Distracted driving and mobile phone use: Overview of impacts and countermeasures

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Abstract

Driver distraction constitutes an important factor of increased risk of road accident worldwide. While human factors in total are the basic causes in 65-95% of road accidents, recent research indicated that 30% of drivers that were involved in a road accident reported some source of distraction before the accident occurred. Furthermore, the penetration of various new technologies inside the vehicle, and the expected increase of use of such appliances in the next years, makes the further investigation of their influence on the attention of drivers, on traffic flow and on road safety very essential. The purpose of this study is to provide a comprehensive picture of the impact of driver distraction regarding mobile phone use on road safety, as well as to propose specific countermeasures. On that purpose, a review of existing studies on the effect of mobile phone while driving was carried out, followed by the presentation of recent research findings from NTUA experiments and the proposal of the respective compensatory strategies against driver distraction.

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle), some of them from communication technology appliances. More specifically, regarding mobile phone use (talking on the phone, texting, navigation, etc.), a range of studies have shown that the use of mobile phones has adverse consequences on driver's behaviour and the probability

of being involved in an accident. However, the quantification of these consequences varies considerably depending on the type of user, of the road environment, of the device interface, etc. Furthermore, results of related research in Greece (in-vehicle observations, field observations and simulator experiments) confirm that mobile phone use results in increased accident risk, especially when unexpected incidents occur. Research results suggest that mobile phone use may be the most important in-vehicle distraction source for drivers. Drivers using their mobile phone while driving present up to 4 times higher accident risk. Moreover, many studies have found that conversing on a hands-free phone while driving is no safer than using a hand-held phone while others indicated that drivers were particularly impaired when sending text messages (and somewhat less when receiving).

Measures against driver distraction may include focused enforcement of traffic rules, driver awareness campaigns, and driver training and education, especially for high-risk groups (e.g. novice drivers, frequent offenders etc.). Technology improvements towards more ergonomic design of in-vehicle devices are rapidly progressing; however the related safety effects are to be validated. Future research should focus on mobile phones use, the analysis of separate impacts from the various distraction factors, as well as the combined effect of all distraction factors, and on the link between distraction, associated driver behaviour and accident risk.

1. Background and objectives

Driver distraction constitutes a basic factor for increased risk for road accidents in Greece and internationally. The penetration of various new technologies inside the vehicle, and the expected increase of use of such appliances in the next years, makes the further investigation of their influence on the attention of drivers, on traffic flow and on road safety very essential.

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle), some of them from communication technology appliances. More specifically, regarding mobile phone use (talking on the phone, texting, navigation, etc.), a range of studies have shown that the use of mobile phones has adverse consequences on driver's behaviour and the probability of being involved in an accident. However, the quantification of these consequences varies considerably depending on the type of user, of the road environment, of the device interface, etc.

The purpose of this paper is to provide a comprehensive picture of the impact of driver distraction regarding mobile phone use on road safety, as well as to propose specific countermeasures. On that purpose, a review of existing studies on the effect of mobile phone while driving was carried out, followed by the presentation of recent research findings from NTUA experiments and the proposal of the respective compensatory strategies against driver distraction.

2. Definitions and types of driver distraction

2.1. Human factors in driver behaviour

Human factors in total are the basic causes in 65-95% of road accidents (Sabey & Taylor, 1980; Salmon et al., 2011). According to a recent approach (Petridou & Moustaki, 2000), these may include factors that reduce the driver's capability to

meet traffic contingencies, in long or short term, or factors that modulate risk taking while driving. Among these human factors, inattention and distraction are key parameters of investigation in the present research. Although distraction may be considered as a typical part of everyday driving (Stutts et al., 2001), it is reported in the international literature that driver distraction is a contributory factor of road accidents in a proportion ranging from 10-15% to 30% (MacEvoy et al., 2007; Wang et al., 1996). As shown in Table 1, a recent exhaustive research conducted in the Great Britain, in which the effect of more than 70 road accident contributory factors was examined, driver impairment or distraction factors account totally for 12% of all road accident contributory factors, while in-vehicle distraction factors account for 2/3 of the total distraction factors (Department for Transport, 2008).

