POLITECNICO DI TORINO
Repository ISTITUZIONALE

Do driver monitoring technologies improve the driving behaviour of distracted drivers? A simulation study to assess the impact of an auditory driver distraction warning device on

(Article begins on next page)

1 **Do driver monitoring technologies improve the driving behaviour of**

2 **distracted drivers? A simulation study to assess the impact of an**

3 **auditory Driver Distraction Warning device on driving performance.**

4

5 **Bassani, M.*, Catani, L., Hazoor, A., Hoxha, A., Lioi, A., Portera, A., Tefa, L.**

6

7 **Marco BASSANI,** marco.bassani@polito.it (* = corresponding author)

8 **Lorenzo CATANI,** lorenzo.catani@polito.it

9 **Abrar HAZOOR,** abrar.hazoor@polito.it

10 **Adem HOXHA,** adem.hoxha@studenti.polito.it

11 **Alessandra LIOI,** alessandra.lioi@polito.it

12 **Alberto PORTERA,** alberto.portera@polito.it

13 **Luca TEFA,** luca.tefa@polito.it

14

15

16 Department of Environment, Land and Infrastructure Engineering

17 Politecnico di Torino

18 24, c.so Duca degli Abruzzi

19 Torino – 10129 (Italy)

ABSTRACT

Being distracted while driving is a major cause of road crashes. To help prevent this particular type of crash, new driver monitoring technologies track ocular and head movement and alert drivers when periods of prolonged distraction are detected, thus preventing hazardous situations on the road. In this mixed-factorial multi-level experiment, the behaviour of drivers was measured as they performed a secondary task while being monitored via an auditory Driver Distraction Warning (A-DDW) device which reminded them to look at the road ahead and cease the activity which was the source of distraction. Here, we evaluated the effectiveness of this type of DDW device by measuring longitudinal and lateral behaviour in situations where the driver is intentionally distracted for a significant period of time, and when the device repeatedly reminds the driver of his/her primary task.

Forty-two participants were randomly stratified into three groups and subjected to the following distraction levels: (i) not distracted (baseline), (ii) distracted, and (iii) distracted but interacting with the A-DDW device. All participants drove in (i) free-flowing and (ii) stable traffic conditions along straight motorway segments. Speed and speed deviation values for distracted drivers were lower than for undistracted ones but they also experienced a significant deterioration in vehicle lateral control. Conversely, drivers assisted by the A-DDW device experienced a considerable improvement in their lateral control even though their speed and speed deviation values were higher. The reaction times of distracted drivers interacting with the A-DDW device deteriorated as revealed in cognitive tests conducted before and after the driving task.

Keywords: crash prevention, distraction, driver behaviour, Driver Distraction Warning device, driving simulation.

1. INTRODUCTION

Driver distraction is a serious road safety issue accounting for up to 25% of road crashes in Europe (ERSO, 2018). In the recent three-year period 2016-2018, distracted driving caused circa 3,000 deaths per year in the United States, with more than a quarter of the distracted drivers in the 20 to 29-year-old age group (National Highway Traffic Safety Administration, 2018; 2019; 2020a). Distraction diverts drivers from primary driving-related activities towards secondary tasks (Regan *et al.*, 2011), which can be driving-related, e.g., focusing on onboard instruments, or non-driving-related, e.g., texting with a smartphone (Stutts *et al.*, 2005). Mind wandering while driving results in poor driver vigilance, and often occurs when the driver is familiar with the route (Baldwin *et al.*, 2017; Burdett *et al.*, 2016). There are four categories of distraction: (i) visual (Bakhit *et al.*, 2018; Kuo *et al.*, 2019), (ii) manual (Stutts *et al.*, 2005; Klauer *et al.*, 2006), (iii) auditory (Strayer *et al.*, 2003; European Road Safety Observatory, 2018), and (iv) cognitive (Strayer *et al.*, 2015). The use of a mobile phone involves a combination of these (Kircher, 2007) as does interaction with the centre console (Kuo *et al.*, 2019), with the driver repeatedly switching attention between the driving (primary) and the secondary task (Kaber *et al.*, 2012). A more demanding secondary task leads to a higher number of off-road glances, both for purely visual (Metz *et al.*, 2011) and visual-manual tasks (Tivesten & Dozza, 2014), while a complex driving task including both visual and auditory stimuli from in-vehicle systems forces drivers to concentrate more on the road ahead and keep their eyes focused spatially on the central part of the road (Victor *et al.*, 2005).

It is well established that distraction affects longitudinal and lateral vehicle control as well as driver reaction times (Papantoniou *et al.*, 2017; Young *et al.*, 2009). Driving simulation studies show that speed (*S*) decreases when the driver is using a cell phone (Alm & Nilsson, 1994; Reed & Robbins, 2008) and the standard deviation of speed (*SDS*) increases as the difficulty of the secondary task increases (Rakauskas *et al.*, 2004). A reduction in speed (Papantoniou *et al.*, 2017) and/or an increase in the distance between the driver and the vehicle in front (Strayer & Drews, 2004) are generally adopted as countermeasures to ensure increased reaction times in response to a potential hazardous event requiring an evasive manoeuvre like steering and/or braking. It should be noted that distracted drivers do not always deteriorate their performance levels. As reported by Oviedo-Trespalacios *et al.* (2018), when the distraction is self-inflicted, drivers select lower speeds to compensate for the risk(s) they are taking.

Regarding transversal control, lateral position (*LP*) and standard deviation of lateral position (*SDLP*) are the most common parameters employed to evaluate the ability to maintain appropriate position and control of the vehicle within the lane (Papantoniou *et al.*, 2017). However, any distractions while driving adversely affect the ability of drivers to maintain their vehicle correctly positioned in the lane (Choudhary & Velaga, 2019; Rumschlag *et al.*, 2015). Furthermore, some studies showed that visual and manual tasks cause more lane deviations, steering errors and higher *SDLP* values than cognitive distractions (Engström *et al.*, 2005; Kaber *et al.*, 2012).

79   Driver monitoring technologies were introduced more than a decade ago, first as a driver behavioural

80   research tool (May & Baldwin, 2009; Taylor *et al.*, 2013), then as in-vehicle technology to alert drivers to

81   inappropriate driving practises and hazardous situations (Reagan *et al.*, 2018; Mase *et al.*, 2020). Recently,

82   the European Parliament (European Parliament & Council of the European Union, 2019) approved

83   Regulation No. 2019/2144 in an effort to protect vehicle occupants and other road users from distraction.

84   The 2019/2144 Regulation imposes the adoption of Driver Distraction Warning (DDW) systems on new

85   vehicles by 2026. These devices were originally introduced to the automotive aftermarket and to new

86   vehicle models afterwards (Doudou *et al.*, 2020). They emit auditory and/or vibratory warnings when the

87   driver is distracted, with the aim of ensuring that the driver is alert and retains or regains full control of the

88   vehicle. The majority of current DDW devices process data relating to the eye region (gaze tracking, eye

89   closure, percentage of eyelid closure over time, etc.) and face monitoring (Sigari *et al.*, 2014).

90   Anti-distraction applications were also introduced on smartphones as low-cost DDW systems (Bergasa *et*

91   *al.*, 2014). The technical documents in support of the 2019/2144 Regulation (European Parliament &

92   Council of the European Union, 2021) indicate that DDW systems are expected to be more effective outside

93   urban zones, e.g., on motorways, where long-distance driving at a constant speed together with less

94   interesting surrounding environments can result in drivers becoming more distracted (Huemer & Vollrath,

95   2011).

96   Despite the effectiveness of DDW technologies in detecting distraction being well recognized (Dumitru

97   *et al.*, 2018; Gallahan *et al.*, 2013), their effects on driver behaviour and performance are still the subject

98   of debate. Donmez *et al.* (2006) investigated the effects of an advisory mitigation strategy used to

99   discourage off-road eye glances while drivers were interacting with an in-vehicle information system, but

100   no relevant advantages in braking and steering performance were observed. Ahlstrom *et al.* (2013) used a

101   seat vibrating DDW system based on a remote eye tracking (AttenD) algorithm to evaluate changes in

102   driving behaviour in field tests under uncontrolled traffic conditions, but it did not result in significant

103   changes in global glance behaviour. The uncertainty regarding the impact of DDW devices on driver

104   performance in controlled traffic conditions suggests that more research is needed.

