOVA with Group as a between-subject factor (1. Control Group; 2. Experimental Group) and Gender (1. Male drivers; 2. Female drivers) as a within-subject factor was performed on the driving parameters as dependent variables. The results showed the presence of a significant difference for distracted and non-distracted drivers with the absence of gender-related differences across the two groups. Participants engaged in a hands-free phone-call while driving assumed lower initial speeds as an element of risk compensation and took the first action to stop at shorter distances from the pedestrian crossing. This suggests a delayed perception of the presence of the pedestrian. In addition, the fluctuation in speed after the distracted driver had released the accelerator pedal reached a statistical significance compared to the control group. These findings suggest that the distraction induced by the use of the mobile phone through the earphones may adversely affect driving behaviour and raise significant safety concerns.

1. Introduction

Driving a vehicle is a complex activity. It entails the integration of multiple subjective (e.g., driver's health state, experience, concentration level, ability to monitor the behaviour of other drivers/vehicles on the road, etc.) and objective (e.g., vehicle performance, road surface condition and geometric features, etc.) factors. From a subjective point of view, drivers need to continuously monitor their behaviour on the road, plan the route, maintain it as well as adapt their behaviour to the accepted level of risk [1, 2]. Meanwhile, the role played by objective factors is of major relevance. This claim is supported by the observation that a significant proportion of road accidents is determined by an inadequate processing of road environment on behalf of the driver [3]. Therefore, the information that the road environment provides to the driver is essential to allow him/her to efficiently modulate driving control parameters and to avoid the occurrence of dangerous behaviours [4, 5].

Among the subjective factors that improve road safety, driver concentration levels on the driving task are crucial. Indeed, while driving people are often involved also in several tasks (e.g., talking to people, thinking about their own plans, dreams, or fears, etc.) that may significantly reduce the quantity of cognitive resources allocated to monitor the driving behaviour. Obviously, this poses serious safety problems. For example, the use of mobile phones while driving is one of the most common distractions among car drivers. In 2018, the National Highway Transportation Safety Administration (NHTSA) estimated that 9.7% of drivers in the United States use a mobile phone while driving (handheld: 3.2%; hands-free: 6.5%) during daylight hours. In particular, mobile phone use is higher among female drivers than male drivers, and more widespread among 16- to 24-years-old drivers [6]. The Motor Vehicle Occupant Safety Surveys (MVOSS) conducted in 2007 [7] and 2016 [6], the NHTSA estimated that the percentage of drivers using hands-free mobile phones, either via a Bluetooth system integrated into the vehicle or a wireless earpiece/speakerphone, increased from 45% to 67% among drivers using their mobile phones while driving. On a sample of 796 Australian drivers (aged 17- to 76-years-old) White et al. [8] showed that 43% of drivers answer calls daily, 36% make calls, 27% read text messages, and the remaining 18% even send text messages. In addition, 36.1% of the surveyed drivers had a hands-free device, but 32% out of them hardly ever used it.

Distractions while driving may affect drivers' performance in several ways. A number of studies [9-13] showed that distracted drivers may reduce their speed control, experience difficulties in maintaining the appropriate trajectories and headways between vehicles, increase their reaction times in responding to hazards, have reduced ability to perceive stimuli coming from the peripheral area of the visual field. In fact, the driver's distraction, defined as a diversion of attention to a competing activity, reduces the cognitive resources assigned to the driving task [14]. Furthermore, the distraction induced by mobile phone usage significantly alters the brain activity associated with driving [15]. The increased cognitive load due to a telephone conversation results in reduced attention to the road environment, where not all the information a driver observes is processed, producing an "inattentional blindness" [16]. In other words, the distracted driver "looks at" the road environment but does not "see" all the objects in the scene because his/her brain compensates for the increased mental workload by reducing the visual information transmitted to working memory. In addition, Amado and Ulupınar [17] observed the negative effects of conversation with a remote person or an in-vehicle person on the driver's attention level and hazard perception skills, showing that these effects do not depend on conversation type (remote/in-person).

