How many crashes are caused by driver interaction with passengers? A meta-analysis approach.

Athanasios Theofilatos, Apostolos Ziakopoulos, Eleonora Papadimitriou, George Yannis

National Technical University of Athens, Department of Transportation Planning and Engineering, 5 Heroon Polytechniou st., GR-15773 Athens, Greece

ABSTRACT

Conversation and other interactions with passengers while driving induce a level of distraction to the person driving. This paper firstly conducts a qualitative literature review on the effect of passenger interaction on road safety and then extends it by using meta-analysis techniques. The literature review indicated that this distraction due to passengers is a very frequent risk factor, with detrimental effects to various driving behavior and safety measures (e.g. slower reaction times to events, increased severity of injuries in crashes), associated with non-negligible proportions of crashes. Particular issues concern the effect of passenger age (children, teenagers) on which the literature is inconclusive. Existing studies vary considerably in terms of study methods and outcome measures. Nevertheless, a meta-analysis could be carried out regarding the proportion of crashes caused by this distraction factor. The selection of studies for the meta-analysis was based on a rigorous method including specific study selection criteria. The findings of the random-effects meta-analyses which were carried out showed 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. Both meta-estimates were statistically significant, revealing the need for further research, especially considering the role of passenger age.

Keywords: Interaction, conversation, passengers, driver distraction, crash risk, meta-analysis.

1. INTRODUCTION

Driver distraction is one of the major causes of road crashes worldwide. As “distracted driving” is characterized any activity that could divert a person's attention from the task of driving, including the vehicle, traffic and the road environment in general. Such distracting activities include passenger interaction, cell phone or smartphone use, food and drink consumption, usage of in-vehicle devices and information systems etc.

According to the official US government website for distracted driving (US Official Website for Distracted Driving, 2016) in 2014, 3,179 people were killed and 431,000 were injured in motor vehicle crashes involving distracted drivers in the U.S. Regarding Europe, it is estimated that about 10-30% of road crashes in the European Union are caused due to road users’ distraction (DG MOVE, 2015). Moreover, police assessments of road crash statistics in Austria state that approximately 35% of all injury road crashes were due to inattention or distraction, while the respective percentage of fatal road crashes are 12% (Austrian Road Safety Fund, 2012; DG MOVE, 2015). It is also important that based on the findings from the ESRA survey (Trigoso et al., 2016), 61% of the participants reported that distracted drivers have increased in the past two years, being considered the behavior that has increased the most, ahead of aggressive drivers (49%) and speeding drivers (45%). Therefore, driver distraction seems to constitute a major concern to societies that requires attention.

Interaction with passengers in particular is an important and frequent in-vehicle distraction activity. This interaction induces extra amounts of mental workload and cognitive functions that drivers have to undertake, and reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it), as stated in the literature (Papantoniou et al., 2015, Stutts, 2001). Similarly to other distractions, passenger interaction can result in acceleration, speed and position variations, and lane changes which are proven causes of road crashes (Aarts and Van Schagen, 2006). For that reason, several studies have tried to investigate possible correlations between interaction with passengers and severe crashes (Lam, 2002; Neyens and Boyle, 2008).

The main objective of this study is to carry out an exhaustive literature review and a meta-analysis of existing findings, in order to find the overall estimate of the proportion of crashes due to driver interaction and conversation with other passengers. A meta-analysis can help combine and summarize results from several other studies, if these results are produced under comparable conditions. In the field of road safety, meta-analyses are often carried out to summarize the effects of risk factors (Elvik 1994, 2001, 2005, 2011, 2013, 2016; Elvik R. and Mysen, 1999; Elvik and Bjørnskau 2017; Phillips et al. 2011). A few meta-analyses also exist in particular in the field of distraction and safety (Caird et al., 2008, 2014; Elvik 2011). In this paper the meta-analysis is supplemented with a qualitative review and discussion of a number of key studies in the field of driver distraction due to interaction and conversation with other passengers.

The rest of the paper is organized as follows: first the data and methods are presented, where the procedure and the criteria for searching and selecting studies are included. An illustration of the meta-analysis methods is also provided. A qualitative review of the key studies in the field, as well as the meta-analysis results are illustrated afterwards. Finally, the concluding remarks as well as suggestions for further research are demonstrated in the last section of the paper.