105   In this driving simulation study, we evaluated the effectiveness of an auditory DDW (A-DDW) device

106   currently available on the automotive aftermarket, which can track eye and head movements and alert

107   drivers if and when their visual behaviour deviates from the reference front position for at least 3 s.

108   Participants were asked to perform a secondary task which involved a cognitive, visual and manual

109   distraction. We were then able to assess the effectiveness of the warning system by measuring driver

110   behaviour when subject to a state of intentional distraction.

111

4

2. METHODS

2.1 Experimental design and hypotheses

A multi-level mixed-factorial design with varying levels of distraction and traffic density was considered. Longitudinal and lateral behavioural indicators were monitored under two different traffic scenarios, while the participants were subjected to one of the following three states: not distracted, distracted, or distracted but with the support of the A-DDW device. This experiment was conducted under the hypothesis that the A-DDW device counteracts the negative impact of the distraction experienced when drivers persist in performing a secondary task.

Although this specific secondary task is not likely in ordinary driving, we considered it because of the conclusions reached by Shinar *et al.* (2005), who observed that solving mathematical operations significantly degraded driving performance compared to a distraction caused by conversation. On the other hand, the simultaneous activation of an alert system that detects distraction and the persistence of a distracted state is likely when A-DDW systems are installed on the next generation of vehicles in 2026.

We also evaluated the effect of the A-DDW device on mental workload by measuring the change in the perception and reaction times (PRT) of participants to visual and auditory stimuli before and after driving. The hypothesis tested in this experiment is that the A-DDW device requires a more demanding driving task, with an increment in the PRT after driving.

The experiment combines distraction as a between-subject factor, and traffic density (i.e., the level of service, LOS) as a within-subject factor (Table 1). The stimulus combined visual, cognitive, and manual distractions and was dispensed along straight segments of 2 km (see Section 2.2).

TABLE 1. Synthesis of the design factors.

Experimental factors	Levels			Type
Distraction level (Group No.)	No Distraction (0)	Distraction (1)	Distraction + A-DDW (2)	Between-subject
Traffic density (Level of Service, LOS)	7 pc/km/lane (A)	14 pc/km/lane (C)	-	Within-subject

2.2 Road scenario

The road scenario consisted of a rural motorway consistent with Italian technical standards (*Ministero delle Infrastrutture e dei Trasporti*, 2001). As the scenario was designed to favour distractions (see Figures 1a and 1b), long straights to increase the feeling of monotony were adopted (Huemer & Vollrath, 2011; Papantoniou *et al.*, 2016; Slootmans & Desmet, 2019). As depicted in Figure 1, the immediate surroundings were slightly hilly with the presence of vegetation, trees, and some buildings in the distance. The weather and visibility conditions for driving were optimal. The carriageway had a width of 7.5 m with 2 lanes (3.75 m each) per direction, a 3 m wide emergency lane, and a 0.7 m wide left shoulder. Horizontal markings and vertical signals conformed to the Italian Highway Code (*Nuovo Codice della Strada*, 1992).

144 The posted speed limit was set at 130 km/h. A safety barrier of 850 mm in height was selected for the
145 median while the barrier along the right roadside was omitted.

146 Drivers started the experiment from a lay-by before merging onto the motorway from a direct ramp.
147 After merging, each participant drove on three long motorway tangents connected by circular arcs of
148 1200 m in radius. The level of service (LOS) was set at A, i.e., free flow conditions, and C, i.e., stable flow
149 with the reduced ability to change lane requiring greater awareness. The randomized order of administration
150 of the LOS along the 2nd and the 3rd straights was adopted. Hence, a number of circulating vehicles
151 corresponding to an average vehicle density of 7 pc/km/lane (LOS A, Figure 1a) and 14 pc/km/lane (LOS
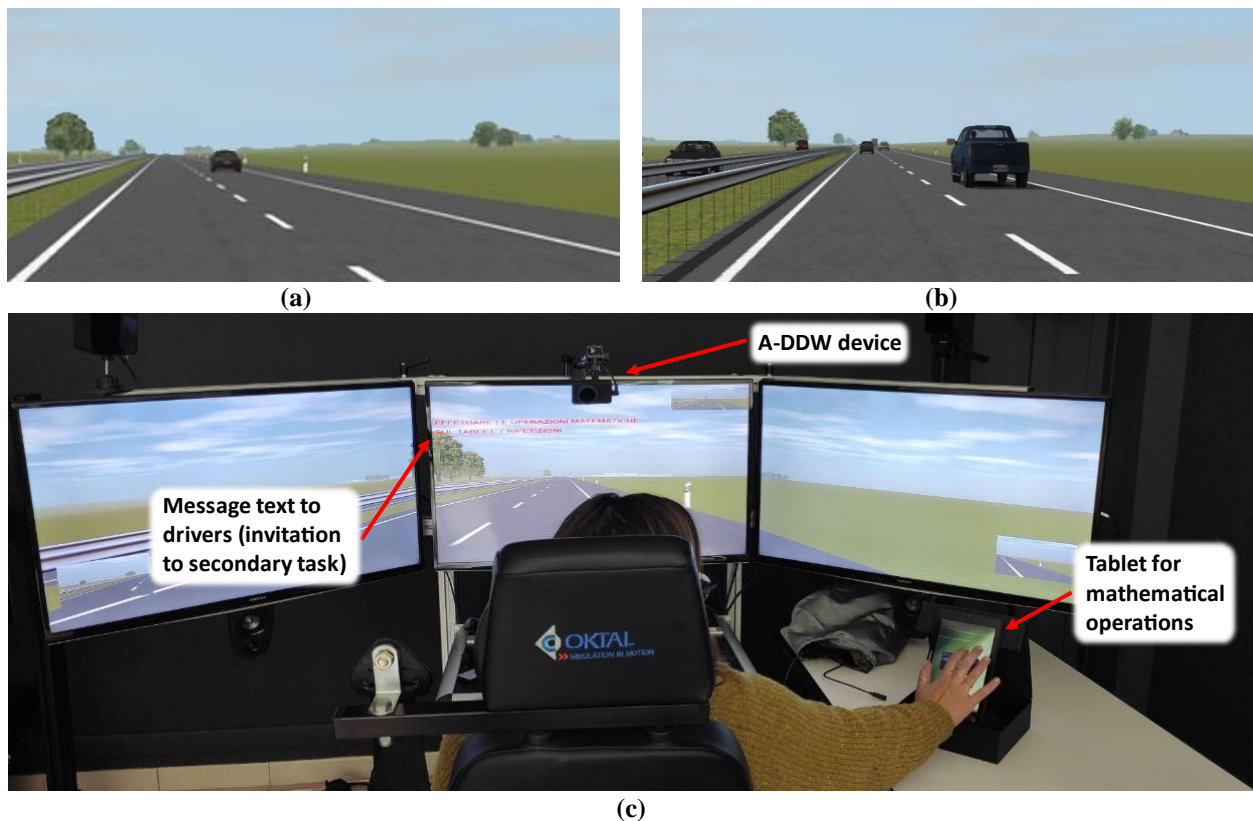152 C, Figure 1b) was adopted (Transportation Research Board, 2016).

153

154
155 (a)   (b)

156
157 (c)
158 **FIGURE 1. Experimental set-up and scenarios: (a) straight segment under LOS A, and (b) LOS C. Simulation**
159 **setting (c) with tablet for the secondary task and the A-DDW device.**
160

161 **2.3 Equipment**
162 Experiments were conducted using the fixed-base driving simulator with SCANeR Studio™ software
163 (AV Simulation) at the Road Safety and Driving Simulation (RSDS) laboratory of the Politecnico di Torino
164 (Figure 1c). With this simulator, the driver has a 130° horizontal and around 30° vertical field of view
165 through three 32-inch full HD screens (1920×1080 pixels each). Together with the video card, the monitors
166 update the images at a frequency higher than 50 Hz and are equipped with rear and side view mirrors. The
167 simulator hardware consists of a cockpit complete with steering wheel, manual gearbox, pedals and

6

168   dashboard. The speedometer, rev counter and other onboard displays are on the small monitor mounted on

169   the back of the steering wheel but in a position where they are always visible to drivers during experiments.

170   The steering wheel is equipped with a force feedback sensor to simulate wheel spin and impacts. Vehicle

171   and traffic sound effects are reproduced through five speakers located behind the screens and a subwoofer

172   under the driver's seat. The simulator repeatedly reached relative validation for longitudinal (Bassani *et al.*,

173   2018), transversal (Catani and Bassani, 2019), and driving operations (Karimi *et al.*, 2020).

