A Review of the Impact of Driver Distraction on Driving Behavior and Road Safety

Armira Kontaxi[1]*, Apostolos Ziakopoulos[2], Dimitrios Tselentis[3], George Yannis[4]

[1]Department of Transportation Planning and Engineering – National Technical University of Athens, 5 Heroon Polytechniou Str., GR-15773 Athens, Greece
E-mail[1]: *corresponding author akontaxi@mail.ntua.gr,
E-mail[2]: apziak@central.ntua.gr,
E-mail[3]: dtsel@central.ntua.gr,
E-mail[4]: geyannis@central.ntua.gr

Abstract

Driver distraction is one of the most significant driving risk factors, which can frequently lead to road accidents. The objective of this research is to present an overview and critical assessment of existing studies on distraction and the consequent results on the driving behavior and safety. For this purpose, 25 scientific papers and reports have been examined on driver distraction and its results, with focus on studies published in international peer-reviewed journals and conference proceedings. Results indicate that driver distraction impacts driver attention (hands-off the wheel, eyes-off the road), driver behavior (speed, headway, lateral position, reaction time) and road accident risk. More specifically, the decrease in speed and the increase in the distance from the central axis, that is usually observed in distracted driving and might be considered beneficial for road safety, cannot always counter-balance the increased reaction times, which eventually lead to increased accident probability.

Keywords: *road safety, driver distraction, cellphone use, conversation, advertising, outside objects*

Περίληψη

Η απόσπαση της προσοχής του οδηγού είναι ένας από τους σημαντικότερους παράγοντες κινδύνου οδήγησης, ο οποίος μπορεί συχνά να οδηγήσει σε οδικά ατυχήματα. Στόχος της παρούσας έρευνας είναι να παρουσιάσει μια επισκόπηση και κριτική αξιολόγηση των υφιστάμενων μελετών σχετικά με την απόσπαση της προσοχής και τα αποτελέσματα σχετικά με την οδηγική συμπεριφορά και την ασφάλεια. Για το σκοπό αυτό, εξετάστηκαν 25 επιστημονικά άρθρα με αντικείμενο μελέτης την απόσπαση προσοχής του οδηγού και τις συνέπειές της, με έμφαση στις μελέτες που δημοσιεύθηκαν σε διεθνή επιστημονικά περιοδικά και σε συνέδρια. Τα αποτελέσματα φανερώνουν ότι η απόσπαση της προσοχής του οδηγού επηρεάζει τη συγκέντρωσή του (χέρια εκτός τιμονιού, τα μάτια εκτός δρόμου), τη συμπεριφορά του οδηγού (ταχύτητα, απόσταση από προπορευόμενο όχημα, απόσταση από δεξιά οριογραμμή, χρόνος αντίδρασης) και την πιθανότητα εμπλοκής σε οδικό ατύχημα. Ειδικότερα, η μείωση της ταχύτητας και η αύξηση της απόστασης από τον κεντρικό άξονα, τα οποία συνήθως παρατηρούνται στην οδήγηση υπό απόσπαση προσοχής και μπορεί να θεωρηθούν ευεργετικά για την οδική ασφάλεια, δεν μπορούν πάντα να αντισταθμίσουν τους αυξημένους χρόνους αντίδρασης, οι οποίοι τελικά οδηγούν σε αυξημένη πιθανότητα ατυχήματος.

Λέξεις-κλειδιά: *οδική ασφάλεια, απόσπαση της προσοχής του οδηγού, χρήση κινητού τηλεφώνου, συνομιλία, διαφημιστικές πινακίδες, εξωτερικά αντικείμενα*

1. Introduction

Driver distraction is one of the most significant driving risk factors, which can frequently lead to road crashes. During the past years, the level at which the drivers' distraction influences driving behaviour and road safety levels has been thoroughly studied worldwide. In existing research, it was presented that approximately 30% of drivers cited at least one distracting activity at the time of crashing and driver distraction was reported to have contributed to 13.6% of all crashes (McEvoy et al, 2007). Moreover, as the number and complexity of in-vehicle technologies (mobile telephones, navigation systems, sound system, other systems of assistance of driving etc.) grow it is likely that the rate of distraction-related crashes will escalate.

In Europe, it is estimated that about 10–30% of road crashes in the European Union are caused by drivers' distraction (DG MOVE, 2015). Moreover, according to the official U.S. government website for distracted driving (NHTSA, United States Department of Transportation), in 2016 alone, 3450 people were killed from distracted driving. Furthermore, 391,000 road users were injured in motor vehicle crashes involving distracted drivers in 2015. In addition, based on the findings from the Reported Road Causalities in Great Britain for 2016 (UK DfT, 2017), out of 1,445 fatal crashes that resulted in one or more deaths, the police recorded 397 incidences of the contributory factor of "failure to look" and a further 140 incidences of the contributory factors of driver in-vehicle distractions, distractions outside the vehicle, and phone use. Therefore, driver distraction constitutes a major risk factor and the investigation of its effect on the behaviour of drivers and on road safety is crucial.

The objective of this report is to present an overview and assessment of existing studies on distraction, focusing specifically on in-vehicle driver distraction. This type of distraction is defined as distraction caused by activities or objects inside the vehicle rather than those outside the vehicle, including mobile phone use, device operation, and conversation with passengers. For this purpose, 25 scientific papers and reports have been examined on driver distraction and its results, with focus on studies published in international peer-reviewed Journals and Conference Proceedings.