2. METHODS AND DATA

2.1 Study Selection Criteria

This paper aims to proceed beyond a typical literature review and endeavors to provide meta-estimates of the effects of the examined risk factor. For that purpose, a dedicated set of study selection criteria were applied, with focus on high quality studies and quantitative effects, as developed within the research project SafetyCube (Martensen et al., 2016):

- Existing meta-analyses were desirable.
- Studies with quantitative findings and statistical models reporting standard errors were highly sought after.
- The number or severity of crashes were preferred over other indirect outcomes indicators (e.g. speed measurements).
- Recent and high quality studies reporting estimates of the examined effects were prioritized. More specifically, only recent papers (after 1990) in the fields of Engineering and Psychology were initially considered.
- Journal papers were preferred over conference papers. However, highly informative conference papers and reports were included when necessary.
- No "grey" literature (such as government reports, newsletters, lecture notes, presentations etc.) was examined.[1]

The databases searched were Scopus and TRID. The search terms used for the topic were "passenger presence" AND "distraction" OR "interaction". The references list of each study was also assessed to find relevant studies that may have not be found during the initial searching. A

[1]It was decided that some high quality technical reports were include to improve source variety and increase the scope of our research.

title and abstract screening was first implemented to identify the relevant studies. A full text screening was then carried out (171 articles in total) to identify the final list of studies meeting the selection criteria for the topics of this research.

2.2 Fixed and Random Effects Meta-Analysis

A meta-analysis is a statistical analysis of set of numerical research results of studies aiming to develop a weighted overall mean result and identify sources of systematic variation in individual results. More details on the theoretical background can be found in more detail in several papers (Elvik and Bjornskau 2017; Hedges and Olkin 1985; Berkey et al., 1995; Van Houwelingen et al., 2002; Viechtbauer, 2016). The reader is encouraged also to refer to Elvik (2005), who provides an introductory overview of carrying out meta-analyses and to Elvik (2011) who illustrates issues arising when studies are few and subpar when performing a meta-analysis.

The results of meta-analyses are normally reported in terms of one or more summary estimates of effect, i.e. weighted mean estimates using the inverse of sampling variance as weight. The summary estimate of risk or effect based on g individual estimates is:

$$\text{Summary mean} = \bar{Y} = \frac{\sum_{i=1}^{g} Y_i \cdot W_i}{\sum_{i=1}^{g} W_i}, \quad (1)$$

Where $\bar{Y}$ is the estimate of the weighted summary mean, based on g individual estimates, each of which is assigned a statistical weight:

$$\text{Statistical weight} = W = \frac{1}{SE_i^2} \quad (2)$$

One traditional approach is to use a fixed effects meta-analysis. However, variability (or heterogeneity) can be present among true effects. In such cases, one solution is to apply a random effect model to account for potential heterogeneity.

In fixed effects meta-analyses, if i=1,…,n independent effect size estimates, each is estimating a corresponding true effect size.

$$y_i = \theta_i + \varepsilon_i, \tag{3}$$

where yi is the observed effect in the i-th study, θi is the corresponding (unknown) true effect, εi is the sampling error (εi~N(0,vi)). As a result, all the yi's are assumed to be unbiased and normally distributed estimates of their corresponding true effects. Note that the sampling variances vi are assumed to be known. However, variability (or heterogeneity) can be present among true effects. A random effects model is used to account for potential heterogeneity. In this case, the true effect θi is:

$$\theta_i = \mu + u_i, \tag{4}$$

Where u_i follows a normal distribution with mean value μ and variance τ^2. If τ^2 equals zero, then the true effects are assumed to be homogenous (i.e. θ1=θ2=…θn=0).

To determine whether there is systematic between-study variation in results, the Q following statistical test is performed. Q is defined as:

$$Q = \sum_{i=1}^{g} W_i \cdot Y_i^2 - \frac{\left(\sum_{i=1}^{g} W_i \cdot Y_i\right)^2}{\sum_{i=1}^{g} W_i} \tag{5}$$

Where Q is an estimate of variance, chi-square distributed with g – 1 degrees of freedom. If the value of Q is statistically significant, the variance between studies is larger than would be expected on the basis of the within-study variation.

Another core part of a meta-analysis is a funnel plot which is a tool used to visualize results of exploratory meta-analyses. Funnel plots are also helpful to detect potential publication bias, i.e. a tendency of not publishing findings which are not statistically significant or go against a-priori expectations of researchers (Elvik and Bjørnskau, 2017). Therefore, if studies with non-significant or small effects remain unpublished, an asymmetric funnel plot will be generated (Sterne et al. 2001; Rothstein et al., 2005).