In recent years, the results of many studies showed that the use of driving simulators can be highly informative in research activities aimed at improving the road geometric design criteria and studying human factors involved in driving. For a thorough overview of the road's geometric features analysed by means of car simulators, please refer to Bella [18]. Ābele et al. [19] assumed that the high incidence of young drivers in road accidents is determined by their lower ability to perceive hazards than older and more experienced drivers; as a result, the authors showed, by means of an experiment

in a virtual environment, that a short training intervention on hazard perception improves young drivers' skills in pedestrian-related situations.

As for the use of mobile phones, a study by Burns et al. [20] showed that telephone conversations affect speed control and response to traffic signals more than having a blood alcohol level at the UK legal limit of 80 mg/100 ml. Furthermore, Rakauskas et al. [21] report that the cognitive distraction induced by mobile phone use causes slower driving speeds that are characterised by a significant fluctuation. The reduction in speed was interpreted as a risk compensatory effect for the increased mental workload [22]. Stavrinos et al. [23] used a driving simulator to examine the behaviour of young drivers (aged 16- to 25-years-old) while engaged in a mobile phone conversation or text messaging. By controlling different driving conditions (i.e., free flow, stable flow, and oversaturation) they showed that distracted driving, particularly texting, may lead to risky behaviours with a negative impact on traffic flow. Similarly, using an advanced driving simulator Haque and Washington [24] concluded that cognitive distractions compromise the reaction times of young drivers (with an increase of almost 40% compared to those un-distracted) while facing a traffic event (i.e., a pedestrian entering a zebra crossing from a sidewalk) that starts from the peripheral area of their visual field. Noteworthy, potential gender-related differences have been only scarcely considered in driving simulator studies [25].

2. Research topic and scope
Encounters between cars and pedestrians at the zebra crossing are critical situations, complex to analyse, in which the safety of the pedestrian depends mainly on the driver's speed behaviour [26]. In fact, the pedestrian's decisions are influenced by the perceived dynamic parameters and distance of the vehicle, which define the driver's arrival time at the crosswalk. On the contrary, depending on such a time, the driver decides whether to "punish" (deny priority to) or "reward" (give priority to) the pedestrian, according to the concept of defensive driving [27]. Therefore, the time taken by the vehicle (keeping its speed unchanged) to reach the crosswalk as soon as the pedestrian arrives at the edge of the curb is a relevant variable in the description of the pedestrian - driver interaction. Such a variable, called Time-To-Zebra (TTZ) in the literature [26], also determines the time available for the driver to react to the pedestrian presence, as it is defined by the ratio between the vehicle's distance from the crosswalk and the vehicle's speed when the pedestrian is about to cross.

Some literature studies have examined the behaviour of drivers approaching a zebra crossing [25-29], but the speed profiles of drivers distracted by mobile phone usage have been insufficiently analysed so far (see Introduction). This gap in research is particularly relevant given that mobile phone use while driving appears to be more widespread among young and less experienced drivers, who remain over-represented in road accident statistics [19].

This study examines the effects of hands-free mobile phone conversations on young drivers' stopping manoeuvres when a pedestrian enters a zebra crossing, using a motion-based driving simulator. In particular, two groups of young drivers were selected. One was asked to drive in an urban scenario with no distraction (control group), whereas the other was required to drive while engaged in a taxing mobile-phone conversation (experimental group). The analyses focused on the moment in which the drivers in the two groups reached a zebra crossing with a pedestrian crossing it. This scenario was reproduced in the present study by adopting a TTZ = 3s, as suggested by the reviewed literature [28]. In addition, the innovative aspect, compared to the documented literature [24], concerns the cognitive task imposed on drivers, which has been planned to reduce the amount of cognitive resources allocated to the driving experience by means of specific psychological methodologies. We hypothesized that persons engaged in a phone-call while driving would adopt a riskier driving behaviour in such a condition. Furthermore, we also analysed the potential effect of Gender by controlling for gender-related effects within the two groups of participants.