1.2 Definitions and types of driver distraction

Driving distraction can be defined as "a diversion of driver's attention by focusing on an object, person, task or event not related to driving, which reduces driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes" (Regan et al., 2008). In particular, it is considered that driver distraction involves a secondary task that distracts driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004).

Driver distraction and driver inattention are two separate yet related aspects of impaired driving; however, they are inconsistently defined in the literature, and the relationship between them is unclear. Driver inattention has been defined (Lee et al., 2008) as "diminished attention to activities critical for safe driving in the absence of a competing activity". Victor et al. (2008) define driver inattention as "improper selection of information, either a lack of selection or the selection of irrelevant information". Through the development of a taxonomy, an attempt was

made by Regan et al. (2011) to distinguish driver distraction from other forms of driver inattention and they concluded that "Driver Inattention means insufficient or no attention to activities critical for safe driving, and that Driver Diverted Attention (which is synonymous with 'driver distraction') is just one form of driver inattention".
There are four distinct categories of distraction defined as:

1. visual distraction (driver's eyes are either totally off the road or on the road but failing to see because another activity takes place simultaneously),
2. auditory distraction (driver's attention is disturbed by external sounds not related with the driving procedure such as conversation, telephone ringing and music),
3. physical distraction (driver has to use one or both hands to perform other activity instead of concentrating on the physical tasks that driving requires)
4. cognitive distraction (driver directs his attention away from the driving task to his own internal thoughts without being distracted by something external), mentioning though that more than one can be active at one time.

Driving distraction factors can therefore be subdivided into internal (in-vehicle) and external. Most existing research emphasizes on the in-vehicle sources of distraction, such as the use of mobile phone or a navigation / recreation system, discussing with another passenger, smoking, eating or drinking etc. (Strayer et al., 2006; Bellinger et al., 2009; Young et al., 2012; Theofilatos et al., 2018), and report useful results on their influence on both driving behaviour (e.g. in terms of driver speed and headways) and road safety (i.e. in terms of crash probability). As for external distraction sources, these may concern various visual and mental stimuli, ranging from landscape and traffic (e.g. other vehicles or pedestrians), to traffic control and road signs, incidents, destination seeking and advertising signs (Sagberg, 2001; Stutts et al., 2001; Regan et al., 2005; Terry et al., 2008). However, research results reveal that neither the drivers' behaviour (e.g., in terms of speeding) nor road safety levels are significantly affected (Horberry et al., 2006) as it is considered that external distraction factors are less than 10% of the total distraction factors (Sagberg, 2001; McEvoy et al., 2007).

The literature has examined a variety of different approaches and ways to study the effect of distraction factors on driving behaviour and road safety. The methodologies with which the effects of distracted driving are assessed vary widely. They range from driving simulator studies over test-track to field studies, and they make use of different methods and measures. Questionnaires, polls and crash analyses are also used. Moreover, there are presented two recent studies that used naturalistic driving data.

More specifically, most studies concerning driver distraction have been carried out either in simulators or under relatively controlled conditions on test tracks or, in some cases, in the field. In almost all those studies, distraction was induced in some way by the experimenter, often by letting the participant perform a secondary task. These tasks may simulate satisfactorily what drivers might do in real traffic, like use the cell phone, enter an address in the navigation system, planning a route on a map versus memorizing and adding numbers, checking for matching words or being temporarily blinded by occlusion goggles. The tasks can be visual, auditory, physical or cognitive, they can be simple or complicated, and they can require immediate attention or leave the driver some leeway in deciding when to attend to the task. The time needed to complete the task can vary considerably, and it may be easy to resume the task after an interruption. Even though these tasks can vary a lot, they are all considered to distract the driver. It is implied that the resources that the driver can use for the driving task are diminished by the additional tasks, which will lead to decreased driving performance.

2. Review of studies on in-vehicle distraction sources

2.1 Mobile phone – talking / texting

The highest perceived risk ratings are associated with the use of mobile phones, both for texting and conversation (Patel et al. 2008). Other research results, as well, suggest that mobile phone use may be the most important in-vehicle distraction source for drivers. Although drivers tend to reduce their speed during a mobile phone conversation and reduced speed is generally associated with lower crash risk, drivers using their mobile phone while driving present up to 4 times higher crash risk, most probably as a result of increased workload and delayed reaction time (McEvoy et al, 2005).

Beede & Kass (2006) conducted a driving simulator study to examine the effects of a conversation task on a hands-free cell phone and a signal detection task while driving. Thirty-six (36) students at the University of West Florida volunteered as participants and after completing a driving history questionnaire, they drove four times a simulated road with different scenarios. Driving performance was assessed in four categories: violations, driving maintenance, attention lapses, and reaction time. Results indicated that driving performance was significantly impaired when participants were talking on cell phones, while the simultaneous execution of the two tasks resulted in increase of the average speed, the number of attention lapses and reduction of speed variability, revealing the adverse effects of talking while driving.