In this study it was tested and then corrected if needed, for publication bias. Firstly, potential asymmetry in funnel plots was detected by testing whether the effects are related with their standard errors. This can be tested via the regression test proposed by Egger et al. (1997). Secondly, the trim-and-fill method was applied if necessary (Duval and Tweedie, 2000a and 2000b), which is non-parametric and can estimate the number of studies missing from a meta-analysis in case of asymmetric funnel plot.

3. LITERATURE REVIEW ON DISTRACTION DUE TO PASSENGERS

3.1 Overview of study methods and outcome measures

The risk factor under consideration is present when a driver is engaged in a form of interaction with other passengers. In the context of road safety, this can imply discussion, a small talk or a heated argument, or even physical interaction with passengers, such as gesturing, handing over objects, a fight or other physical contact.

The literature review carried out in the present study identified numerous outcome measures for the relationship between the interaction with passengers and driver behaviour or safety. As a variable, passenger interaction is usually of binary nature (e.g. presence of passengers or not, interacting with passengers or not). In several studies, the main focus is on reporting the absolute number or the percentage (absolute proportion) of crashes or near misses caused by various distractions, including interaction with passengers; these outcomes are of primary interest in the present research. Other studies investigate the effect of interaction with passengers on driving performance measures such as speed, reaction time to incidents, violation types etc. The literature review carried out covered all reported outcomes and particular issues, in order to have an overall picture on the examined risk factor. However, the meta-analysis focuses on the proportion of crashes due to interaction with passengers.

Given the fact that it is not recommended to conduct driver distraction experiments on real circumstances (field experiments on the road) because it would induce risks for the participants, researchers have a number of alternative methods. These involve firstly examining databases of past crashes and analyzing the effect of interaction with passengers (which sometimes leads to lack of data, especially regarding specific characteristics such as children presence or even underreporting), and secondly conducting experimental studies, i.e. laboratory or simulation experiments which are in a virtual environment where no hazard is present or naturalistic driving studies which involve installing instruments and monitoring real driving conditions over a period of time. Furthermore, there are studies involving the examination of naturalistic driving, which involve monitoring instrumented vehicles and analyzing driving behaviour. Moreover, this is the only type of studies that allows for exposure corrections and thus allows for risk metrics. Lastly, some researchers opt to interview drivers and other persons involved in road crashes to ascertain the circumstances under which the crash occurred (this always entails a chance of false reports of data via non-disclosure of information or subpar perception or memory).

The methodologies applied for capturing the impacts of driver interaction with passengers vary considerably among studies, mainly in regards to the mathematical models utilized, and secondly the outcomes evaluated as dependent variables (Papantoniou et al. 2015). More specifically, studies relying on past crash data used straightforward methods, such as raw absolute proportion (percentage) of crashes caused by driver interaction with passengers, or percentage of drivers engaged in this distraction activity. On the other hand, studies focusing on injury severity utilized statistical models such as the ordered logit model.

Sometimes this particular risk factor is examined alongside other similar distraction factors such as handheld cell phone use, texting, consumption of goods, and not solely by itself. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case. Consequently, the study designs might not always be completely tailored towards capturing the effect of interaction with passengers. There are studies that are focused exclusively on this risk factor, however.

Finally, there are studies focusing on particular issues related to driver-passenger interaction, such as children passengers and behavioral compensation effects through conversation modulation.

3.2 Studies based on crash records

The literature indicates that driver interaction with passengers has a generally negative effect on road safety. In general, studies utilizing past crash data argued that a non-negligible percentage of crashes are caused due to interaction with passengers. A first examination of studies using past crash data and examining the crash causes (Lansdown, 2012; McEvoy et al., 2007; Wang et al., 1996) shows that a consistent number of crashes and near-misses happen due to interaction with passengers.

As an indication, Neyens and Boyle (2007) have studied the effects that various types of distraction impose in the types of crashes suffered by teenage drivers, using a stratified sample of crashes that is weighted to represent USA crash trends. Passenger-related distractions, alongside distractions involving inattention and other cognitive functions, were found to increase the likelihood of appearance of rear-end crashes. The authors do mention that their distraction sample could be larger, but nevertheless these results have novelty value.