3. Material and methods

3.1. Participants

A cohort of eighty university students took part in the driving simulator experiment. Two participants experienced motion sickness and simulator discomfort while driving the virtual scenarios and thus were excluded from the experiment. These young drivers were recruited by means of a request for participation sent to the university e-mail addresses of students, enrolled in different (Civil Engineering, Agricultural Science, Legal Services, and Public Relations) bachelor degree courses of the University of Udine. In order to participate in the study, the driver had to be between 20 and 30 years old, hold a valid European driving licence, and not suffer from motion sickness or other illnesses that could compromise the driving activity. Participation was voluntary, there was no monetary reward and none of the students were informed about the purposes of the study. All participants filled in a questionnaire [24] on their demographics and driving behaviour. In addition, their non-verbal intellective quotient (IQ) was indirectly assessed by administering the Raven's Coloured Progressive Matrices [30].

They formed a control and an experimental group. The control group was left free to drive without any imposed cognitive task. Differently, the experimental group was asked to drive while making a phone call. The experimental group consisted of 30 males and 22 females with a mean age of 24.4 (SD 2.14) and 23.8 (SD 3.36) years, respectively. The average IQ for males and females in the experimental group was 33.9 (SD 1.72) and 33.2 (SD 2.24), respectively. In contrast, the control group consisted of 15 males and 11 females. The mean ages for male and female in such a group were, respectively, 23.5 (SD 1.55) and 22.6 (SD 1.96) years. The IQ level for drivers in the control group was 33.7 (SD 1.63) for males and 32.3 (SD 3.06) for females. Therefore, the two groups were balanced by age and non-verbal intellectual IQ level. On the whole, 19.2% of the recruited students had their driving licence for less than 3 years (the rest for more than 3 years). In Italy, drivers with less than 3 years of driving experience are identified as "newly licensed" and must comply with stricter driving rules than experienced drivers. 52.6% of participants drove less than 10,000 km per year; 41.0% drove about 10,000-20,000 km per year; the remainder drove more than 20,000 km in a typical year. In the last 3 years, 20.5% of participants had been involved in a road accident and 11.5% had received an infringement notice for exceeding speed limits (Art. 142 of the Italian Road Traffic Code). Conversely, none of the participants had received an infraction notice for red light running (Art. 146), use of the mobile phone (Art. 173) or driving under the influence of alcohol and/or drugs (Art. 186-187).

When asked "Do you use your mobile phone while driving?", 71.8% of the participants answered yes. These 56 drivers answered more specific questions about the type and frequency of mobile phone usage, of which only the most alarming data are reported: 7.1% of these young drivers reported using a hand-held phone while driving; at least once in a day, 28.6% of such participants use their mobile phone while driving to answer and make calls, 25.0% to read and send text messages and 5.4% to read e-mails or surf the Internet; finally, 3.6% have phone conversations while driving that last over 10 minutes.

3.2. AutoSim 1000-M driving simulator

The experiment took place at the Roads Laboratory of the Polytechnic Department of Engineering and Architecture of the University of Udine. Driving was simulated by using the AutoSim 1000-M car simulator. The simulator cabin, composed of real car parts (the same interior equipment of a Fiat 500), is mounted on a two-degree of freedom motion system to reproduce the rolls and pitches of the vehicle in the virtual road environment. The combination of these rotations, as well as the steering force feedback, provide the tested driver with partially realistic driving sensations. In front of the driver's seat and above the dashboard, three Philips 43-inch LCD screens, connected to two top-of-the-range

PCs with Nvidia GTX graphics boards, allow the road scenario to be visually reproduced with a 180° field of view. A HiFi sound system with 3D and doppler effect simulates the noise of the vehicle and the driving environment. Different vehicle types are individually configurable on all relevant parameters (engine power, transmission, physics, etc.) and such information is transmitted to the hardware interfaces (steering wheel, pedals, gear lever and handbrake). During the simulation, many dynamic parameters describing the driver's behaviour, as well as the driver's actions on the brake pedal, accelerator and steering wheel, can be recorded with even quite short spatial or temporal intervals.