Strayer et al. (2006) used a driving simulator in order to examine the effects of the phone type (control, handheld, and hands-free) as a within-subject factor on driving performance. Forty (40) participants with an average age of 25 years, who were recruited for the experiment, drove in a stimulated highway and were asked to follow a paced car that was intermittently braking. Conversation through a cell phone (both handheld and hands-free) for a duration of 15 minutes was used to simulate the demands of cell phone use for conversation while driving. The dependent measures consisted of the number of crashes, vehicle speed, following distance, and braking reaction time (RT). Results showed that the number of traffic crashes increased when participants were talking on the phone, irrespective of the phone type. Furthermore, braking RT was slower, and following distance was more variable in the phone conditions, than in the control condition. Regarding vehicle speed, no significant difference was not found between the control and the phone conditions though there was a slight tendency for slowing down during phone use.

A similar experimental process by Bellinger et al. (2009) was conducted on a driving simulator. Twenty-seven (27) licensed drivers between the ages of 19 and 23 participated in a simulated braking task in order to investigate the effects of cell phone conversation on the two primary subcomponents of braking response time, reaction time (RT) and movement time (MT). The results showed that the cell phone conversation slowed participants' response time compared to when it was not present. In particular, participants had slower reaction time while talking on cell phones, but increased movement time to the brake pedal as an attempt to counterbalance their attention lapse.

Gliklich et al. (2016) conducted the Distracted Driving Survey (DDS), where 1,211 United States drivers were asked to complete an 11-item validated questionnaire in order to asses common cell phone reading and writing tasks, such as writing and reading text messages and email, social media site use, and GPS use. The survey revealed that 60% of participants used their mobile phone for reading or writing purposes while driving within the period of 30 days. In particular, the most commonly reported distracted driving behaviour was reading texts (48%), followed by viewing maps (43%) and writing texts (33%). Additionally, the analysis of DDS scores in terms of demographic data and self-reported crash rate, showed that distraction while using the mobile phone is positively associated with the crash risk of the driver.

Fitch et al. (2015) conducted a naturalistic driving study with 204 participating drivers in order to examine the effects on drivers' visual behaviour of handheld and portable hands-free mobile phones. In particular, a total of 1,564 cell phone calls and 844 text messages were identified and later analyzed using total eyes-off-road time (TEORT) in order to assess the visual demands of cell phone subtasks while driving. Results showed that drivers impaired their visual attention when visual-manual cell phones subtasks occurred, dialing, browsing, locating the cell phone, browsing/reading, text messaging, ending the cell phone use. Furthermore, it was noted that drivers looked away from the road much longer when performing handheld visual-manual subtasks compared to hands-free visual-manual subtasks.

Dingus et al. (2016) evaluated driver crash risk factors using naturalistic driving data collected with multiple onboard video cameras and sensors from more than 3,500 drivers across a 3-years period. The study included only crashes during which injury or property damage occurred. In terms of analysis, mixed effect random logistics models were used. Results revealed that driver-related factors (i.e. error, impairment, fatigue, and distraction) are present in almost 90% of crashes. With respect to the cell phone use, it is noted an overall impact of handheld cell phones on crash risk. More specifically, the overall risk of interacting with a handheld cell phone was found 3.6 times higher than driving in normal conditions (namely had an odds ratio of 3.6). Thus, handheld cell phone dialing (odds ratio of 12.2), cell phone texting (odds ratio of 6.1), and cell phone reaching (odds ratio of 4.8) had the highest risks.

Caird et al. (2008) performed a meta-analysis to estimate the true effects of cell phone interaction on driver performance. A total of 33 studies contributed 94 effects size entries with a total sample size of 2000 participants. The authors used a coding procedure in terms of phone type, dependent measures, research setting, type of conversation and conversation target. In particular, the phone type was either handheld or hands-free, the dependent measures consisted of: reaction time (RT), lateral position, headway and speed, the research setting, was categorized into laboratory, simulation and on-road, conversation target, was coded as either passenger or non-passenger and finally conversation type, was coded as either an information-processing or experimental task or a naturalistic conversation. Results indicated that cell phone conversation while driving significantly increases reaction time to events and stimuli, especially in older driver groups. Furthermore, speed was elevated from the baseline for all drivers. In contrast, headway and lateral control measures were not appreciably influenced by cell phone conversation.

Backer-Grøndahl & Sagberg (2011) investigated crash risk when using handheld and hands-free mobile phones by means of data from 1997 and 2007. In particular, a sample of 4,307 drivers who were involved in crashes in 2007 and 5,007 drivers in a similar survey from 1997 were used at the study. The participants filled a questionnaire referring to: mobile phone use while driving, culpability of crash, crash type, perception of risk of mobile phone use while driving and driving exposure. In order to estimate relative risk ‘‘quasi-induced exposure” method was used with respect to multiple-vehicle crashes. Results from both studies indicate that hands-free phones impose a statistically significant increased relative risk of crash when combined with handheld phones only, and a non-significant relation when examined alone.

2.2. Conversation with passengers

Conversation and other interactions with passengers consist of a significant distraction factor that can lead to an impaired driving performance and as a result to an increased crash risk. It is considered that conversation while driving induces higher mental workload and cognitive functions and slows reaction times to events (Papantoniou et al., 2015)

McEvoy et al. (2007) evaluated the prevalence and types of distracting activities involved in serious crashes using past crash data. A total of 1,367 drivers involved in serious crashes in Perth, Western Australia were interviewed between April 2002 and July 2004. Within some hours after the crash, a questionnaire was directed to each driver and supplementary data were collected from ambulance and medical records. A set of logistic regression models were examined. Results showed that a distracting activity was reported in one-third of all crashes. In particular, conversing with passengers was found to be the most frequent distracting activity (155 drivers, 11.3%) following by lack of concentration (148 drivers, 10.8%) and outside people, objects or events (121 drivers, 8.9%).