174   An A-DDW device available in the automotive aftermarket (Figure 1c), i.e., an infrared camera that

175   detects eye pupil and head movements, was used. It determines whether pupils dilate or blink, and if the

176   head position changes with respect to the initial calibration. As soon as any such change is detected, the

177   sensor alerts the driver in real-time to help maintain a condition of safe driving. When the gaze is directed

178   downwards or the pupils constrict, a continuous beep sounds and alerts the driver in less than 2 s. Following

179   3 s of persistent distraction, i.e., head and gaze not directly focused on the road, a warning voice message

180   informs the driver that he/she has to look ahead. Preliminary tests established that the ideal camera position

181   is close to the rear-view mirror and at a distance of 60 ± 5 cm from the driver's head (see Figure 1c).

182

183   **2.4 Participants**

184   A hundred participants were contacted via email, and since the study was conducted in line with the Code

185   of Ethics of the World Medical Association (World Medical Association, 2018), all participants signed an

186   informed consent form before starting the experiments. Based on an expected effect size (f) of .30, a

187   significance level of .05, and a power of .90, forty-two out of one hundred were involved. Drivers were

188   aged between 24 and 63, and were divided into three groups according to the between-subject factor

189   (Table 1) in order to avoid any learning effect in the data, while the duration of a driving session was limited

190   to no more than 15 min along the 25 km of the experimental track, so as to keep any fatigue phenomena to

191   a minimum. Groups were stratified by age and gender, with five females and nine males in each group

192   (Table 2).

193

194   **TABLE 2. Descriptive statistics for participant characteristics.**

Participant characteristics	Group	N	Mean	SD	Minimum	Maximum
Driver age	0	14	43.8	11.9	24	64
	1	14	43.0	11.3	23	61
	2	14	43.4	15.1	23	64
Experience (km/y)	0	14	14,857	10,516	1,000	30,000
	1	14	14,607	12,783	1,500	40,000
	2	14	11,429	9,764	2,000	35,000
Experience (license y)	0	14	25.1	11.9	5	45
	1	14	23.1	10.7	4	43
	2	14	23.7	14.7	4	45

195

2.5 Protocol

Each participant filled out a pre-drive questionnaire on their general health before driving on a test circuit to get familiar with the simulator commands. Drivers were instructed to drive as they would in a real motorway setting, while respecting traffic regulations. Those supported by the A-DDW device (Group 2) were instructed to complete the secondary task regardless of the fact that they were advised by the device to desist from doing so. After that, each participant drove for a maximum of 20 minutes. Before and after the driving task, participants completed two visual and auditory stimuli PRT tests using the online tool *Cognitive Fun!* (retrieved from https://new.cognitivefun.net/). We collected data with this online platform through a computer with a high-speed internet connection without conducting any validation tests.

During the distraction phase, a written message on the central windscreen invited participants to perform simple mathematical operations (Figure 1c). A random sequence of simple, solvable in your head additions, subtractions, multiplications, and divisions was proposed to influence driving performance (Shinar *et al.,* 2005) through *MathGames* (retrieved from https://www.mathplayground.com/math-games.html) installed on a 7" tablet positioned 55 cm to the right of the steering wheel (Figure 1c). The A-DDW device was activated each time drivers looked at the tablet for more than 3 seconds and it remained active until drivers reverted their gaze from the tablet back onto the road for a while. Once they had regained full control of the vehicle, drivers were able to continue with the secondary task. No driver performed any incorrect manoeuvres, or crashed into road installations or surrounding vehicles.

Finally, each driver filled out a post-drive questionnaire to provide feedback on the simulation and the anti-distraction device. The responses to the questionnaire demonstrated that the presence of the A-DDW device did not irritate or annoy the drivers during the test. Positive responses were received on the realistic nature of the simulation when compared to real driving conditions.

2.6 Observed variables, data collection and statistical analysis

Data for speed and lane position were collected at a frequency of 10 Hz for all testing configurations. Any outcomes relating to sections in which drivers were engaged in lane change manoeuvres were excluded from the database and the results. In accordance with the SAE J2944 standard (Society of Automotive Engineers, 2015), the following dependent variables depicting the longitudinal and lateral behaviour of drivers were measured:

    (i)   average speed (*S*),

    (ii)   standard deviation of speed (*SDS*),

    (iii) average lateral position (*LP*), and

    (iv) standard deviation of lateral position (*SDLP*).

LP indicates the distance from the vehicle centre of gravity to the lane centreline of both lanes in the carriageway. Positive *LP* values signify that the centre of gravity (CoG) was on the left side of the lane

centreline. *SDS* and *SDLP* values reflect the ability of the driver to remain in control of the vehicle vis-à-vis use of the throttle and the steering wheel, respectively (Verster & Roth, 2011).

PRT tests were conducted to determine if the cognitive performance of participants suffered during the simulation due to the increased mental workload caused by the distracting secondary task (Group 1) and the simultaneous interaction with the A-DDW device (Group 2).

Linear mixed-effects models (LMM) and the generalized linear models (GLM), in the case of violation of LMM assumptions, were considered. Among the fixed effects of both LMM and GLM, the two experimental factors (distraction level, and level of service) and gender were included as categorical, while age and driving experience (average distance travelled in a year, and number of years holding a licence) were included as covariates. In the LMM, random effects (RE) accounted for the unobserved heterogeneity due to participants' subjective characteristics. Therefore, the *Test driver ID* was used as a cluster variable in the analysis. Clinical research (Pietrzak *et al.*, 2010) demonstrates that the LMM rather than other statistical methods like RM-ANOVA, reduces the standard error in the estimation, and increases the effect size (i.e., lower *p*-value), and the reliability of results, especially in mixed experimental designs. LMM is used with datasets including repeated measurements, as in this investigated case where each driver was monitored under two different traffic density scenarios.

Statistically non-significant variables and relative interactions were removed in accordance with the backward elimination technique. By minimizing the Akaike Information Criterion (AIC, Eq. 1) (Akaike, 1974) and the Bayesian Information Criterion (BIC, Eq. 2) (Stone, 1979):

$$AIC = -2\ln(L) + 2k \tag{1}$$

$$BIC = -2\ln(L) + \ln(n) \times k \tag{2}$$

where L is the model likelihood parameter, k is the number of parameters estimated, and n is the number of observations, the model performance was improved. When statistically significant effects and interactions were detected in LMM and GLM, post-hoc tests with Holm correction were performed. The significance level was always set at 5%. Statistical data analyses and modelling were carried out with Jamovi ver. 2.3.18 (The Jamovi Project, 2021).

3. RESULTS

3.1 Descriptive statistics

Table 3 provides the average and standard deviation of the experimental outcomes. The results have been grouped by distraction level and traffic density conditions.

TABLE 3. Mean (and standard deviation) of outcomes for average speeds (*S*), standard deviation of speeds (*SDS*), average lateral position (*LP*), and standard deviation of lateral position (*SDLP*).

Groups No. (Distraction level)	Level of Service (LOS)	S (km/h)	SDS (km/h)	LP (m)	$SDLP$ (m)
0 (Baseline)	A	123.3 (9.1)	4.71 (1.45)	0.123 (0.199)	0.223 (0.076)
	C	122.5 (11.9)	4.14 (2.42)	0.124 (0.245)	0.217 (0.063)
1 (Distraction)	A	114.4 (18.3)	2.81 (2.23)	0.175 (0.413)	0.344 (0.140)
	C	114.8 (15.3)	3.01 (1.68)	-0.061 (0.407)	0.420 (0.235)
2 (Distraction + A-DDW)	A	123.3 (18.9)	5.14 (4.35)	0.176 (0.375)	0.315 (0.130)
	C	128.3 (20.8)	3.39 (2.70)	-0.055 (0.335)	0.330 (0.169)

3.2 Models estimation

Table 4 shows the estimated parameters for the four dependent variables investigated. *S* and *LP* data were used to calibrate LMM, while *SDS* and *SDLP* data were used to calibrate GLM since (i) no significant impact of the *Test driver ID* as a cluster variable was observed after a preliminary analysis with LMM, and (ii) to avoid any violation of assumptions on residuals for LMM. In Table 4, all models have the lowest AIC and BIC values possible. The assumption checks carried out by the Kolmogorov-Smirnov test confirmed the normality of residuals of the LMM for *S* and *LP* (*p*-values always higher than .05).

TABLE 4. LMM and GLM for driver behavioural outcomes.