3.3. Experimental procedure and virtual road scenarios

This study used two road scenarios that have been simulated in a virtual environment by the Norwegian company AutoSim. Such scenarios reproduce some Norwegian localities and urban districts, with a good level of detail. In particular, a sub-urban scenario (total driving time of 5 minutes), with geometric features suitable for the purposes of this study, was chosen to train the participants of both groups to use the driving simulator (usage of gearshift, steering wheel, clutch, accelerator and brake). A second typically urban scenario was engaged for the experimental driving condition, lasting about 15 minutes. The simulated urban environment was characterized by numerous traffic light intersections, rectilinear short development roads, sharp curves (90°), pedestrian zebra crossings. The speed limit in the city was mostly 50 km/h, whereas the speed limit in the sub-urban environment varied between 50 and 60 km/h. In both scenarios, the route that participants were required to follow was showed by green arrows that appeared on the central screen. In order to restore psychological conditions similar to those at the beginning of the test and to limit the possible habituation or fatigue of participants, a 5-minute break was inserted between the training and the experimental driving, during which participants were asked to fill in a questionnaire [24] about their driving styles and daily use of the mobile phone (even while driving). At the end of the experimental scenario, the participants of both groups completed a second questionnaire on the experience perceived in the virtual environment.

While driving in the experimental scenario, the participants of both groups experienced a traffic event: a girl crossed the road on the pedestrian crossings, starting from the sidewalk. Figure 1 shows the driver's view of the pedestrian scenario as represented in the driving simulation. This traffic event took place on a four-lane road with two lanes in each direction separated by a continuous centre line, where the speed limit was 50 km/h. The crosswalk has been designed by placing appropriate markings and traffic signs for pedestrian crossing according to Norwegian road standards. The traffic event was scripted so that the pedestrian would start moving from a sidewalk to the zebra crossing when the driven car was about TTZ = 3 s from the crosswalk itself, at a speed of 1.4 m/s in line with the reviewed literature [29]. Although the pedestrian scenario originated from the drivers' peripheral vision, the drivers had a clear view to the pedestrian and the zebra crossing from 200 m in advance the crosswalk, where a red traffic light forced the participants of both groups to stop.

Figure 1. Crosswalk scenario in the driving simulator

The control group drove through the experimental scenario without any imposed cognitive task. In this way, data were obtained on reference to the driving behaviour under conditions of normal

attention on the road (with expected fluctuations of attention levels in monotonous routes). These data include: position of the vehicle on the roadway; operating speeds; accelerations and decelerations.

The experimental group was asked to drive while making a phone call that was planned to diminish the amount of cognitive resources allocated to the driving experience. Specifically, during the 5-minute break between the training and the experimental driving conditions, the participants in the experimental group were shown one of three cartoon-picture stories made of six images each (The Flower Pot story [31]; The nest Story [32]; the Quarrel story [33]). The stories were balanced for the number of concepts, words and sentences they might elicit. The order of administration of these stories was rotated from participant to participant in order to reduce a possible story bias.

The stories were shown to the participants on a PC turned towards them, so that the examiner could claim not to know its content. In this way, the possible effect of sharing with the referent has been minimized. Participants were asked to mentally imagine the story reported in the stimulus figures and not to report it at that moment. The examiner called each participant in the experimental group prior to the urban drive and a single continuous call occupied both parties until the end of the drive. For 10 minutes, participants were left free to drive through the urban environment. At the stroke of the tenth minute, the experimenter asked the drivers, connected to their mobile phones by earphones, to tell the story they had previously seen. During the story retelling (whose duration was approximately 2 minutes), the drivers in the experimental group suddenly saw the girl entering the zebra crossing. Finally, the last few minutes of driving were free of distractions.