Within the same framework, Lee & Abdel-Aty (2008) investigated the impact of passengers on the driver’s crash potential on freeways. The study used 5-year crash data that have occurred on the Interstate-4 freeway (I-4) in Florida. Several bivariate models were developed in order to relate three passenger characteristic variables such as the presence of passenger, the number of passengers and the younger driver/younger passenger combination to three crash characteristic variables such as driver citation, crash type and driver’s injury severity. Results indicated positive correlations between passenger presence and crash characteristics. More specifically, it is revealed that more passengers in the car induced a safer behaviour effect on the driver and reduced their crash potential, implying a feeling of driver responsibility. However, this positive impact of passengers varies across driver’s age, as younger drivers accompanied by only younger passengers were more likely to cause crashes.

White & Caird (2010) conducted a driving simulator study in order to examine the possibility of reliably producing the looked-but-failed-to-see (LBFTS) phenomenon, and to determine whether LBFTS errors are affected by passenger conversation and gender. In the Driving Simulator of the University of Calgary 40 young drivers encountered motorcycles and pedestrians while making left turns; drivers either drove alone or conversed with an attractive confederate passenger. After completing two different driving scenarios, participants were asked to fill out a questionnaire that measured the drivers' levels of introversion/extraversion and anxiety. Measures of looked-but-failed-to-see errors (LBFTS), hazard detection and social factors were analyzed. Results revealed that higher rates of LBFTS errors and hazard detection occurred while conversing than while driving alone, indicating that distraction from a passenger conversation interferes with appropriate hazard detection and response.

Furthermore, another driving simulator study was conducted by Papantoniou et al. (2016) aiming at the investigation of the effect of area and traffic conditions on driving performance of drivers while talking on the mobile phone or conversing with the passenger. Ninety-five (95) drivers from all different age groups (young, middle-aged and older), drove under different types of distraction (no distraction, conversation with passenger, cell phone use) in different driving scenarios. In terms of analysis, generalized linear and linear mixed models regarding average speed and reaction time were developed. Results indicated that while conversing with passengers, participants across all age groups showed increased reaction times. Additionally, young and middle-aged drivers displayed higher reaction times when interacting with passengers than when talking on a cell phone. Regarding average speed, it was found that while conversing with the passenger, drivers do not change significantly the average speed neither in different area type nor in different traffic scenarios.

Theofilatos et al. (2018) performed a meta-analysis in order to investigate the overall estimate of the proportion of crashes due to driver interaction and conversation with other passengers. A set of several studies were examined from the existing international literature in order to select the most appropriate studies for the various meta-analyses of the research. The selection of studies for the meta-analysis was based on a rigorous method including specific study selection criteria. Moreover, the authors curried out a meta-regression in order to check the study characteristic effect such as data type, examination year, or study designs (simulator, naturalistic, etc.), and therefore study variation was investigated as well. Results of the random-effects meta-analyses indicated that driver interaction with passengers causes a non-negligible proportion of road crashes, namely 3.55% of crashes regardless of the age of the passengers and 3.85% when child and teen passengers are excluded.

2.3 In-vehicle driver assistance systems and entertainment systems

In-vehicle route-guidance, navigation systems (e.g. GPS) or other information systems devices, described as in-vehicle information systems (IVIS) are designed to assist drivers but have the potential to distract them as well. Enabling drivers to benefit from IVIS without diminishing their safety has therefore become an important area of research.

Jamson & Merat (2005) examined the systematic relationship between primary and secondary task complexity for a specific task modality in a particular driving environment. A fixed-base driving simulator was used to test 48 participants on a car following task. A series of repeated measures ANOVA were carried out to assess the main effects and interactions between the factors. Results show that the participants seemed incapable of fully prioritising the primary driving task over either the visual or cognitive secondary tasks. Thus, an increase in demand from an IVIS related task was associated with impairment of driving performance: drivers performed reduced anticipation of braking requirements and shorter time-to-collision.

Additionally, Donmez et al. (2006) conducted a driving simulation study to investigate the effects of distraction mitigation strategies on drivers' performance and productivity while engaged in an in-vehicle information system task. For this purpose, 16 middle-aged and 12 older participants drove a total of six different driving scenarios as their real-time feedback was tested, through a system that alerts drivers based on their off-road eye glances when the roadway required their attention, specifically when the lead vehicle was braking or there was a curve ahead. Results revealed that distractions undermined driving performance for both age groups. Drivers compensated by slowing down when following a lead vehicle and when entering a curve as indicated by delayed accelerator releases.

Furthermore, Metz et al. (2011) examined attentional processes while performing visual secondary tasks in driving, again with the use of driving simulator. A total of 40 participants were asked to either solve an externally paced, highly demanding visual task or navigate a self-paced menu system task while driving. Results indicate that collisions go together with an inadequate distribution of attention during distraction. The results are interpreted regarding the attentional processes involved in driving with visual secondary tasks.