		Estimate (*p*-value)			
		LMM		GLM	
		S (km/h)	LP (m)	SDS (km/h)	$SDLP$ (m)
Factors, covariates (fixed effects):	Effect				
Intercept		119.884 (<.001)	0.0810 (.057)	3.8654 (<.001)	0.3082 (<.001)
Distraction level	1-0	-8.4658 (.119)	-0.0638 (.497)	-1.3988 (.045)	0.1462 (<.001)
	2-0	1.9054 (.726)	-0.0655 (.522)	-0.0778 (.910)	0.0894 (.014)
LOS	C-A	-	-0.1574 (.018)	-	-
Gender	F-M	-8.4705 (.097)	-	-	-
Gender * Distraction level	F-M*1-0	0.8575 (.937)	-	-	-
	F-M*2-0	-23.3404 (.054)	-	-	-
LOS * Distraction Level	C-A*1-0	-	-0.2311 (.148)	-	-
	C-A*2-0	-	-0.2255 (.158)	-	-
Driver age (y)		-0.5621 (.019)	-	-	0.0197 (.001)
Experience (km/y)		$7.64 \cdot 10^{-4}$ (.010)	-	-	-
Experience (licence y)		-	-	0.0607 (.011)	-0.0162 (.008)
Cluster variable for LMM (random effect):					
Test driver ID		(<.001)	(.109)	-	-
Summary statistics					
AIC		649.64	63.50	402.25	-95.20
BIC		660.04	101.16	414.41	-80.61
R^2 marginal		.339	.082	-	-
R^2 (conditional for LMM)		.879	.314	.139	.349
Observations / Drivers				84/42	
Kolmogorov-Smirnov test for normality of residuals		.457	.913	-	-

3.3 Longitudinal behaviour

Regarding *S* (Table 4), the LMM explains around 88% of the total variance, with most of this ascribable to the random effect associated with the *test driver ID* (54% of the total variance in the data), thus indicating the predominant effect of subjective behaviour. Distraction level and LOS were not significant in explaining

10

281   *S*. In fact, LMM did not reveal any significant differences when comparing undistracted drivers with both

282   distracted groups. Estimated marginal means revealed that distracted drivers ($M_1 = 113.6$ km/h,

283    $SE_1 = 3.67$ km/h) adopted lower speeds than undistracted ones ($M_0 = 122.1$ km/h, $SE_0 = 3.79$ km/h), and

284   that drivers who interacted with the A-DDW device drove at speeds similar to those of the undistracted

285   drivers in Group 0 ($M_2 = 124.0$ km/h, $SE_0 = 3.86$ km/h). A post-hoc test revealed that distracted males

286   supported by the A-DDW device (Group 2) drove at significantly higher speeds than male drivers in

287   Group 1 ($S_{1M} - S_{2M} = $ -22.47 km/h, $t_{37} = $ -3.26, *p*-value$_{Holm} = .037$). Moreover, when distracted while under

288   the influence of the A-DDW device, females drove at lower speeds with respect to males

289   ($S_{2M} - S_{2F} = 24.32$ km/h, $t_{37} = 2.97$, *p*-value$_{Holm} = .069$), a fact that explains why gender and distraction level

290   interact in the model (Table 4). LMM results also indicate that participants used to driving more kilometres

291   per year also drove faster than those used to driving less, while older drivers behaved more cautiously than

292   younger ones.

293   *SDS* was marginally influenced by distraction. Distracted drivers reduced speed variation more than

294   non-distracted drivers did ($SDS_0 - SDS_1 = 1.40$ km/h, $z = 2.04$, *p*-value$_{Holm} = .134$). However, distracted

295   drivers supported by the A-DDW (Group 2) device exhibited speed variations similar to undistracted ones

296   ($SDS_0 - SDS_2 = 0.8$ km/h, $z = 0.11$, *p*-value$_{Holm} = .910$). Experienced drivers also exhibited greater speed

297   variations than novice drivers. As before though, no significant differences were imputable to the LOS.

298

3.4 Lateral behaviour

300   The LMM for *LP* revealed that it was significantly influenced by LOS ($LP_A - LP_C = 0.157$ m, $t_{41} = 2.44$,

301   *p*-value$_{Holm} = .019$), and marginally by the driving style of participants (*p*-value $= .141$) which, nevertheless,

302   accounts for circa 23% of the total variance in the model. As shown in Table 3, distracted participants

303   generally drove more on the right side of the centreline under denser traffic conditions (i.e., LOS C) than

304   those undistracted and those distracted but operating under free-flow conditions (LOS A) did. However,

305   LMM did not reveal a significant difference in *LP* ascribable to distraction levels and the covariates.

306   Conversely, *SDLP* was heavily influenced by distraction levels, driver age and experience. Distracted

307   drivers increased their *SDLP* notably more than undistracted ones ($SDLP_0 - SDLP_1 = $ -0.146 m, $t_{37} = $ -3.97,

308   *p*-value$_{Holm} < .001$). However, Group 2 drivers showed only a marginally better level of lateral control

309   whilst performing the secondary distracting task than that shown by their Group 1 counterparts

310   ($SDLP_1 - SDLP_2 = 0.057$ m, $t_{37} = 1.57$, *p*-value$_{Holm} = .125$), albeit not enough to reduce their *SDLP* values

311   to those of undistracted drivers ($SDLP_0 - SDLP_2 = $ -0.089 m, $t_{37} = $ -2.44, *p*-value$_{Holm} = .039$). LMM revealed

312   that free- and stable-traffic conditions had no significant effect on *SDLP*. As shown by the estimates for

313   model coefficients, younger drivers maintained better lateral control than older ones, thereby demonstrating

314   the significant effect of age on *SDLP* (*p*-value$_{Holm} = .002$). However, more experienced drivers performed

315   fewer corrections along the trajectory, i.e., had lower *SDLP* values.

316

3.5 Visual and auditory PRT tests

The comparison between data for the visual and auditory PRT tests carried out before and after the driving test for the three groups of participants is shown in Figure 2. For each group of drivers (i.e., undistracted, distracted, and distracted but interacting with the A-DDW device), PRT data were found to be Gaussian distributed according to outputs from Kolmogorov-Smirnov tests for normality (all p-values larger than .05). The average visual and auditory PRT values after the experiments were always higher than the PRTs measured before. Moreover, data confirmed that the visual stimuli led to longer PRTs, because of the longer time required for the transmission of the photoreception signal to the brain compared to that required for the auditory stimulus (Kemp, 1973).

The results obtained revealed no significant differences between before and after visual and auditory PRT values for the undistracted drivers (Group 0). In contrast, significant statistical differences were observed for the distracted drivers in Groups 1 and 2. While the change in PRT within Group 1 was only significant for the auditory values ($t_{13} = -2.37$, p-value = .017), both visual and auditory tests revealed that distracted drivers who interacted with the A-DDW device experienced a statistically significant change in their PRT values after the driving test (visual: $t_{13} = -3.49$, p-value = .004; auditory: $t_{13} = -4.17$, p-value = .001).
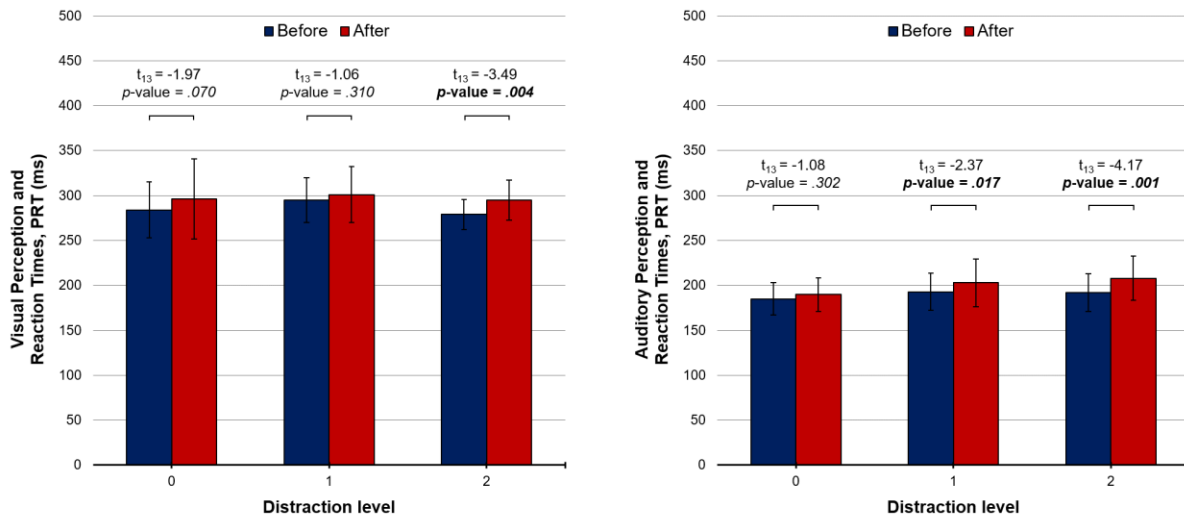

FIGURE 2. Visual and auditory perception and reaction times (mean and standard deviation) before (blue bars) and after (red bars) the driving session.