Furthermore, a couple of studies investigated the effect of driver interaction with passengers and found that more severe crashes tend to occur under these conditions. Donmez and Liu (2015) considered different age groups (e.g. young, middle, old), whilst Neyens and Boyle (2008) considered only teenage drivers (16-19 years old) involved in crashes only with passenger vehicles. Both studies used real crash data records and developed ordered logit models for crash injury severity. Both studies report that this distraction activity is associated with more severe injuries regardless of the age group when distracted by a cell phone or by passengers, than if the source of distraction was related to in-vehicle devices or if the driver was inattentive. Donmez and Liu (2015) mention that "A partial explanation for this effect might be that when distractions are outside of the vehicle, the visual attention is still likely on the road"; consequently, response to crash occurrence (e.g. braking, maneuvering) may be more efficient and result in less severe crash outcomes.

Similarly, a study by Aldridge et al. (1999) utilized the quasi-induced exposure method and concluded that the presence of passengers affected the tendencies of causing crashes by young drivers (between 16 and 20 years old). A large database of 77,312 crashes of the Kentucky area was analyzed with the use of at-fault to not-at-fault ratios for drivers. The young driver age group displayed the lowest tendency to single or two-vehicle crashes when accompanied by adults and/or children, while the tendency is increased when traveling with their peers.

A report compiled by Stutts et al. (2001) examined various distraction categories, which included passenger interaction. The report was based on data from a five year period (1995-1999), obtained from the U.S. Crashworthiness Data System. It was concluded that this activity was one of the most frequent sources of distraction related crashes, alongside adjusting music device controls and events outside of the vehicle. It was mentioned, however, that the exposure differences of said categories was not represented in the dataset.

On a similar note, Stevens and Minton (2001) explored the intricacies of coding a distraction related database for research purposes. The correlation of in-vehicle distraction and vehicle collisions was one of the key targets, and the authors report that the most frequent form of distraction inside the vehicle was found to be the interaction with passengers, followed by others. An important point that is mentioned is that the presence of passengers, unlike other distractions, induces a constant exposure for the entirety of the time they are there.

Another critical study is that of Lee and Abdel-Aty (2008), which investigated the impact of passengers on the driver's crash potential on freeways. Several bivariate models were developed for 5 year crash data, which depicted positive correlations between passenger presence and crash characteristics. An interesting finding was 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, with the exception of the combination of young drivers with young passengers.

An observational study of Sullman (2012) examined six UK urban centers. More specifically, this study carried out observations that took place on randomly selected roads at three different time periods during two consecutive Tuesdays. The study found that that 14.4% of the 7,168 drivers observed were found to be engaged in a distracting activity. Conversation with passengers was the most common distraction activity.

Fu et al. (2013), utilized data from the USA which has been derived from the National Automotive Sampling System (NASS) General Estimates System (GES) from the year 2011. Authors have applied a multinomial logit model in order to compare violation types (traffic sign and signals violations vs. turning-yielding-signaling violation vs. speeding related violations) for reported crashes. It was found that the most common violations due to interaction with passengers were the speeding related violations.

3.3 Experimental studies

There are several simulator studies, where controlled environments allow for safe driving and detailed recording and examination of data. Various dependent variables are examined such as driver speed, reaction time, lateral position, virtual crashes or other errors and events which are significantly affected when the driver is engaged in discussion with passenger. These driving performance measures are not directly related to the main variable of interest in this research, which is the proportion of crashes due to interaction with passengers, and therefore the review of studies mentioned below is not exhaustive.

As an example, Consiglio (2003) carried out an experiment in a laboratory station which simulated the foot activity in driving. 22 research participants were requested to release the accelerator pedal and depress the brake pedal following the activation of a red brake light. Results suggested that conversation with passengers increased the reaction time in breaking response (releasing throttle and pressing brake).

In another study, Laberge et al. (2004) focused on investigating the differences between cellphone and passenger conversations. It was established that heightened traffic demands affected reaction times to pedestrian conflicts, as well as lane and speed maintenance.

Another simulator study by Papantoniou et al. (2016) observed that while conversing with passengers, participants across all age groups showed increased reaction times. Furthermore, young and middle aged drivers displayed higher reaction times when interacting with passengers than when talking on a cell phone. Behavioural adaptation effects have been observed in the study as well, especially in urban areas as opposed to rural areas.

Several other simulator studies investigate conversation with passengers, by itself or compared to other factors e.g. Charlton 2009; Drews et al. 2008; Yannis et al. 2011. For an exhaustive review of these studies the reader is referred to Papantoniou et al. 2015.