3.4. Driving data

The impact of mobile phone distraction and the potential effect of gender on drivers' behaviour were assessed considering the vehicle speed and its variations near the pedestrian crossing for each group of drivers.

The braking behaviour of the drivers' cohort was characterized looking at their speed profiles along a section of 100 m in advance the crosswalk [25] and collecting the following variables [28, 29, 34]:

- V_i and L_{Vi}: the driver's speed (also called initial speed) and associated distance from the crosswalk when (s)he decided to release the accelerator pedal and decrease the vehicle speed after perceiving the pedestrian on the sidewalk;
- V_b and L_{Vb}: the driver's speed and associated distance from the axis of the pedestrian crossing when (s)he applied the brakes;
- L_{Vmin}: the distance from the conflict point at which the vehicle's minimum speed V_{min} has been observed;
- $\sigma(V_n)$: the standard deviation of vehicle speed during the braking manoeuvre, also called fluctuation in speed.

It is worth noting that the simulated scenario (TTZ = 3s) necessarily forces the driver to stop or to drastically reduce the vehicle's initial speed. For this reason, the minimum speed of the braking manoeuvre was not considered among the study variables. Figure 2 shows the drivers' mean speed profiles (sketched by means of V_i and L_{Vi}, V_b and L_{Vb}, V_{min} and L_{Vmin}) for each of the 4 groups considered in the study: MC – male drivers in the control group, ME – male drivers in the experimental group, FC – female drivers in the control group, FE – female drivers in the experimental group.
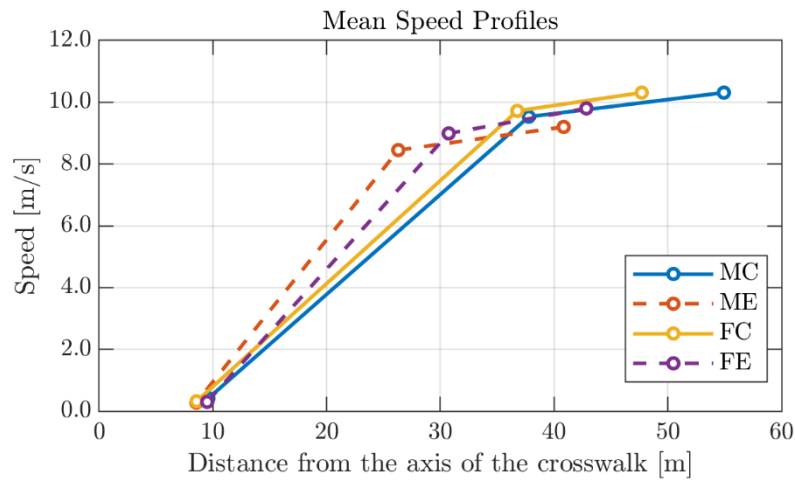
Figure 2. Driver's mean speed profiles. *Legend*: MC: male drivers in the control group; ME: male drivers in the experimental group; FC: female drivers in the control group; FE: female drivers in the experimental group

The selected variables were analysed using a mixed two-way ANOVA with Group as a between-subject factor (1. Control Group; 2. Experimental Group), Gender (1. Male drivers; 2. Female drivers) as within-subject factor and the driving parameters as dependent variables (V_i, L_{Vi}, V_b, L_{Vb}, V_{min}, L_{Vmin}, $\sigma(V_n)$). The application of the ANOVA test involves the verification of some basic assumptions: the absence of outliers, the normality of the dependent variables and the homogeneity of the variance among the groups. In particular, the box-plots did not identify any outliers among the selected variables, whose normality was assessed by means of the Shapiro-Wilk test (p > 0.05). Except for the L_{Vb} parameter associated with the group of male drivers in the experimental group (group ME), all other dependent variables have met the assumption of a normal distribution of scores, for each of the four defined groups. Anyway, the sample size (the group ME consists of 30 drivers) and the robustness of the ANOVA test against the violation of this assumption [35] made possible the application of such a method also for the L_{Vb} variable. Finally, the Levene's test (p > 0.05) showed that the variance of each dependent variable between groups was equal.