4. DISCUSSION

We examined the effect of an A-DDW device on driver performance while he/she is distracted by having to perform a secondary task along a motorway. In doing so, we took the performance of drivers distracted by the same task and non-distracted drivers as benchmarks.

The results with the LMMs and GLMs indicate that along motorways the personal characteristics of drivers have a significant influence over speed and a marginal influence over lateral position in the lane. In contrast, longitudinal and transverse control ability are mainly influenced by the level of driver distraction and age.

As depicted in Figure 3a, drivers slightly reduced their speed when distracted to compensate for the risk associated with continuing to perform the secondary task. In this study, this reduction did not prove to be statistically significant, while the same trend but statistically significant in difference was observed by Choudhary and Velaga (2019) in a driving simulation study on a four-lane (two lanes per direction) undivided carriageway with a posted speed limit of 110 km/h. Similar outcomes were registered by Rakauskas *et al.* (2004) for a simulation study in a two-lane rural road setting. Based on our results, we can confirm that, when distracted, drivers prudently maintain a lower speed than they do when focused on the primary driving task only.

We also observed that the behaviour of distracted drivers interacting with the A-DDW device differed with gender. Whereas males drove significantly faster than the distracted-only drivers in Group 1, females reduced their speed to levels lower than males operating under the same conditions. The prudent nature of female drivers was observed by Onate-Vega *et al.* (2020), while Choudhary *et al.* (2022) confirmed that females demonstrated a greater perception of the risk associated with distracting secondary activities than their male counterparts. However, care must be taken not to generalise this result, as the study had an unbalanced composition of males (65%) and females (35%). LMM outcomes also reveal that drivers with greater driving experience in terms of distance travelled adopted higher speeds. This is consistent with the results from Oviedo-Trespalacios *et al.* (2017), who observed that inexperienced drivers reduced their speed more than experienced ones when distracted.

Figure 3b shows the impact of the different distraction levels on the standard deviation of speed (*SDS*). Distracted drivers reduced their speed variation, while those distracted but interacting with the A-DDW assumed speed variation values comparable to those of undistracted drivers. This outcome contrasts with that observed by Rakauskas *et al.* (2004) who measured an increment of 0.5-1 mph (0.8-1.6 km/h) in the *SDS* of drivers talking on their cell phones in realistic driving conditions. The differences between these two studies are attributable to the difference in distraction type, which was solely cognitive in Rakauskas *et al.* (2004), while cognitive, manual and visual in the present study. However, the not statistically significant increment observed for drivers interacting with the A-DDW device with respect to those simply distracted is consistent with the results from Rakauskas *et al.* (2004) who observed larger speed variation

13

374 values in tasks requiring a higher mental workload such as participation in mobile phone conversations.
375 Furthermore, the higher *SDS* values recorded for more experienced drivers indicate that they tended to
376 adjust speed more frequently when alerted by the A-DDW device, which emitted a "beep" sound and some
377 warning messages. This result is in line with that of Donmez *et al.* (2006), who observed that older drivers
378 accept and trust strategies to combat distraction more than young drivers do.
379
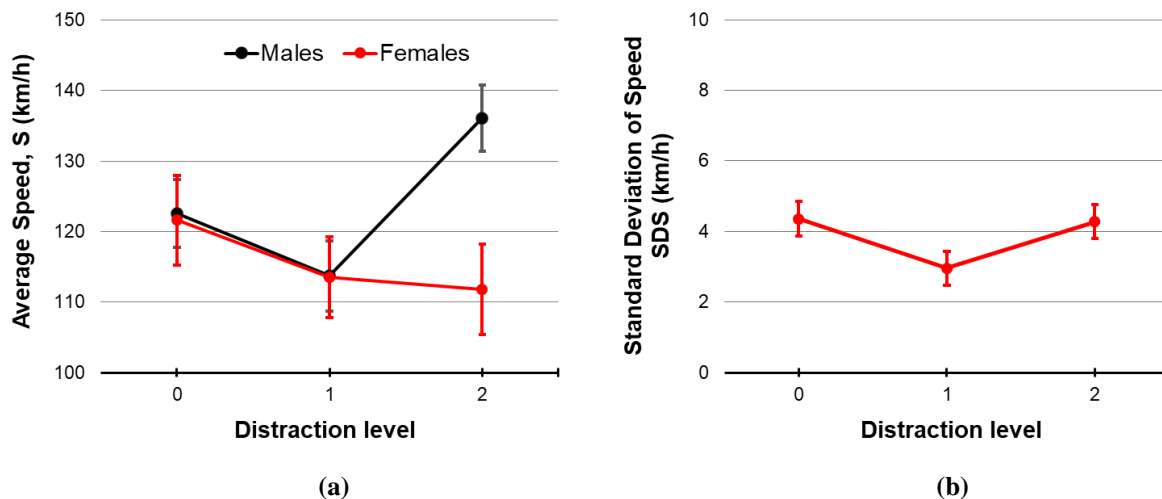
381 (a)   (b)
382 **FIGURE 3. Effect plots of the LMM and GLM analyses for the effect of distraction level on (a) average speed**
383 **(*S*), and (b) standard deviation of speed (*SDS*), respectively. Bars indicate the standard error.**
384

385 Significant differences in lane position were attributable to traffic density, as supported by the
386 observations from Mecheri *et al.* (2017) and Dijksterhuis *et al.* (2011), although their studies were
387 conducted on two-lane rural roads. In the case investigated here (Figure 4a), the average lateral position
388 values for distracted drivers in both Groups 1 and 2 were negative under LOS C conditions (see Table 3).
389 The higher the traffic density (Figure 1b), the farther to the right the position of the vehicle driven by
390 distracted participants. This clearly indicates the propensity of distracted drivers to occupy the right side of
391 the lane to limit the degree of interaction with any faster vehicles arriving from behind when occupying the
392 rightmost lane, or to increase the distance from a fixed installation like the traffic barrier when driving in
393 the leftmost lane. This can be seen as a risk compensation strategy to counteract the impact of distraction
394 in a more dangerous environment with vehicles on a multi-lane road, a strategy which was also observed
395 by Oviedo-Trespalacios *et al.* (2020).
396 In terms of lateral control, distracted drivers exhibited higher *SDLP* values than undistracted ones
397 (Figure 4b) consistent with the studies of Engstrom *et al.* (2005) and Kaber *et al.* (2012), who claimed that
398 tasks combining visual and manual actions like texting with a smartphone cause more lane deviation and
399 result in higher *SDLP* values than distractions which are purely cognitive in nature. Nevertheless, when
400 comparing distracted drivers, the A-DDW device improved lateral behaviour (i.e., lower *SDLP*). Although
401 distracted, Group 2 drivers were invited by the A-DDW device to look at the road ahead, thus maintaining

better lateral control. The observation study carried out by Wang *et al.* (2019) in real driving conditions corroborates this hypothesis, with distracted drivers reducing the number and duration of glances required to perform the secondary distraction task so as to remain more focused on the road ahead.
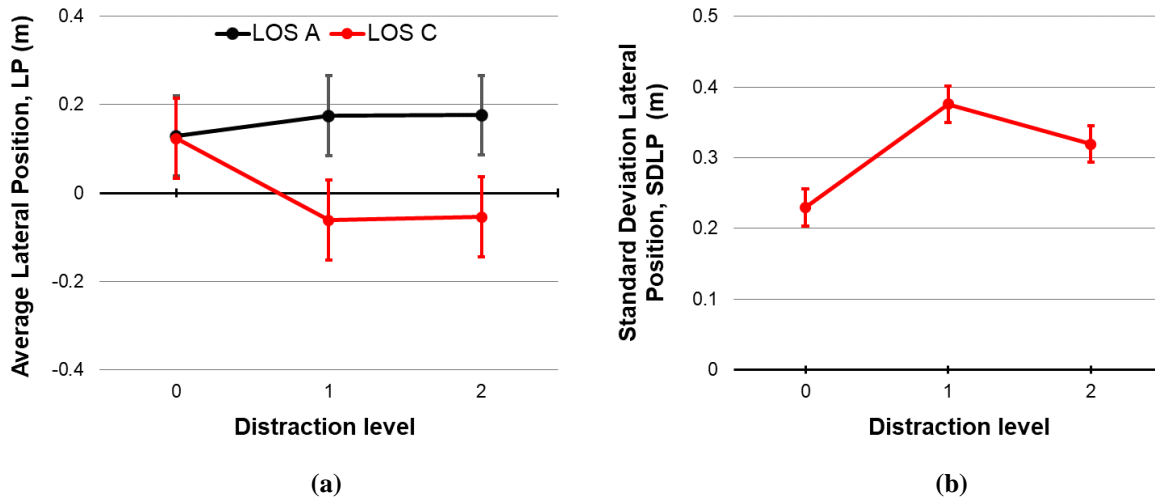