There have also been some naturalistic driving experiments, such as the one conducted by Klauer et al. (2006). The study involved calculating crash risk odds ratios using both crash and near-crash data as well as normal baseline driving data for various sources of inattention. The presence of passengers in adjacent or seats displayed low odds ratios (0.50 and 0.39 respectively), indicating that it was safer to drive accompanied by passengers than alone; the authors pose the additional road scanning capabilities provided by passengers as a possible explanation.

Dingus et al. (2015) further expanded on naturalistic driving experiments, creating a massive real-world driving video and sensor database to be analyzed and used by following studies. Dingus et al. (2016) capitalized on this data to analyze a number of distractions. Interaction with adult or teen passengers was found to have increased odds ratios, namely a crash risk 40% higher than model driving. The authors acknowledge the difference with findings of studies such that of Klauer et al. (2006), and cite methodological differences as possible reasons. In general, the binary approach mentioned above is the most common method, which categorizes drivers as exposed or not exposed to the risk factor that is interaction with passengers.

3.4 Particular issues

3.4.1. Age group differences

Apart from the perspective of study design particulars, age differences of drivers are of interest. Adult drivers with adult passengers can be very different than teen drivers with teen passengers, and there are so many possible combinations, all with different dynamics. From the aforementioned studies, the findings of Donmez and Liu (2015) indicate that interaction with passengers affect driver injury severities adversely for young and middle-age drivers, while results were not significant for older drivers. Furthermore, Neyens and Boyle (2008) report that teenage drivers that were distracted at an intersection by passengers were more likely to be involved in certain crash types over others. There seems to be more room for research in this specific research area, as more configurations of age differences have not yet been explored. However, there have been significant findings based on the presence of child passengers in the vehicles, as shown in the following section.

3.4.2. Children

The behavior of children in the context of road safety (especially in small ages) is commonly accepted as unpredictable as and less perceptive than that of adults. A review from the United Kingdom reported that while the majority of children and accompanying parents respected the restraining equipment, there were instances where the cars were overcrowded. There were also cases of very young children being carried on the laps of front-and rear-seat passengers (Green et al., 2008). Apart from the safety equipment inefficiency and induced risks, this might imply a lot of interaction and activity with the driver.

Furthermore, Lansdown (2012) mentions that interaction with child passengers ranked first amongst the most frequently reported distracting behaviours that resulted in crashes in his study sample (a proportion of 2.1%), and amongst the three most reported distracting behaviors in general. Another relevant study by Beanland et al. (2013) included driven distraction from children in the category of voluntary distractions, namely those that could have been preventable by the drivers. In this case, this was considered due to the physical posture of the driver who was turned towards the back seat, although it should be mentioned that this category included a singular case only.

It has been observed in an older study that a well-behaved child, by being less of a distraction to the driver, will decrease the probability of a crash occurring. Data analyzed from North Carolina crash files indicated that from 1974 through 1978 there were nearly 750 collisions in which unrestrained children were either the direct or contributing cause of the collision (Eriksen and Gielen, 1983).

There have been indications of counterintuitive effects for the presence of children, however, as reported in the aforementioned study of Aldridge et al. (1999), which indicates that their presence compelled young drivers to behave more cautiously. Moreover, in a study focused especially on this particular issue, the authors reported mixed results (Koppel et al. 2011). While most journeys (98%) involved a certain kind of distraction, and children were a sizeable source (12%), it was found that drivers were significantly more likely to engage in potentially distracting activities that were not child occupant-related. Interestingly, although front seat passengers were only present for 36% of trips, their presence distracted drivers almost as frequent as the children (9% and 12%, respectively), and passenger related distraction was for significantly longer amount of time.

3.4.3. Modulation of conversation

Drivers may modulate interaction with passengers, because a conversation at the physical presence of passengers is amenable to resumption after selective disengagement, while for example mobile phone conversation may be more difficult to interrupt and resume, once initiated.

A study conducted by Drews et al. (2008) explored such differences. It was found that the circumstances of driving reduce driver efficiency to respond and hold a complex conversation, as traffic demands more attention, in contrast to a cellphone conversation where the other party is absent. Contrary to the findings of Laberge et al. (2004), it is suggested that by sharing the perception and the circumstances of the driver, passengers adjust to more light conversation statuses and the overall interaction effects are somewhat mitigated.

This was also the focus of a simulator study conducted by Charlton (2009). The main concern was the identification and detection of the phenomenon of conversation suppression, which describe the tendency of passengers to halt conversation when a road hazard appeared, and to offer warning comments to the drivers. It was asserted that passenger conversations are different than the more hazardous mobile phone conversations, and that this applied to some degree to remote passengers as well.