Table 1. Driver distraction as road accident contributory factor (Adapted from: Department for Transport, 2008)

Road accident contributory factors*	Fatal accidents (%)	Total accidents (%)
Road environment	9	16
Vehicle defects	3	2
Injudicious action	29	25
Driver/rider error or distraction	64	68
Impairment or distraction	22	12
Alcohol	11	5
Drugs	3	1
Fatigue	3	1
Illness or disability	5	1
Mobile phone use	1	0
In-vehicle distraction	3	2
External distraction	2	1
Behaviour or inexperience	27	24
Vision affected	7	10
Pedestrian accident	19	13

** The sum of percentages may exceed 1 due to multiple contributory factors per accident*

2.2. Driver distraction and inattention

There is a lack of consensus in the literature about what is meant by the terms “driver inattention” and “driver distraction”. Definitions of these two constructs, and thinking about the relationship between the two, vary enormously.

The term distraction has been defined as "a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes" (Hedlund et al., 2005). On the other hand, very few definitions of driver inattention exist in the literature, and those that do, like driver distraction, vary in meaning. Lee et al. (2008), for example, define driver inattention as "diminished attention to activities critical for safe driving in the absence of a competing activity".

Regan et al. (2011) summarise this discussion and suggest that: "Driver Inattention" means insufficient or no attention to activities critical for safe driving and "Driver distraction" is just one form of driver inattention, with the explicit characteristic of the presence of a competing activity.

2.3. Types of driver distraction

Driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four distinct elements: (i) visual (e.g. advertising signs, landscape), (ii) acoustic (e.g. radio), (iii) motor (e.g. mobile phone use, eating or drinking), (iv) cognitive distraction (e.g. conversation with a passenger, daydreaming). These elements are often difficult to isolate.

Driver distraction factors can be generally subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Although different studies report different specific distraction factors in each category, one of the most complete and comprehensive approaches is presented in Table 2.

Driver distraction factors that occur inside the vehicle seem to have greater effect on driver behaviour and safety (Horberry et al.2006, Strayer et al., 2003; Johnson et al., 2004; Lesch & Hancock, 2004; Neyens & Boyle 2008; Bellinger et al. 2008; Yannis et al., 2010).

Table 2. Driver distractions by category (Regan et al., 2005).

Driver distraction sources	
In-vehicle	**External**
Passengers	Traffic control
Communication	Other vehicle
Entertainment systems	Seeking location / destination
Vehicle systems	Pedestrian / cyclist
Eating / drinking	Accident / incident
Smoking	Police / Ambulance / Fire brigade
Animal / insect in the vehicle	Landscape / architecture
Coughing / sneezing	Animal
Stress	Advertising signs
Daydreaming	Road signs and markings
	Sun / other vehicle lights

3. Review of mobile phone use and driver distraction

3.1. Mobile phone conversation – hand-held vs. hands-free

Research results 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 accident risk, drivers using their mobile phone while driving present up to 4 times higher accident risk, most probably as a result of increased workload and delayed reaction time (MacEvoy et al, 2005). Although the physical distraction associated with handling the phone can present a significant safety hazard, the cognitive distraction associated with being

engaged in a conversation can also have a considerable effect on driving.

Many studies have found that conversing on a hands-free phone while driving is no safer than using a hand-held phone (Matthews et al. 2003; Redelmeier & Tibshirani, 1997). Using a driving simulator, Strayer et al. (2003) found that conversing on a hands-free mobile phone while driving led to an increase in following distance from a lead vehicle and this increase was particularly pronounced under high traffic density conditions. The study also revealed that when drivers were engaged in a phone conversation using either a hand-held or hands-free phone, they demonstrated similar driving deficits. Mazzae et al. (2004) suggest drivers tend to overestimate the ease of using hands-free phones while driving.

Haigney et al. (2000) examined the effects on driving performance of engaging in a mobile phone task using hand-held and hands-free mobile phones. Thirty participants completed four simulated drives while completing a grammatical reasoning task designed to simulate a mobile phone conversation. The results revealed that mean speed and the standard deviation of acceleration decreased while participants were conversing on the mobile phone.