(a) **(b)**

FIGURE 4. Effect plots of the LMM and GLM analyses for the effect of distraction level on (a) the average lateral position (*LP*), and (b) the standard deviation of lateral position (*SDLP*), respectively. Bars indicate the standard error.

Cognitive tests carried out before and after the driving task revealed a significant increase in PRTs for drivers that used the A-DDW device. While the distracted drivers in Group 1 exhibited a significant reduction in their auditory performances only, Group 2 drivers experienced a significant deterioration in PRT values for both visual and auditory stimuli on completion of the driving session. It is worth noting that while visual information is the most important type for drivers (Sivak, 1996), the noise level also impacts the driving task (Denjean *et al.*, 2012), and auditory reactiveness is inversely proportional to the cognitive workload while driving (Reimer & Mehler, 2011). These results concur with those obtained by Chen *et al.* (2005) regarding the increase in driver perception and reaction times while they are engaged in a series of mental processing tasks. In this study, we measured the difference before and after the driving session, and drivers who were exposed to distraction and interaction with the A-DDW device experienced a significant deterioration in their cognitive performances. Milosevic (1997) observed that a driver's mental workload leads to excessive fatigue which in turn leads to an increase in visual and auditory PRT values. Since simulated driving is much more demanding than real driving (Philip *et al.*, 2005), it cannot be excluded that the observed differences were attributable to the simulation effect, while in real driving conditions the same cognitive deterioration can be observed after a prolonged exposure to the A-DDW interaction (Engström *et al.*, 2005).

4. CONCLUSIONS

Carmakers and automotive companies are introducing new driver monitoring systems which use communication apparatuses to draw attention to and contrast the unsafe behavioural habits of distracted drivers, thus helping to reduce the number of road crashes. However, their effectiveness on driver performance has yet to be established.

In this study, the effectiveness of an auditory driver distraction warning (A-DDW) device was tested under motorway driving conditions by measuring longitudinal and lateral behaviour indicators when drivers are deliberately distracted for a sustained period of time with the device repeatedly reminding them to concentrate on their primary task. The longitudinal and transversal behaviour patterns of forty-two volunteers spanning a wide spectrum of ages and levels of driving experience were monitored.

Based on statistical data modelling, the main outcomes of this investigation were as follows:

1. in cars equipped with an A-DDW device and travelling along motorways, drivers experience a marginal improvement in their lateral control when distracted with respect to those who are not supported by such a device;

2. distracted male drivers interacting with an A-DDW device react differently to female drivers; while males tend to travel at higher speeds, females reduce their speed to levels lower than those of distracted and non-distracted drivers;

3. distracted drivers interacting with an A-DDW operate with a higher mental workload;

4. stable and free-flow traffic conditions impact the lateral position in the lane of distracted drivers irrespective of the presence of an A-DDW device;

5. the individual personality traits of drivers affect speed and to a lesser extent their position within the lane, while longitudinal and lateral control indicators are mostly influenced by the level of distraction and the countermeasures used to contrast same.

The hypothesis being tested is only partially confirmed in terms of average speed, since female drivers supported by the A-DDW device behave differently from males, a finding which merits further investigation, since we have adopted an unbalanced composition of males and females. However, the hypothesis is confirmed for lateral control. We observed that distracted drivers interacting with the A-DDW device reduce their lateral weaving movement within the lane more than that of simply distracted drivers. Hazardous interactions with fixed installations (e.g., safety barriers, vertical signals) and surrounding vehicles are reduced with the presence of an A-DDW device onboard. In conclusion, the use of an A-DDW device only partially contrasts driving impairments caused by deliberate distraction.

The results of this study should be considered by those who are developing anti-distraction systems of the type investigated here. Although their use should serve to discourage anyone from engaging in secondary activities that divert attention from the (primary) driving task, the possibility that drivers will persist in such safety-threatening behaviour must, nevertheless, receive serious consideration. In addition,

this study emphasises the need to explore the safety implications when drivers adopt improper driving behaviour despite the influence of technological countermeasures that promote better driving practises but which do not override their actions.

However, the results obtained must also be viewed in the light of five shortcomings. First, we used only one A-DDW device which uses an acoustic message to alert the driver. A different warning interface design, e.g., with visual or haptic warnings of different intensity, duration and/or repetition, could have a different impact on driver behaviour. Similarly, the timing and reliability of warnings determine their effectiveness. If drivers receive false warnings, they may begin to ignore the information and fail to respond quickly and appropriately. Therefore, visual and haptic modes should also be tested in the short and long term to see which of them are the most effective in terms of driving performance, subjective acceptance and usability. Second, the nature of the secondary task (i.e., doing math while driving) may imply external validity issues since such a scenario does not occur in real driving. Third, due to the differences in driving behaviour between males and females highlighted here and also reported in the literature, especially in terms of speed (Reed and Robbins, 2008; Li *et. al.*, 2015), gender must also be considered among the experimental factors. For this reason, balanced groups consisting of equal numbers of males and females should be adopted in the future. Fourth, the extension of this observation to other road types and environmental contexts should be the subject of future investigations. Finally, this study was conducted on a fixed-base driving simulator with drivers encouraged to perform a secondary task while driving; future studies should be conducted in a more ecological way with real vehicles running on testing tracks and with the secondary task also performed on a voluntary basis. The issue of how to directly measure crash risk should also be addressed in addition to driving performance measurements.

REFERENCES

Ahlstrom, C., Kircher, K., & Kircher, A. (2013). A Gaze-Based Driver Distraction Warning System and Its Effect on Visual Behavior. *IEEE Transactions on Intelligent Transportation Systems, 14*(2), 965-973. doi: 10.1109/TITS.2013.2247759.

Akaike, H. (1974). A new look at the statistical model identification. *IEEE transactions on automatic control*, 19(6), 716-723.

Alm, H., & Nilsson, L. (1994). Changes in driver behaviour as a function of handsfree mobile phones – A simulator study. *Accident Analysis & Prevention, 26*(4), 441-451. https://doi.org/10.1016/0001-4575(94)90035-3.

Bakhit, P. R., Guo, B., & Ishak, S. (2018). Crash and Near-Crash Risk Assessment of Distracted Driving and Engagement in Secondary Tasks: A Naturalistic Driving Study. *Transportation Research Record, 2672*(38), 245-254. https://doi.org/10.1177/0361198118772703.