4. Results and discussions

Table 1 reports the mean values of the selected dependent variables of the drivers' braking behaviour. It is worth noting that the braking manoeuvres for the implemented scenario (TTZ = 3s) were abrupt: an independent-samples t-test was conducted to compare the speed reduction time (the time to pass from V_i to V_{min}) between distracted and un-distracted drivers. There was no significant difference in scores [$t(39.02) = -1.57$, $p = 0.13$] between the control group (9.86s) and the experimental one (8.42s).

Table 1. Mean value (standard deviation) of the speed profile variables across groups. *Legend*: V_i and L_{Vi} are speed and associated distance from the crosswalk when the driver released the accelerator pedal; V_b and L_{Vb} are speed and associated distance from the crosswalk when the driver applied the brakes; L_{Vmin} is the distance from the crosswalk at which the minimum speed was observed; $\sigma(V_n)$ is the standard deviation of vehicle speeds.

Groups	V_i [m/s]	L_{Vi} [m]	V_b [m/s]	L_{Vb} [m]	L_{Vmin} [m]	$\sigma(V_n)$ [-]
Control	10.6 (1.62)	59.3 (15.68)	9.6 (2.05)	37.3 (14.46)	9.2 (2.89)	3.9 (0.82)
Experimental	9.7 (1.51)	50.9 (16.01)	8.7 (1.63)	28.2 (11.35)	9.0 (2.72)	4.2 (0.68)

4.1. Driver's initial speed and associated distance from the conflict point

As for the drivers' initial speed (V_i; see Table 1) the analysis showed the presence of a significant group-related difference with a medium effect size (according to Cohen's criterion [36]): [$F_{(1, 74)} = 4.94$, $p < 0.03$, partial eta squared = 0.06]. Interestingly, the analyses revealed the absence of any effect of gender [$F_{(1, 74)} = 1.21$, $p = 0.28$] with no significant Group*Gender interaction [$F_{(1, 74)} = 0.46$, $p = 0.50$]. Similarly, also on the associated distance from the conflict point (L_{Vi}, see Table 1) the group-related difference was significant with a medium effect size [$F_{(1, 74)} = 4.22$, $p < 0.04$; partial eta squared = 0.05] and no effects of Gender [$F_{(1, 74)} = 0.02$, $p = 0.90$] or Group*Gender interaction [$F_{(1, 74)} = 0.36$, $p = 0.55$]. Overall, these results suggest that distracted drivers (both males and females) tend to proceed with a lower speed than undistracted ones but to begin the braking operation significantly later than controls. These results are likely related to the reduction of cognitive resources allocated to the driving behaviour [22] with a potentially significant impact on the safety of the pedestrian. Indeed, the L_{Vi} positions showed an alarming situation: Table 1 reports the values 59.3 and 50.9 m for un-distracted and distracted drivers respectively. Consequently, hands-free mobile phone distraction induced a delayed perception of the hazard situation and drivers approached the crosswalk at higher speeds because beginning the deceleration at shorter distances from the conflict point.

4.2. Driver's speed at application of the brakes and associated distance from the conflict point

As for the drivers' speed at application of the brakes (V_b; see Table 1) and associated distance from the conflict point (L_{Vb}; see Table 1) the analyses showed the presence of a significant group-related difference with a medium effect size for V_b and a large one for L_{Vb} [V_b: $F_{(1, 74)} = 4.38$, $p < 0.04$; partial eta squared = 0.06; L_{Vb}: $F_{(1, 74)} = 8.33$, $p < 0.01$; partial eta squared = 0.10]. In either case, no effects of Gender [V_b: $F_{(1, 74)} = 0.69$, $p = 0.41$; L_{Vb}: $F_{(1, 74)} = 0.32$, $p = 0.58$] or Group*Gender interaction [V_b: $F_{(1, 74)} = 0.17$, $p = 0.68$; L_{Vb}: $F_{(1, 74)} = 0.80$, $p = 0.37$] was found. These results confirmed what was previously observed for the variables V_i and L_{Vi}, showing that the distraction negatively affects the speed profile, at least in the first phase.