Rakauskas et al. (2004) used a driving simulator to determine the effect of easy and difficult cell phone conversations on driving performance, and found that cell phone use caused participants to have higher variation in accelerator pedal position, drive more slowly with more variation in speed, and report a higher level of workload regardless of conversation difficulty level.

Furthermore, Kass et al. (2007) examined the impact of cell phone conversation on situation awareness and performance of novice and experienced drivers. The performance of 25 novice drivers and 26 professional drivers was measured by the number

of driving infractions committed such as speeding, collisions, pedestrians struck, stop signs missed, and centerline and road edge crossings. The results indicated that novice drivers committed more driving infractions and were less situationally aware than their experienced counterparts during the cell phone conversation.

3.2. Type of conversation

Bryas et al. (2009) investigated whether making a conversation asynchronous (using an answer phone instead of a cell phone) reduces the negative impact of phone calls, as the communication in this occasion is under the driver's control, allowing allows him/her to pace the interaction better. The results showed better scores for correct responses to stimuli for answer phone communications than for phone communications, although response times were higher in both communication conditions than in the driving alone condition.

Complex conversation (e.g. recalling information, solving arithmetical problems, emotional conversation) is associated with more impaired driving, due to higher cognitive demands (McKnight and McKnight, 1993; Pattel et al. 2005). In naturalistic conversation experiments, however, the differences between simple and complex conversation were less striking than in simulator experiments (Rakauskas et al., 2004).

3.3. Texting

Another important risk factor concerning the use of mobile phone while driving is texting. An important distinction should be made: texting is amenable to resumption after selective disengagement, while conversation may be more difficult to interrupt and resume, once initiated. The question of whether drivers actually modulate texting engagement is not well addressed in the literature.

Results indicated that drivers were particularly impaired when sending text messages and less so when receiving (Hosking et al. 2009). When texting, participants express greater following variability, greater lateral variability, reduced response time to the lead vehicle, and increase in collision frequency (Drews et al. 2009). A recent naturalistic driving experiment suggests that the effects of texting may be significantly underestimated in previous (simulator) experiments (Cooper et al. 2011). In a recent simulator study (Yannis et.al., 2013b), text messaging was found to lead to statistically significant decrease of the mean speed and to increase of the headway in normal and in specific conditions on motorways, and simultaneously leads to an increase of accident's probability, probably due to increased reaction time of the driver in case of an incident.

Schlehofer et al. (2011) explored psychological predictors of cell phone use while driving for 69 college students who firstly completed a survey and predicted their driving performance both with and without a simultaneous phone conversation and finally drove on a driving simulator. Cell phone use was found to reduce their performance on the simulation task. Reimer et al. (2010) examined the impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD) resulting that drivers with ADHD had more difficulty on the telephone task, yet did not show an increased decrement in driving performance greater than control participants. In contrast, participants with ADHD showed a larger decline in driving performance than controls during a secondary task in a low demand setting.

3.4. Other risk factors

Mobile phone use has been found to interact with several other risk factors:

- Driving environment: Impairment due to mobile phone use may increase in more complex road environments (e.g. urban

areas, unfamiliar environment), more traffic density, adverse weather (Cooper & Zheng, 2002; Strayer et al. 2003).

- Driver age: Older people have a decreased ability to share attention between two concurrent tasks while driving.
- Driving experience: Young novice drivers may also be relatively more vulnerable to the effects of distraction than experienced drivers (Young & Regan, 2007).

Other issue affecting the effect of mobile phone use on driver behaviour and safety includes the experience in using mobile phone while driving. More specifically, repeated experience may lead to learning effects (Shinar et al. 2005).

4. Review of research results in Greece

Results of related research in Greece (in-vehicle observations, field observations and simulator experiments) confirm that mobile phone use results in increased accident risk, especially when unexpected incidents occur. These are summarized in the following sections.