503 Baldwin, C. L., Roberts, D. M., Barragan, D., Lee, J. D., Lerner, N., & Higgins, J. S. (2017). Detecting
504   and Quantifying Mind Wandering during Simulated Driving. *Frontiers in Human Neuroscience,*
505   *11*, 406. https://doi.org/10.3389/fnhum.2017.00406.
506 Bassani, M., Catani, L., Ignazzi, A.A., & Piras, M. (2018). Validation of a Fixed-Base Driving Simulator
507   to Assess Behavioural Effects of Road Geometrics. Proceedings of the 17th Driving Simulation &
508   Virtual Reality Conference, Antibes (France), 101–108.
509 Bergasa, L. M., Almería, D., Almazán, J., Yebes, J. J., & Arroyo, R. (2014). Drivesafe: An app for
510   alerting inattentive drivers and scoring driving behaviors. In *2014 IEEE Intelligent Vehicles*
511   *Symposium Proceedings*, 240-245. doi: 10.1109/IVS.2014.6856461.
512 Burdett, B. R., Charlton, S. G., & Starkey, N. J. (2016). Not all minds wander equally: The influence of
513   traits, states and road environment factors on self-reported mind wandering during everyday
514   driving. *Accident Analysis & Prevention, 95*, 1-7. https://doi.org/10.1016/j.aap.2016.06.012.
515 Catani. L., & Bassani, M. (2019). Anticipatory Distance, Curvature, and Curvature Change Rate in
516   Compound Curve Negotiation: A Comparison between Real and Simulated Driving. Proceedings
517   of the 98th Transportation Research Board Annual Meeting, Washington D.C. (US).
518 Chen, W. H., Lin, C. Y., & Doong, J. L. (2005). Effects of Interface Workload of In-Vehicle Information
519   Systems on Driving Safety. *Transportation Research Record, 1937*(1), 73-78.
520   https://doi.org/10.1177/0361198105193700111.
521 Choudhary, P., & Velaga, N. R. (2019). Effects of phone use on driving performance: A comparative
522   analysis of young and professional drivers. *Safety Science, 111*, 179-187.
523   https://doi.org/10.1016/j.ssci.2018.07.009.
524 Choudhary, P., Gupta, A., & Velaga, N. R. (2022). Perceived risk vs actual driving performance during
525   distracted driving: a comparative analysis of phone use and other secondary distractions.
526   *Transportation Research Part F: Traffic Psychology and Behaviour*, 86, 296-315.
527   https://doi.org/10.1016/j.trf.2022.03.001
528 Denjean, S., Roussarie, V., Kronland-Martinet, R., Ystad, S., & Velay, J.-L. (2012). How does interior car
529   noise alter driver's perception of motion? Multisensory integration in speed perception. *Acoustics*.
530   Acoustics, Nantes, France. https://hal.archives-ouvertes.fr/hal-00811257.
531 Dijksterhuis, C., Brookhuis, K. A., & De Waard, D. (2011). Effects of steering demand on lane keeping
532   behaviour, self-reports, and physiology. A simulator study. *Accident Analysis & Prevention*, 43(3),
533   1074-1081. https://doi.org/10.1016/j.aap.2010.12.014
534 Donmez, B., Boyle, L. N., Lee, J. D., & McGehee, D. V. (2006). Drivers' attitudes toward imperfect
535   distraction mitigation strategies. *Transportation Research Part F: Traffic Psychology and*
536   *Behaviour, 9*(6), 387-398. https://doi.org/10.1016/j.trf.2006.02.001.
537 Doudou, M., Bouabdallah, A., & Berge-Cherfaoui, V. (2020). Driver Drowsiness Measurement
538   Technologies: Current Research, Market Solutions, and Challenges. *International Journal of*
539   *Intelligent Transportation Systems Research, 18*(2), 297-319. https://doi.org/10.1007/s13177-019-
540   00199-w.
541 Dumitru, A. I., Girbacia, T., Boboc, R. G., Postelnicu, C. C., & Mogan, G. L. (2018). Effects of
542   smartphone based advanced driver assistance system on distracted driving behavior: A simulator
543   study. *Computers in Human Behavior, 83*, 1-7. https://doi.org/10.1016/j.chb.2018.01.011.
544 Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and
545   simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour,*
546   *8*(2), 97-120. https://doi.org/10.1016/j.trf.2005.04.012.
547 European Parliament & Council of the European Union (2019). Regulation (EU) 2019/2144 of the
548   European Parliament and of the Council of 27 November 2019 on type-approval requirements for
549   motor vehicles and their trailers, and systems, components and separate technical units intended for
550   such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable
551   road users. Retrieved from Official Journal of the European Union:
552   http://data.europa.eu/eli/reg/2019/2144/oj.
553 European Parliament & Council of the European Union (2021). Regulation (EU) 2021/1341 of 23 April
554   2021 supplementing Regulation (EU) 2019/2144 of the European Parliament and of the Council by

laying down detailed rules concerning the specific test procedures and technical requirements for the type-approval of motor vehicles with regard to their driver drowsiness and attention warning systems and amending Annex II to that Regulation. Retrieved from Official Journal of the European Union: http://data.europa.eu/eli/reg_del/2021/1341/oj.

European Road Safety Observatory (2018). *Driver distraction Summary 2018*. European Commission, Directorate General for Transport. Retrieved from https://ec.europa.eu/transport/road_safety/system/files/2021-07/ersosynthesis2018-driverdistraction-summary.pdf.

Gallahan, S. L., Golzar, G. F., Jain, A. P., Samay, A. E., Trerotola, T. J., Weisskopf, J. G., & Lau, N. (2013). Detecting and Mitigating Driver Distraction with Motion Capture Technology: Distracted Driving Warning System. In *2013 IEEE Systems and Information Engineering Design Symposium*, 76-81. doi: 10.1109/SIEDS.2013.6549497.

Huemer, A. K., & Vollrath, M. (2011). Driver secondary tasks in Germany: Using interviews to estimate prevalence. *Accident Analysis & Prevention, 43*(5), 1703-1712. https://doi.org/10.1016/j.aap.2011.03.029.

Kaber, D. B., Liang, Y., Zhang, Y., Rogers, M. L., & Gangakhedkar, S. (2012). Driver performance effects of simultaneous visual and cognitive distraction and adaptation behavior. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(5), 491-501. https://doi.org/10.1016/j.trf.2012.05.004.

Karimi, A., Bassani, M., Boroujerdian, A.M., & Catani, L. (2020). Investigation into passing behavior at passing zones to validate and extend the use of driving simulators in two-lane roads safety analysis. *Accident Analysis & Prevention*, *139*, 105487. https://doi.org/10.1016/j.aap.2020.105487.

Kemp, B. J. (1973). Reaction time of young and elderly subjects in relation to perceptual deprivation and signal-on versus signal-off conditions. *Developmental Psychology, 8*(2), 268-272. https://doi.org/10.1037/h0034147.

Kircher, K. (2007). *Driver distraction: A review of the literature* (Final Report VTI rapport 594A). Swedish National Road and Transport Research Institute.

Klauer, C., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data* (Final Report DOT HS 810 594). Virginia Tech Transportation Institute and National Highway Traffic Safety Administration.

Kuo, J., Lenné, M. G., Mulhall, M., Sletten, T., Anderson, C., Howard, M., Rajaratnam, S., Magee, M., & Collins, A. (2019). Continuous monitoring of visual distraction and drowsiness in shift-workers during naturalistic driving. Safety Science, 119, 112-116. https://doi.org/10.1016/j.ssci.2018.11.007.

Mase, J. M., Majid, S., Mesgarpour, M., Torres, M. T., Figueredo, G. P., & Chapman, P. (2020). Evaluating the impact of heavy goods vehicle driver monitoring and coaching to reduce risky behaviour. *Accident Analysis & Prevention*, 146, 105754. https://doi.org/10.1016/j.aap.2020.105754.

May, J. F., & Baldwin, C. L. (2009). Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. Transportation Research Part F: Traffic Psychology and Behaviour, 12(3), 218-224.

Mecheri, S., Rosey, F., & Lobjois, R. (2017). The effects of lane width, shoulder width, and road cross-sectional reallocation on drivers' behavioral adaptations. *Accident Analysis & Prevention*, 104, 65-73. https://doi.org/10.1016/j.aap.2017.04.019.

Metz, B., Schömig, N., & Krüger, H. P. (2011). Attention during visual secondary tasks in driving: Adaptation to the demands of the driving task. *Transportation Research Part F: Traffic Psychology and Behaviour, 14*(5), 369-380. https://doi.org/10.1016/j.trf.2011.04.004.

Milosevic, S. (1997). Drivers' fatigue studies. *Ergonomics, 40*(3), 381-389. https://doi.org/10.1080/001401397188215.

Ministero delle Infrastrutture e dei Trasporti (2001). *Norme Funzionali e Geometriche per la Costruzione delle Strade*, D.M. 5 novembre 2001, n. 6792, Gazzetta Ufficiale n.3 del 4-1-2002 Suppl. Ordinario n.5 D.M. 5 Novembre 2001, n. 6792.

National Highway Traffic Safety Administration (2018). Traffic Safety Facts. Research Note: Distracted Driving 2016 (Document No. DOT HS 812 517). Washington, D.C.: U.S. Department of Transportation. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812517.

National Highway Traffic Safety Administration (2019). Traffic Safety Facts. Research Note: Distracted Driving in Fatal Crashes, 2017 (Document No. DOT HS 812 700). Washington, D.C.: U.S. Department of Transportation. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812700.