3.5 Study selection for meta-analysis

A number of key findings of the effect of interaction with passengers identified can be summarized on the basis of the literature. Interaction with passengers is one of the most frequent distracting activities undertaken by drivers and a non-negligible number of crashes were caused by interaction with passengers. Significant increase on injury severity is associated to interaction with passengers. Moreover, significant prevalence of specific violation types is involved, and significant increase on reaction times is often reported. The effect of passenger age (including children and teenagers) is inconclusive, and the extent to which behavioral adaptation through the modulation of conversation or interaction with passengers has not been validated.

After the results were reviewed together, the following points were observed as regards the feasibility for meta-analysis: There is an adequate number of studies, however those studies have not used the same analysis methods but largely different ones, there are usually different outcome indicators and the sampling frames were quite different. Consequently, the implementation of a global meta-analysis of existing studies would not be feasible.

After reviewing the literature, it was found that it was feasible to carry out a meta-analysis on the proportion of crashes that involve distraction by passengers. The reasons for the meta-analysis decision are:

a) a minimum required number of effects is achieved;

b) sampling frames for the selected studies to be included in the meta-analysis were similar;

c) outcome indicators of studies in each meta-analysis were the same (absolute proportion of crashes due to this distraction activity, including the exact numbers leading to the particular proportion).

Viechtbauer (2010) proposes the raw proportion, the logit transformed proportion and other configurations as useful outcome measures. The studies provided data to specify the values of xi and ni, which denote the number of crashes involving passenger distraction and the total number of crashes respectively. Therefore, the absolute raw proportion was used which was calculated as xi/ni. It is worth noting that if a study reports only the proportion or percentage, it cannot be considered for the meta-analysis, due to the fact that both the numerator and the denominator, namely xi and ni are required.

It was eventually decided to carry out 2 separate meta-analyses in order to find the overall estimate of the effect of interaction with passengers on road safety. More specifically, it was attempted to investigate the overall estimate of the absolute proportion of crashes due to interaction with passengers when a) all passengers are included and b) without the studies indicating teen or child passengers.

An overview of the main features of the considered studies (sample, method, outcome and results) is illustrated on Table 1. As demonstrated in the previous, several papers have been examined from the existing international literature in order to select the most appropriate studies for the various meta-analyses of this paper. While the list is not exhaustive, an effort has been made to apply rigorous study selection criteria and locate critical studies for the topic of passenger interaction.

No	Author(s); Year; Country;	Sampling frame	Method*	Outcome indicator considered	Main Result
1	Charlton, S. G.; 2009; New Zealand	This is a simulator study investigating distraction. It conducted one relevant experiment, in several conversation drive conditions, using a sample of 119 participants.	Absolute proportion	Number of Crashes	Driving while talking on a cell phone is more hazardous from driving while talking to a passenger.
2	Lansdown; 2012; United Kingdom	Survey data were collected using an anonymous online questionnaire. 482 respondents contributed to the survey during a 2 month data collection period.	Absolute proportion	Number of Crashes	Results suggest drivers are conducting highly distracting, and in many cases illegal tasks (in the UK) while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.
3	McEvoy et al.; 2007; Australia	Between April 2002 and July 2004, 1367 drivers involved in serious crashes in Perth, Western Australia were interviewed after a crash using questionnaires, and supplementary data were collected from ambulance and medical records.	Absolute proportion	Number of Crashes	Distracting activities at the time of serious crashes are common and can cause crashes.
4	Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M.; 2005; USA	Data obtained from the 100-Car Naturalistic Driving Study database, including 2,000,000 vehicle miles	Absolute proportion	Number of Crashes	Passenger-related tasks were not a major cause of crashes, but were represented nonetheless.
5	Neyens, D. M., & Boyle, L. N.; 2007; USA	Data from the US General Estimates System from the year 2003 were used for the analysis	Absolute proportion	Number of Crashes	Passenger-related distractions appeared more commonly than cell phone ones, and for teen drivers increased the likelihood of rear-end collisions.