Xie et al. (2013) examined the effects of using in-vehicle information systems (IVIS) on drivers' glance behaviour and safety by on-road test and simulator experiment. Twelve (12) drivers, who were used to interact with IVIS while driving, were recruited for the study. In on-road test, driving task was performed with voice prompt and non-voice prompt navigation device, while secondary tasks, including cognitive, visual and manual tasks, were performed in a driving simulator. ANOVA analysis was used to analyze gaze points, fixation durations, task durations and subjective rating. Results indicated that IVIS with voice prompt causes less visual demand to drivers, thus a better glance behaviour. Moreover, it was noted that manual response task requires higher mental workload than oral response and mental workload grows as the difficulty of the task is increasing.

Regarding to entertainment systems, listening to music is a commonly used activity which aims to entertain the driver and/or passengers. It can originate from a number of sources, like a built-in vehicle radio or other portable music and sound devices that may or may not connect to the audio system of the vehicle. In the context of road safety, listening to music and the engagement with various music devices induces a level of distraction to the person driving (Stutts et al., 2001; McEvoy et al., 2007).

Hatfield & Chamberlain (2008) conducted a driving simulator study to investigate the effect of audio materials from a rear-seat audiovisual entertainment system or from radio on drivers' performance. A total of 27 participants completed drives under each of three conditions: without audio materials, with audio materials from a movie, and with audio materials from radio. The simulator was programmed to record a range of driver performance variables reflecting lateral control, speed control, and response to hazards. Additionally, participants provided self-reports of distraction and driving impairment. Results suggest a minimal impact of listening to audio materials, either from an audio-visual program or the radio, on simulated driving, perhaps because listening while driving is fairly well practiced and easily modulated, and does not involve speech production.

Furthermore, Young et al. (2012) examined the effects of performing scrollable music selection tasks using a portable music player on simulated driving performance and task-sharing strategies, measuring eye glance behaviour and secondary task performance. Thirty-seven (37) participants completed five drives; while searching for songs in short and long lists without an interruption, while searching for songs in short and long lists with a system initiated interruption and once while performing no secondary task. The driving performance results suggest that, regardless of list length, engaging in music search tasks on a touch screen interface significantly degrades performance on a range of driving measures. More specifically, it was noted increased amount of time that drivers spent with their eyes off the roadway and decreased ability to maintain a constant lane position and time headway from a lead vehicle.

Brodsky & Slor (2013) conducted an on-road study using a monitored instrumented Learners Vehicle in order to examine the effects of driver-preferred music on driver behaviour. A total of 85 young-novice drivers drove six trips in three aural-background driving conditions: driver preferred music, in-car music alternative, and no music. Results revealed that young drivers enjoy driving with music which contributes to increased positive mood states, but as well elevates the risk for distraction and aggressiveness as indicated by increases in deficient driving behaviour, perceptual error, performance miscalculation, and traffic violations. However, it is noted that music that is structurally designed to generate moderate levels of perceptual complexity improves vehicular performance leading to increased driver safety.

3. Review of studies on external distraction sources

Distraction by external sources like individuals, objects or situations outside the vehicle while driving is a common phenomenon in everyday life. It can originate from the surroundings, such as an extraordinary scenery or an unusual occurrence (e.g. a separate road crash), environmental factors, such as intense sun glare (or fog) and finally static objects designed to capture the attention of the driver, such as road and/or advertising signs that might hinder the drivers (Ziakopoulos et al., 2017). In this framework, this chapter presents studies that focus on the effects of external distraction sources.

3.1 Roadside advertising

Young et al. (2009) conducted a driving simulator study to demonstrate the effects of roadside advertising (billboards) on driver attention and performance in different road environments; urban, rural, and motorway conditions. Forty-eight (48) participants were asked to drive each of these routes with and without billboards. Performance data (time spent out of lane and number of lane excursions) and eye-movement data (number of fixations and duration of glances) were treated to a repeated measures ANOVA with two factors: adverts and road type.

The clearest finding from the results indicates that the presence of billboards adversely affects driving performance in terms of lateral control, increasing lateral variation and driver attention, increasing visual demand. Moreover, there is a tentative suggestion from the results that more crashes occur when billboards are present.

On a similar note, Edquist et al. (2011) examined the effects of billboards on drivers, including older and inexperienced drivers who may be more vulnerable to distractions. A total of 48 participants were recruited for the driving simulator study and divided equally in three age/experience groups; the novice driver group (18-25), the older driver group (above 65) and the reference group (25-65). After completing a demographic questionnaire, participants drove through the simulated scenarios which consisted of commercial and industrial environments with and without billboards. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between subjects factors of instructions and age/experience was developed in terms of analysis. Results indicated that the presence of billboards changed drivers' patterns of visual attention, increased the amount of time needed for drivers to respond to road signs, and increased the number of errors in this driving task.

Yannis et al. (2013) developed a before-and-after statistical analysis in nine different road sites within the greater Athens area, in Greece, in order to investigate the impact of advertising signs on road safety. More specifically, the authors examined the correlation between the placement or removal of advertising signs and the related occurrence of road crashes. Crash data for the 'before' and 'after' periods on the test sites and the control sites were extracted from a national database. Results of the statistical analysis showed no correlation between road crashes and advertising signs in any of the cases examined, i.e. in none of the specific sites or in total. The authors explained the outcome by the fact that, in the examined road sites, drivers are overloaded with information so that the additional information load from advertising signs may not further distract them.