4.1. Mobile phone use in Greece – Roadside observations

A recent study investigated the rate of mobile phone use among car drivers in Greece and its association with drivers' characteristics and other parameters. Data collected through an observation survey were used to highlight the explanatory factors of using a mobile phone while driving (Yannis et. al., 2013). The observation survey showed that 9% of car drivers in Greece use a hand-held mobile phone. Mobile phone use rate is increased for young car drivers (16 - 24) and inside built-up area. Powered-Two-Wheeler riders present very low mobile phone use rates, except for young females (12%).

4.2. Impacts of mobile phone use – In-vehicle and roadside observations

A field survey was carried out on 2008 in real road traffic conditions, in which drivers' speeds and headways were measured by means of in-vehicle equipment, during driving and while using or not using a mobile phone. The survey took place within a University Campus area, allowing to distinguish between settings approximating to either free flow or interrupted flow conditions. Linear and loglinear regression methods were used to investigate the effects of mobile phone use and several other young driver characteristics, such as gender, driving experience and annual distance travelled, on vehicle speeds and headways (Yannis et. al., 2010).

Results show that mobile phone use leads to a statistically significant reduction in traffic speeds of young drivers in all types of traffic conditions. Furthermore, male and female drivers reduce their speed similarly when using a mobile phone while driving. However, male drivers using their mobile phone drive at lower speeds than female drivers not using their mobile phones.

Another related field survey was carried out on 2008 in real traffic conditions, by means of roadside observations. Traffic data were recorded on a four-lane urban arterial segment by means of a video camera and a speed gun. Linear regression models were developed for the analysis of the effect of cell phone use and other variables on traffic speed and time / space headways (Yannis et. al., 2013).

It was found that vehicle's time headways were not found to be affected by cell phone use. However, headspaces, estimated as the product of vehicle speed and time headways, were found to be decreased for drivers using their cell phone, young drivers and older drivers. Overall, drivers between 25-55 years old are associated with larger space headways regardless of the use of cell phone, possibly due to a combination of adequate driving experience and skills. Furthermore, cell phone use results in lower speeds. The reduction is more pronounced when the speed

and headway difference between successive vehicles was not significant in the first place, e.g. vehicle platoons.

4.3. Impacts of mobile phone use – Simulator experiments

A series of experiments at the NTUA driving simulator (see Figure 1) was devoted to the investigation of the impact of mobile phone and other distraction sources on driver behaviour and safety.

Figure 1. The NTUA driving simulator (left panel) – Simulated driving on a mountainous road and view of unexpected incident (right panel)

The results (see Figure 2) suggest that mobile phone use leads to statistically significant overall decrease of the mean speed. However, some drivers increased their speed during the mobile phone conversation, a case which has received little attention in the literature. Mobile phone use leads to significant increase of accident probability, indicating that the speed reduction when using a mobile phone is not sufficient to counterbalance the overall increased risk, especially when an unexpected incident occurs. The odds of accident occurrence at an unexpected incident while using a mobile phone and driving were found to be almost 9 times higher compared to not using a mobile phone. It was further indicated that the combination of increase in speed, use of mobile phone and adverse weather conditions makes accident avoidance in case of an unexpected incident very difficult.