No	Author(s); Year; Country;	Sampling frame	Method*	Outcome indicator considered	Main Result
6	Stevens and Minton; 2001; England-Wales**	Analysis of crashes over the period 1985–1995 in England and Wales.	Absolute proportion	Number of Fatal Crashes	Interaction with passengers is reported as a contributory factor in about 26 out of 5740 fatal crashes.
7	Stutts, J. C., Reinfurt, D. W., Staplin, L., & Rodgman, E. A.; 2001; USA	The Crashworthiness Data System (CDS) was employed to obtain more in-depth information on driver distraction related crash causes, including various distractions. 1995-1999 CDS data were used.	Absolute proportion	Number of Crashes	Percentages show that driver interaction is an important factor on distraction crashes.
8	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	CDS data was employed to obtain more in-depth information on driver distraction related crash causes, including various distractions.	Absolute proportion	Number of Crashes	Judging by the percentages, passenger distraction is a major factor on relevant distraction crashes.

Table 1: Description of studies considered the meta-analyses.

*: In some cases more than one analysis was applied or the absolute proportion was only the preliminary part of the analysis. Moreover, a study could report data from other sources (e.g. official statistics).
**: Excluded from the analysis because only fatal crashes were considered.

4. RESULTS

4.1 Meta-analysis on the interaction with all passengers

The studies considered were the following:

1) Charlton, 2009 (1 estimate)

2) Lansdown, 2012 (2 estimates)

3) McEvoy et al., 2007 (1 estimate)

4) Neale et al., 2005 (1 estimate)

5) Neyens and Boyle, 2007 (1 estimate)

6) Stutts et al., 2001 (1 estimate)

7) Wang et al., 1996 (1 estimate)

In this meta-analysis the overall estimate of the raw proportion of crashes due to interaction with all passengers was investigated. To do so, the number of crashes due to interaction with adult passengers (xi) as well the total number of crashes (ni) had to be defined for each study. Then, the estimate (y) and the variance vi of raw proportion (xi/ni) was estimated for each study following Viechtbauer (2010). Results of the random-effects meta-analysis indicate that the overall estimate of the effect of interaction with adult passengers on absolute proportion of crashes is 0.05, and the 95% confidence intervals are 0.0121, and 0.0879 respectively, as shown on Table 2 and Figure 1. The p-value (0.0097) indicates a significant effect at 95% level.

Variable	**Unit**	**Estimate**	**Std. Error**	**p-value**	**95% CI**
Interaction with adult or teen passengers	Absolute proportion of crashes	0.0355	0.0158	0.0251	(0.0044, 0.0665)

Table 2: Summary of meta-analysis estimates of interaction with passengers (all) on absolute proportion of crashes.

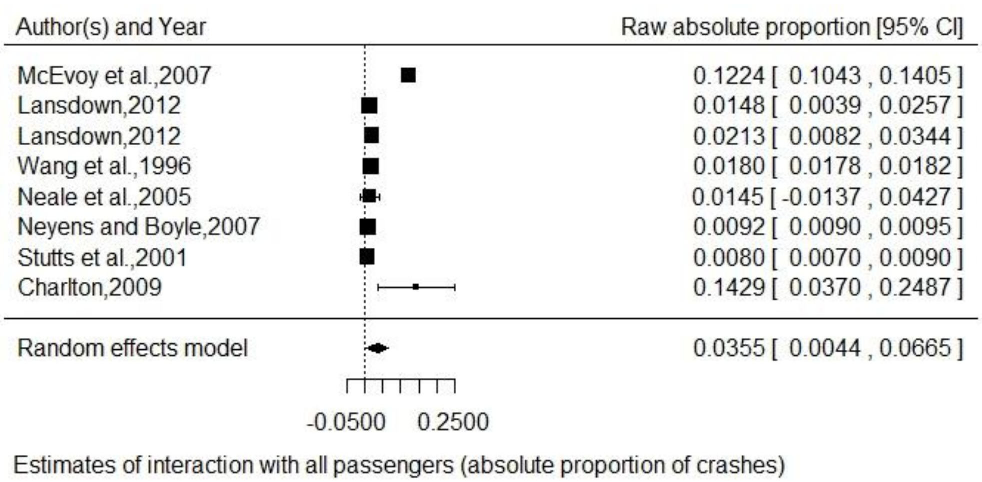

Figure 1: Forest plot for absolute proportion of total crashes that happen due to interaction with adult and teen passengers while driving. Figure1 illustrates the forest plot for absolute proportion of total crashes that happen due to interaction with adult passengers while driving.