4.3. Distance from the conflict point at the end of the braking manoeuvre

As for the distance from the conflict point at the end of the braking manoeuvre (L_{Vmin}; see Table 1), the analysis showed the absence of any significant group-related difference [$F_{(1, 74)} = 0.10$, $p = 0.92$] with no effects of Gender [$F_{(1, 74)} = 0.00$, $p = 0.95$] or Group*Gender interaction [$F_{(1, 74)} = 2.20$, $p = 0.14$]. This suggests that, even if effects of the distraction can be noted in the first phases of the approach to the zebra crossing, the risk-compensated behaviour of the drivers in the experimental group may be effective in stopping the vehicle at a distance from the pedestrian comparable to that of the participants in the control group.

4.4. Fluctuation in speed

A significant main effect of mobile phone distraction on fluctuation in speed was observed with a medium effect size [$F_{(1, 74)} = 4.29$, $p < 0.04$; partial eta squared = 0.06] but no Gender [$F_{(1, 74)} = 3.25$, $p = 0.08$] or Gender*Group interaction [$F_{(1, 74)} = 0.09$, $p = 0.76$]. This suggests that $\sigma(V_n)$ increases with distraction as distracted drivers may find it difficult to keep speed variations under control. For example (see Table 1), the fluctuation in speed for drivers in the experimental group was 7.1% higher than that for participants in the control group.

5. Conclusions

This study compared the braking manoeuvres of drivers distracted by hands-free mobile phone conversations (experimental group) with those of undistracted drivers (control group). Driving data from a cohort of 78 young drivers, aged 20-30 years old, were collected using a virtual car driving simulator. Immersed in a simulated urban scenario, participants were required to respond to an ordinary traffic event: a pedestrian entering a zebra crossing from a sidewalk. The phone call was planned to diminish the amount of cognitive resources allocated to the driving experience. The results

of the statistical analyses showed that hands-free mobile phone conversations significantly affected several variables during driving. In particular, the effect was statistically significant on speed selection and fluctuation, and on distances from the crosswalk at which the driver released the accelerator pedal or applied the brakes. In fact, the drivers in the experimental group maintained lower speeds compared to baseline drivers who were left free to drive without any imposed cognitive task. This finding could reflect a compensatory behaviour for the increased risk associated with the mobile phone conversations, even when earphones are used. Such risk-compensatory behaviour has been elsewhere observed and reported in the literature [22, 37]. The increase of fluctuation in speed suggests that mobile phone distraction impairs speed control while coping with pedestrians crossing the road [34]. Furthermore, the distances kept by the two groups from the crosswalk in two different moments of the operation (i.e., L_{Vi} and L_{Vb}) suggest that distracted drivers perceived the pedestrian on the sidewalk later than baseline drivers. This delayed their braking response, which happened much closer to the conflict point [29]. In this sense, distracted driving poses a significant threat to safety, not only to distracted drivers but also to other vulnerable road users. Differently, no difference was found between the behaviour of male or female drivers who seem to have the same affected performance while approaching the zebra crossing due to redirection of attention away from the roadway ahead.

This study contributes to the growing evidence that hands-free mobile phone use while driving compromises driving performance in a similar way to handheld use [24, 34]; therefore, this finding should encourage legislative bodies to review the laws on mobile phone use. However, further assessments on a wider cohort of drivers are needed, not only to confirm the conclusions of this study, but also to investigate and compare the effect of mobile phone distraction on different groups, such as younger and older drivers. In addition, the effect of reading and writing text messages while driving, or behavioural components (such as aggressiveness) on driving performance will be addressed in future studies.

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