3.2 Other external distraction sources

In a study by Donmez & Liu (2015), distractions outside the vehicle (i.e., paying attention to non-driving-related objects outside of the vehicle) were considered among other factors. Overall, the study investigated the associations between the severity of injuries sustained by a driver who is involved in a two-vehicle crash, the existence and type of driver distraction as well as driver's age. The authors developed an ordered logit model to predict injury severity sustained by drivers using crash past data from 2003 to 2008. With respect to distractions outside the vehicle results indicated that in comparison to in-vehicle distractions, the external factors decreased the odds of severe injuries for each of the age categories examined in the study, young, middle-aged and old drivers.

Terry et al. (2008) conducted a driving simulator study in order to assess the ability of drivers to detect the deceleration of a preceding vehicle in a simulated vehicle-following task while the size of the preceding vehicles (car, van, or truck) and following speeds (50, 70, or 100 km/h) were systematically varied. In particular, a sample of 78 participants was recruited to detect the deceleration of the preceding vehicle, once without distractions and once while a series of roadside signs were added to the simulation scenario. Results indicate that a driver's detection of a looming vehicle is compromised in the presence of a sign-related distracting task. Moreover, increases in vehicle size had the effect of decreasing drivers' braking latencies and drivers engaged in the secondary task were significantly closer to the lead vehicle when they began braking, regardless of the size of the leading vehicle.

4. Discussion

This report provides a critical review of an important part of driver distraction research, focusing on the main features and results of related international studies. An exhaustive literature review examined 25 studies with respect to the impact of driver distraction to road safety. Similar studies have been conducted by Young et al. (2007) and Ranney (2008), presenting a wide review of the literature regarding driving distraction up to that time. The existing research has concluded to several interesting and useful results regarding the effect of various distraction factors on driving performance. It is critical that, despite the different research question, method and analysis used, the results of the existing studies are consistent overall, in terms of the sign and size of the effects of the various distraction factors for several driving performance measures. An overview of the main characteristics of each study with respect to experiment type, distraction source, sample characteristics, outcome indicators and analysis method can be found on Table 1.

Table 1: Overview of driving distraction studies

Study Chacteristics		Experiment Type						Distraction Source					Sample Characteristics						Outcome Indicator										Analysis Method
													Gender			Age													
Author(s)	year	simulator	naturalistic	accident analysis	on road	questionnaire	meta-analysis	cell phone	conversation	music	IVIS	external	total	male	% male	25-	26-55	55+	speed	reaction time	lane position	headway	number of accidents	accident severity	accident probability	attention lapses	eye glance	accel./deceleration	
Beede & Kass	2006	●						●					36			●	●			●	●	●				●			Descriptive statistics | Absolute difference comparison
Strayer et al.	2006	●						●					40	25	0.63	●	●		●	●		●	●						Multivariate analysis of variance
Bellinger et al.	2009	●						●		●			27	16	0.59	●				●									Descriptive statistics | Absolute difference comparison
Gliklich et al.	2016					●		●					1211	608	0.5	●	●	●							●				Logistic regression | Cronbach's alpha
Fitch et al.	2015		●					●					204	75	0.37	●	●	●									●		Descriptive statistics | Analysis of variance
Dingus et al.	2016		●					●	●	●	●	●	3500	1559	0.45	●	●	●							●				Mixed effect random logistics model
Caird et al.	2008						●	●											●	●	●	●					●		Meta-analytic correlation analysis
Backer-Grøndahl &	2011			●				●					9314	5961	0.64	●							●						Quasi-induced exposure
McEvoy et al.	2007					●		●	●	●	●	●	1367	652	0.48	●	●	●					●						Logistic regression models
Lee & Abdel-Aty	2008			●					●				2817	1859	0.66	●	●	●					●	●					Bivariate probit model | binary logit model
White & Caird	2010	●							●				40	20	0.5	●										●			Discriminant function analysis
Papantoniou et a	2016	●						●	●				95	47	0.49	●	●	●	●	●									Generalized linear models | generalized linear mixed models
Theofilatos et al.	2018						●		●														●						Random effects meta-analysis
Jamson & Merat	2005	●									●		48				●			●									Repeated measures analyses of variance
Donmez et al.	2006	●									●		28				●	●	●			●					●	●	Mixed linear model
Metz et al.	2011	●									●		40	22	0.55		●										●		Mixed analyses of variance
Xie et al.	2013	●			●						●		12	4	0.33	●	●	●									●		Analysis of variance | Bonferroni Multiple Comparisons
Hatfield & Chamberlain	2008	●								●			27	12	0.44	●	●	●	●		●		●						Repeated-measures analyses of variance with planned contrasts
Young et al.	2012	●								●			37	17	0.46	●	●		●		●	●				●	●		Repeated-measures analyses of variance, with five levels
Brodsky & Slor	2013				●					●			85	49	0.58	●			●			●				●			Repeated measures analyses of variance
Young et al.	2009	●										●	48	29	0.6	●	●				●						●		Repeated measures analyses of variance with two factors
Edquist et al.	2011	●										●	48	30	0.63	●	●	●								●			Mixed-model analyses of variance
Yannis et al.	2013			●								●											●						Before-and-after statistical analysis at 95% confidence level
Donmez & Liu	2015			●								●	115796			●	●	●						●					Ordered logit model
Terry et al.	2008	●										●	78	43	0.55	●	●	●		●		●							Repeated-measures multivariate analysis of variance

Distraction caused by interacting with in-vehicle devices while driving seems to impair drivers on the road more than external distractions. Mobile phone use (handheld or hands-free) and complex conversation (at mobile phone or with passengers) appear to be the most critical in-vehicle distraction factors. Drivers using their mobile phone while driving present up to 4 times higher accident risk. Regarding external distraction sources, advertising signs are associated with increased driver distraction but not with crash risk. The complexity of the secondary task being performed and of the driving environment, as well as driver characteristics (age and driving experience) can all influence the potential for non-driving tasks to distract drivers.