National Highway Traffic Safety Administration (2020). Traffic Safety Facts. Research Note: Distracted Driving 2018 (Document No. DOT HS 812 926). Washington, D.C.: U.S. Department of Transportation. Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812926.

Nuovo Codice della Strada (1992). Decreto Legislativo 30 aprile 1992, n. 285 (Gazzetta Ufficiale n.114, 18-5-1992, Suppl. Ordinario n.74).

Onate-Vega, D., Oviedo-Trespalacios, O., & King, M. J. (2020). How drivers adapt their behaviour to changes in task complexity: the role of secondary task demands and road environment factors. *Transportation Research part F: Traffic Psychology and Behaviour*, 71, 145-156. https://doi.org/10.1016/j.trf.2020.03.015

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2017). Self-regulation of driving speed among distracted drivers: An application of driver behavioral adaptation theory. *Traffic Injury Prevention, 18*(6), 599-605. https://doi.org/10.1080/15389588.2017.1278628.

Oviedo-Trespalacios, O., Haque, M. M., King, M., & Demmel, S. (2018). Driving behaviour while self-regulating mobile phone interactions: A human-machine system approach. *Accident Analysis & Prevention, 118*, 253-262. https://doi.org/10.1016/j.aap.2018.03.020.

Oviedo-Trespalacios, O., Afghari, A. P., & Haque, M. M. (2020). A hierarchical Bayesian multivariate ordered model of distracted drivers' decision to initiate risk-compensating behaviour. *Analytic Methods in Accident Research*, 26, 100121. https://doi.org/10.1016/j.amar.2020.100121.

Papantoniou, P., Papadimitriou, E., & Yannis, G. (2017). Review of driving performance parameters critical for distracted driving research. *Transportation Research Procedia, 25*, 1796-1805. https://doi.org/10.1016/j.trpro.2017.05.148.

Papantoniou, P., Yannis, G., Antoniou, C., Papadimitriou, E., Pavlou, D., & Golias, J. (2016). Investigating the effect of area type and traffic conditions on distracted driving performance. *Transportation Research Procedia, 14*, 3839-3848. https://doi.org/10.1016/j.trpro.2016.05.469.

Philip, P., Sagaspe, P., Taillard, J., Valtat, C., Moore, N., Åkerstedt, T., ... & Bioulac, B. (2005). Fatigue, Sleepiness, and Performance in Simulated Versus Real Driving Conditions. *Sleep, 28*(12), 1511-1516. https://doi.org/10.1093/sleep/28.12.1511.

Pietrzak, R. H., Fredrickson, A., Snyder, P. J., & Maruff, P. (2010). A comparison of statistical approaches used to evaluate change in cognitive function following pharmacologic challenge: an example with lorazepam. *Human Psychopharmacology: Clinical and Experimental, 25*(4), 335-341. https://doi.org/10.1002/hup.1121.

Rakauskas, M. E., Gugerty, L. J., & Ward, N. J. (2004). Effects of naturalistic cell phone conversations on driving performance. *Journal of Safety Research, 35*(4), 453-464. https://doi.org/10.1016/j.jsr.2004.06.003.

Reed, N., & Robbins, R. (2008). *The effect of text messaging on driver behaviour: A simulator study.* Transportation Research Laboratory, Published Project Report No. 367, Berkshire, UK.

Reagan, I. J., Cicchino, J. B., Kerfoot, L. B., & Weast, R. A. (2018). Crash avoidance and driver assistance technologies – Are they used? *Transportation research part F: traffic psychology and behaviour*, 52, 176-190. https://doi.org/10.1016/j.trf.2017.11.015.

Regan, M. A., Hallett, C., & Gordon, C. P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis & Prevention, 43*(5), 1771-1781. https://doi.org/10.1016/j.aap.2011.04.008.

Reimer, B., & Mehler, B. (2011). The impact of cognitive workload on physiological arousal in young adult drivers: a field study and simulation validation. *Ergonomics, 54*(10), 932-942. https://doi.org/10.1080/00140139.2011.604431.

Rumschlag, G., Palumbo, T., Martin, A., Head, D., George, R., & Commissaris, R. L. (2015). The effects of texting on driving performance in a driving simulator: The influence of driver age. *Accident Analysis & Prevention, 74*, 145-149. https://doi.org/10.1016/j.aap.2014.10.009.

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention, 37*(2), 315-326. https://doi.org/10.1016/j.aap.2004.09.007.

Sigari, M. H., Pourshahabi, M. R., Soryani, M., & Fathy, M. (2014). A Review on Driver Face Monitoring Systems for Fatigue and Distraction Detection. *International Journal of Advanced Science and Technology, 64*, 73-100. http://dx.doi.org/10.14257/ijast.2014.64.07.

Sivak, M. (1996). The information that drivers use: is it indeed 90% visual?. *Perception, 25*(9), 1081-1089. https://doi.org/10.1068/p251081.

Slootmans, F., & Desmet, C. (2019). *Distraction. Thematic File Road Safety N°5* (2nd edition, 2019) (Research Report No. 2018-T-07-SEN). Vias institute -Knowledge Centre Road Safety.

Society of Automotive Engineers (2015). *Operational definitions of driving performance measures and statistics*. Surface Vehicle Recommended Practice J2944.

Stone, M. (1979). Comments on model selection criteria of Akaike and Schwarz. *Journal of the Royal Statistical Society*. Series B (Methodological), 276-278.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied, 9*(1), 23. https://doi.org/10.1037/1076-898X.9.1.23.

Strayer, D. L., & Drews, F. A. (2004). Profiles in Driver Distraction: Effects of Cell Phone Conversations on Younger and Older Drivers. *Human Factors, 46*(4), 640-649. https://doi.org/10.1518/hfes.46.4.640.56806.

Strayer, D. L., Turrill, J., Cooper, J. M., Coleman, J. R., Medeiros-Ward, N., & Biondi, F. (2015). Assessing Cognitive Distraction in The Automobile. *Human Factors, 57*(8), 1300-1324. https://doi.org/10.1177/0018720815575149.

Stutts, J., Feaganes, J., Reinfurt, D., Rodgman, E., Hamlett, C., Gish, K., & Staplin, L. (2005). Driver's exposure to distractions in their natural driving environment. *Accident Analysis & Prevention, 37*(6), 1093-1101. https://doi.org/10.1016/j.aap.2005.06.007.

Taylor, T., Pradhan, A. K., Divekar, G., Romoser, M., Muttart, J., Gomez, R., Pollatsek, A., & Fisher, D. L. (2013). The view from the road: The contribution of on-road glance-monitoring technologies to understanding driver behavior. *Accident Analysis & Prevention*, 58, 175-186. https://doi.org/10.1016/j.aap.2013.02.008.

The Jamovi Project (2021). Jamovi. (Version 2.3.18) [Computer Software]. Retrieved from https://www.jamovi.org.

Transportation Research Board (2016). *The Highway Capacity Manual: A Guide for Multimodal Mobility Analysis*. Transportation Research Board of the National Academies, 6th Edition.

Tivesten, E., & Dozza, M. (2014). Driving context and visual-manual phone tasks influence glance behavior in naturalistic driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 26*, 258-272. https://doi.org/10.1016/j.trf.2014.08.004.

Verster, J. C., & Roth, T. (2011). Standard operation procedures for conducting the on-the-road driving test, and measurement of the standard deviation of lateral position (SDLP). *International Journal of General Medicine, 4*, 359. doi: 10.2147/IJGM.S19639.

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 167-190. https://doi.org/10.1016/j.trf.2005.04.014.

Wang, C., Li, Z., Fu, R., Guo, Y., & Yuan, W. (2019). What is the difference in driver's lateral control ability during naturalistic distracted driving and normal driving? A case study on a real highway. *Accident Analysis & Prevention, 125*, 98-105. https://doi.org/10.1016/j.aap.2019.01.030.

709   World Medical Association (2018). *WMA Declaration of Helsinki–Ethical Principles for Medical*
710   *Research Involving Human Subjects*, 9 July 2018. Retrieved from: https://www.wma.net/what-we-
711   do/medical-ethics/declaration-of-helsinki/.
712   Young, K. L., Regan, M. A., & Lee, J. D. (2009). Measuring the effects of driver distraction: Direct
713   driving performance methods and measures. In *Driver Distraction: Theory, effects and mitigation*,
714   85-105.