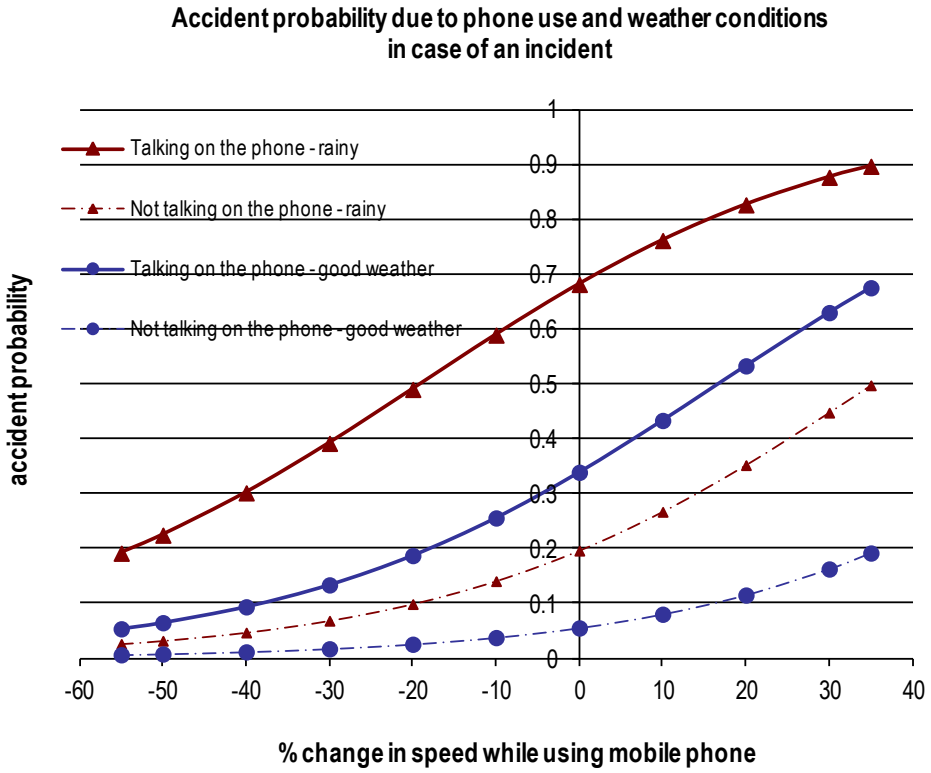

Figure 2. Accident risk in relation to mobile phone use, change of speed and weather conditions in case of an incident.

A subsequent experiment took place on 2012 (Yannis et. al., 2014a), attempting to investigate and compare the impact of mobile phone use and listening to music on driver behaviour and the probability of being involved in an accident. The participants drove in a mountainous road with and without mobile phone (handheld mode) and music. Lognormal regression models were developed for driver speed and it appeared that mobile phone use leads to a statistically significant decrease in speed, while music tends to increase it. Moreover, a 'difficult' conversation at the mobile phone leads to an increase in reaction time at unexpected events, and mobile phone use in general leads to an increase in the distance of the vehicle from the central axis of the road. Through a logistic regression analysis it appeared that the 'difficult' conversation at the mobile phone may bring about a significant increase in the accident probability, in case of an unexpected event.

A recent experiment (Yannis et. al., 2014b) examined the impact of texting on the behavior and safety of young drivers on urban and rural roads. 34 young participants drove in different driving scenarios; specifically, driving in good weather, in raining conditions, in daylight and in night. With similar analysis methods with the previous studies (i.e. lognormal and logistic regression methods) it was found that texting leads to statistically significant decrease of the mean speed and increase of the mean reaction time in urban and rural road environment. It also leads to an increased accident risk and delayed reaction at the moment of the incident. It appeared that drivers using mobile phones with a touch screen present different driving behavior with respect to their speed, however, they had an even higher probability of being involved in an accident.

5. Synthesis of mechanism of distracted driving due to mobile phone

The synthesis of both driving simulator studies and naturalistic driving studies on driver distraction confirmed that driver distraction may have an impact to driver attention (i.e. hands-off the wheel, eyes-off the road), driver behaviour (i.e. vehicle speed, headway, vehicle lateral position) and driver accident risk at unexpected incidents (i.e. reaction time).

The literature review suggests that the key elements affecting the distracted driving accident risk mechanism appear to be the following:

- Attentional demands, i.e. the amount of resources required to perform the distraction task. Secondary tasks involving some type of motor distraction (e.g. mobile phone use) impair driving behaviour to a greater extent. Moreover, the more demanding the visual or cognitive distraction (e.g. a 'difficult' conversation, a video / blinking advertising sign), the higher the impact on driver attention and behaviour.
- Exposure, i.e. how often and when drivers engage in the task. Distraction factors that can be considered as a typical part of everyday driving (e.g. listening to music, eating or drinking, a simple conversation with passengers) have a smaller effect on driver behaviour. Accordingly, the effect of the various in-vehicle devices, such as mobile phones and navigation systems, appear to have a higher effect on older drivers.
- Risk compensation: Drivers appear to adopt various strategies to compensate for distraction while driving.