Driver distraction may have an impact to driver attention, driver behaviour and driver accident risk. Although drivers conduct compensatory strategies, they may fail, especially when unexpected incidents occur. More specifically, the mechanism of distracted driving accident risk is such that, the decrease in speed and the increase in the distance from the central axis, that might be considered beneficial for road safety, cannot always counter-balance the increased reaction times, which eventually lead to increased accident probability, especially at unexpected events.

Furthermore, it is noted that it would be important to understand distracted driving as a chain of events, starting from a shift in attention (expressed by attention measures), resulting in differences in driving performance (expressed by several driving behaviour measures) (Papantoniou et al., 2015). These differences may concern a risky driving behaviour, or a compensatory driving behavior, resulting in outcomes associated with driving performance at demanding situations (expressed in terms of loss of control, response to incidents, or accident occurrence). Very few existing studies tackle the entire distracted driving mechanism as described above. Most studies investigate a specific part of the chain and, although their results are very useful and insightful, the synthesis of the mechanism from the available studies is very complicated. This is probably because most of the studies examined, used a driving simulator in order to collect driving performance data, resulting in specific simulated test situations and not in incidents of “true distraction”.

Consequently, the next steps of the research on driver distraction could focus on the exploitation of technological advancements in data recording systems. Overall, it is considered that naturalistic driving experiments, especially those conducted with smartphone data, are appropriate for the assessment of driving behaviour (Yannis et al., 2017a) taking into consideration that drivers drive as they normally do, without artificially imposed tasks and without driving preselected routes. Under more naturalistic conditions it is also possible to test whether a dedicated distraction countermeasure really helps or rather leads to further distraction. In this case it might be advisable to focus more on the adaptation of other warnings depending on driver state. Finally, it is highlighted that utilizing smartphones as an alternative for driving behaviour analysis, allows for the measurement of driver distraction due to mobile phone use, which is found to be one of the most critical road safety risk factors.

Acknowledgements

This research is co-financed by the European Union - European Regional Development Fund (ERDF) and Greek national funds through the Operational Program "Competitiveness, Entrepreneurship and Innovation" (EPAnEK) of the National Strategic Reference Framework (NSRF) - Research Funding Program: BeSmart - Multi-modal driver behaviour and safety support system on the basis of smartphone applications.

5. References

Backer-Grøndahl, A., & Sagberg, F. (2011). Driving and telephoning: Relative crash risk when using hand-held and hands-free mobile phones. Safety Science, 49(2), 324-330.

Beede, K., Kass, S. (2006). Engrossed in Conversations: The impact on cell phones on simulated driving performance. Accident Analysis and Prevention, 38, 415.

Bellinger, D.B., Budde, B.M., Machida, M., Richardson, G.B., Berg, W.P. (2009). The effect of cellular telephone conversation and music listening on response time in braking. Transportation Research Part F 12 (6), pp. 441-451.

Brodsky, W., & Slor, Z. (2013). Background music as a risk factor for distraction among young-novice drivers. Accident Analysis & Prevention, 59, 382-393.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. Accident Analysis & Prevention, 40(4), 1282-1293.

DG MOVE (2015) Study on good practices for reducing road safety risks caused by road user distractions – Final report. Available:

Dingus, T. A., Guo, F., Lee, S., Antin, J. F., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. Proceedings of the National Academy of Sciences, 113(10), 2636-2641.

Donmez, B., & Liu, Z. (2015). Associations of distraction involvement and age with driver injury severities. Journal of safety research, 52, 23-28.

Donmez, B., Boyle, L. N., & Lee, J. D. (2006). The impact of distraction mitigation strategies on driving performance. Human factors, 48(4), 785-804.

Edquist, J., Horberry, T., Hosking, S., & Johnston, I. (2011). Effects of advertising billboards during simulated driving. Applied ergonomics, 42(4), 619-626.

Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A. (2015). Drivers' visual behaviour when using handheld and hands-free cell phones. Journal of safety research, 54, 105-e29.

Gliklich, E., Guo, R., & Bergmark, R. W. (2016). Texting while driving: A study of 1211 US adults with the Distracted Driving Survey. Preventive medicine reports, 4, 486-489.

Hatfield, J., & Chamberlain, T. (2008). The effect of audio materials from a rear-seat audiovisual entertainment system or from radio on simulated driving. Transportation research part F: traffic psychology and behaviour, 11(1), 52-60.

Horberry, T., Anderson J., Regan, M.A., Triggs, T.J., Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accident Analysis and Prevention 38, 185-191.

https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/behaviour/distraction_study.pdf.

Jamson, A. H., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. Transportation Research Part F: Traffic Psychology and Behaviour, 8(2), 79-96.

Kass, S. J., Cole, K. S., & Stanny, C. J. (2007). Effects of distraction and experience on situation awareness and simulated driving. Transportation Research Part F: Traffic Psychology and Behaviour, 10(4), 321-329.

Lee, C., & Abdel-Aty, M. (2008). Presence of passengers: does it increase or reduce driver's crash potential? Accident Analysis & Prevention, 40(5), 1703-1712.