More specifically, the most common compensatory strategies during distracted driving involve a decrease in speed and an increase in the distance from the central axis of the road. These types of behaviour might be considered beneficial for road safety. Overall, lower speed and higher distance from the central road axis are associated with better road safety. However, the literature review results reveal that these compensation strategies they cannot always counterbalance the driver distraction related impairment, leading to increased reaction

times, and eventually increased accident probability, especially at unexpected incidents.

This entire chain of behavioural and safety impacts of distracted driving has been identified in several studies. A distracted driving accident risk mechanism is illustrated in Figure 3.

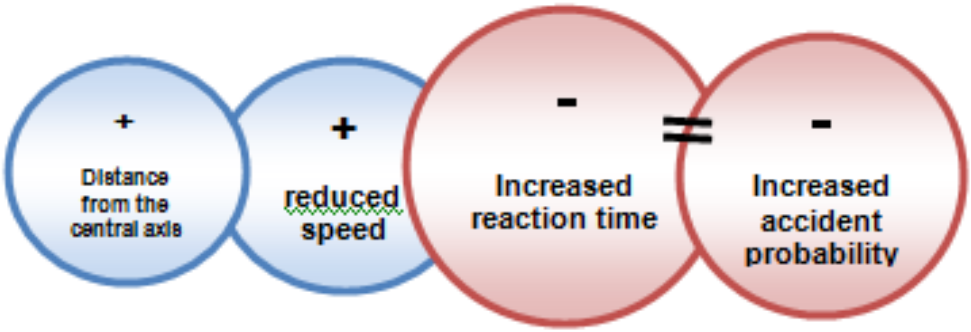

Figure 3. Distracted driving mechanism

6. Measures addressing driver distraction

Nowadays, the use of a mobile phone while driving is prohibited by road traffic regulations in most European countries (ETSC, 2010), however there are several differences in the related legislations in different countries (see Table 3).

Table 3. Legislation concerning mobile phone use in Europe (IGES Institut, ITS Leeds, ETSC (2010))

Country		AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK	CH	IS
Legislation requires	Complete ban																													
	use of hands free equipment	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Hand-held phone is prohibited if	engine is running		X				X	X			X			X	X		X											X		X
	vehicle is moving	X		X	X	X			X	X		X	X			X		X	X	X	X	X	X	X		X	X		X	
Requirement to use	headset/Blue tooth	X	X	X	X	X	X	X	X			X	X	X	X		X		X		X	X	X	X			X	X	X	X
	additionally fixed phone									X						X		X		X						X				
Hands-free required when using	phone function	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
	other function		X	X		X	X	X		X		X	X			X	X				X	X	X			X	X	X	X	
Forbidden to use	texting function				X		X			X			X			X		X	X				X			X			X	
	all functions that involve continous handling											X					X	X					X			X				
	head phones										X																			
Requirements concerning	location of mounting																													
	way of fixing									X							X													

A number of measures against driver distraction have been proposed, mostly aiming to the driver. First, through enforcement of traffic rules on the use of mobile phones. Second, driver awareness campaigns aim to inform drivers about the risk associated to mobile phone use, and the risk associated to driver distraction in general. Third, driver training and education, with particular emphasis on distracted driving, through traffic education at school, for novice drivers, for frequent offenders etc.

Technology improvements are also aiming to reduce the driver distraction from in-vehicle devices. Steering mounted buttons systems to input information, systems which rely on voice activation for input, and tactile marks on the phone key pad buttons to give each button a distinct feel, may reduce the need for drivers to look away from the road. However, negative impacts on safety of voice-activated systems have been identified, and the potential safety impact of other systems are unknown. Moreover, blocking phone calls while driving is a rapidly developing technology, but currently not supported by all phone types.

In general, more ergonomic design of the human-machine interface of in-car information systems is required to allow safe use. The current trend of miniaturisation of mobile phones may lead to safety problems.

There are no roadway countermeasures directed specifically at distracted drivers. However, many effective roadway design and operation practices that improve traffic safety in general, such as edge line and centreline rumble strips, can warn distracted drivers or can mitigate the consequences of distracted driving. In general, the creation of less demanding road and traffic conditions, through interventions on infrastructure and traffic management are expected to have a positive impact on the frequency and severity of distracted driving accidents.

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