Lee, J.D., Young, K.L. and Regan, M.A. (2008). Defining driver distraction. In: Regan, M.A., Lee, J.D., Young, K.L. (Eds.), Driver Distraction: Theory, Effects, and Mitigation. CRC Press Taylor & Francis Group, Boca Raton, FL, USA, pp. 31–40.

McEvoy S.P. Stevenson M.R., McCartt A.T., Woodward M., Haworth C., Palamara P., Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. British Medical Journal 331

McEvoy, S.P., Stevenson, M.R., Woodward, M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. Accident Analysis and Prevention 39, 475-482

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.

Neyens, D.M., Boyle, L.N. (2008). The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. Accident Analysis and Prevention 40, 254-259

Papantoniou, P., Papadimitriou, E., & Yannis, G. (2015). Assessment of driving simulator studies on driver distraction. Advances in transportation studies, (35).

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.

Patel, J., Ball, D. J., Jones, H. (2008). Factors influencing subjective ranking of driver distractions. Accident Analysis and Prevention 40, 392-395.

Ranney, T. A. (2008). Driver distraction: A review of the current state-of-knowledge (No. HS-810 787).

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.

Regan, M. A., Young, K. L., Johnston, I. J. (2005). Monash University Accident Research Centre Submission to the Parliamentary Road Safety Committee: Inquiry into Driver Distraction. Monash University Accident Research Centre, Clayton, Victoria.

Sagberg, F. (2001). Crash risk of car drivers during mobile telephone use. Int. J. Vehicle Design 26, 57–69.

Sheridan, T. B. (2004). Driver distraction from a control theory perspective. Human factors, 46(4), 587-599.

Strayer, D. L., Drews, F. A., & Crouch, D. J. (2006). A Comparison of the Cell Phone Driver and the Drunk Driver. Human Factors, 48(2), 381–391.

Stutts, J.C., Reinfurt D.W., Staplin L., Rodgman E.A. (2001). The role of driver distraction in traffic crashes. Report Prepared for AAA Foundation for Traffic Safety. Retrieved June 10, 2003 from http://www.aaafoundation.org/pdf/distraction.pdf

Terry, H. R., Charlton, S. G., & Perrone, J. A. (2008). The role of looming and attention capture in drivers' braking responses. Accident Analysis & Prevention, 40(4), 1375-1382.

Theofilatos, A., Ziakopoulos, A., Papadimitriou, E., & Yannis, G. (2018). How many crashes are caused by driver interaction with passengers? A meta-analysis approach. Journal of safety research, 65, 11-20.

United Kingdom, Department for Transport (UK DfT). (2017). Contributory factors for reported road accidents (RAS50). Reported Road Casualties Great Britain: 2016, Department for Transport, Table RAS50001.

US Government Official Website for Distracted Driving, distraction.gov (2016). Facts and statistics.

Victor, T.W., Engstrom, J., Harbluk, J.L., 2008. Distraction assessment methods based on visual behaviour and event detection. In: Regan, M.A., Lee, J.D., Young, K.L. (Eds.), Driver Distraction: Theory, Effects, and Mitigation. CRC Press Taylor & Francis Group, Boca Raton, FL, USA, pp. 135–165.

White, C. B., & Caird, J. K. (2010). The blind date: The effects of change blindness, passenger conversation and gender on looked-but-failed-to-see (LBFTS) errors. Accident Analysis & Prevention, 42(6), 1822-1830.

Xie, C., Zhu, T., Guo, C., & Zhang, Y. (2013). Measuring IVIS impact to driver by on-road test and simulator experiment. Procedia-Social and Behavioural Sciences, 96, 1566-1577.

Yannis, G., Papadimitriou, E., Bairamis, C., Sklias, V., "Is it risky to talk, eat or smoke while driving? Findings from a driving simulator experiment", Proceedings of the 3rd International Conference on Road Safety and Simulation, Indianapolis, September 2011

Yannis, G., Papadimitriou, E., Papantoniou, P., & Voulgari, C. (2013). A statistical analysis of the impact of advertising signs on road safety. International journal of injury control and safety promotion, 20(2), 111-120.

Yannis, G., Tselentis, D. I., Vlahogianni, E. I., & Argyropoulou, A. (2017a). Monitoring distraction through smartphone naturalistic driving experiment. In: 6th International Naturalistic Driving Research Symposium, The Hague, Netherlands, 7-9 June 2017.

Young, K. L., Mitsopoulos-Rubens, E., Rudin-Brown, C. M., & Lenné, M. G. (2012). The effects of using a portable music player on simulated driving performance and task-sharing strategies. Applied ergonomics, 43(4), 738-746.

Young, K., Regan, M., & Hammer, M. (2007). Driver distraction: A review of the literature. Distracted driving, 2007, 379-405.

Young, M. S., Mahfoud, J. M., Stanton, N. A., Salmon, P. M., Jenkins, D. P., & Walker, G. H. (2009). Conflicts of interest: the implications of roadside advertising for driver attention. Transportation research part F: traffic psychology and behaviour, 12(5), 381-388.

Ziakopoulos A., Theofilatos A., Papadimitriou E., Yannis G. (2017). "Driver distraction without presence of secondary tasks: Inattention, cognitive overload and factors outside the vehicle – an overview." Road Safety and Simulation International Conference (RSS), The Hague, 17-19 October 2017.