The Q test is significant ($Q_{[df=7]}$ = 3127.7663, p-value < 0.0001) suggesting considerable heterogeneity among the true effects. Therefore, the random effects meta-analysis that was carried out is preferred and there is no need to perform a fixed effects meta-analysis. A funnel plot was firstly produced in order to detect potential publication bias (see Figure 2). The regression test for funnel plot asymmetry was not significant at 95% level (p-value = 0.7854), suggesting no evidence for publication bias. This is something expected, since the majority of studies utilized crash data from official sources and therefore “unexpected or insignificant” results could not remain unpublished. There is therefore no need for correcting the estimates with the trim-and-fill method.

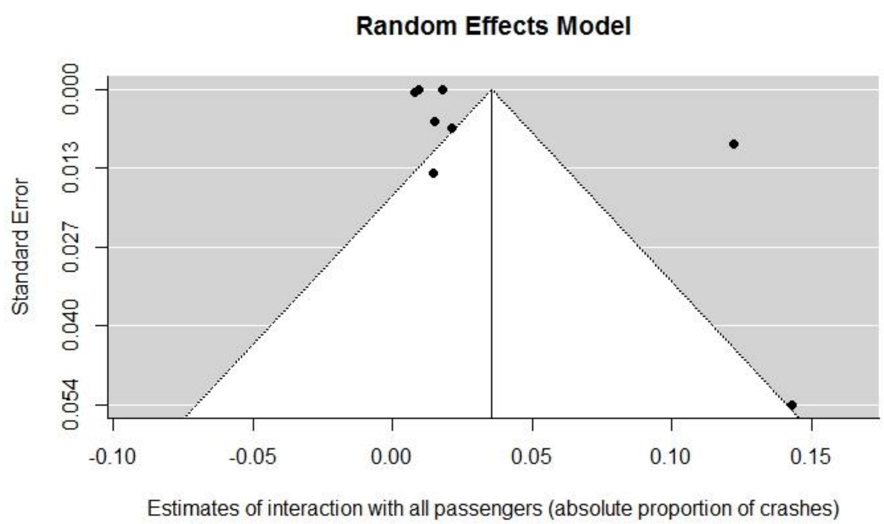

Figure 2: Funnel Plot for absolute proportion of total crashes that happen due to interaction with passengers while driving.

Additionally, a meta-regression was also carried out in order to check the study characteristic effect such as data type, examination year or study designs (simulator, naturalistic, etc.), and therefore study variation is investigated as well. A negative correlation between real-crash data and the proportion of crashes due to passenger interaction was found at a 95% level (estimate

= -0.0872, p-value = 0.0447, R-squared = 0.211). Thus, this type of data presents fewer events due to passenger interaction than simulator for example. The year of the study was also entered as an independent variable but was found insignificant (p-value = 0.244). However, due to the low number of cases, the results of the meta-regression should be interpreted with care and are only indicative.

The objective of this paper is to analyze the share of crashes due to passenger interaction as a crash contributory factor and does not aim to analyze the risk of passenger interaction. Certainly exposure is a considerable factor when examining road safety parameters. In the case of passenger interaction, this would entail monitoring the conversations and other interactions of drivers and passengers for the entirety of the respective trips, and calculate the risk based on interaction exposure for the moments leading to a crash. In practice, however, there are no relevant data available; in our approach we examined crashes that had already occurred and as random events they can be considered to take into account the related exposure.

4.2 Meta-analysis on the interaction with passengers (excl. teens and children)

In this meta-analysis the following studies are included:

1) Charlton, 2009 (1 estimate)
2) Lansdown, 2012 (1 estimate)
3) McEvoy et al., 2007 (1 estimate)
4) Neale et al., 2005 (1 estimate)
5) Neyens and Boyle, 2007 (1 estimate)
6) Stutts et al., 2001 (1 estimate)
7) Wang et al., 1996 (1 estimate)

The overall estimate of the raw proportion of crashes due to interaction with adult passengers only (excluding teens and children) was investigated. The approach was the same as in the previous analysis. Results of the random-effects meta-analysis indicate that the overall estimate of the effect of interaction with all passengers on absolute proportion of crashes is 0.0385, and 95% confidence intervals are 0.0019 and 0.0752 respectively as shown on Table 3 and Figure 3. The p-value (0.0394) indicates a significant effect at 95% level.

Variable	Unit	Estimate	Std. Error	p-value	95% CI
Interaction with adult passengers only	Absolute proportion of crashes	0.0385	0.0187	0.0394	(0.0019, 0.0752)

Table 3: Summary of meta-analysis estimates of interaction with passengers (excl. teen or children) on absolute proportion of crashes.

Figure 3 illustrates the forest plot for absolute proportion of total crashes that happen due to interaction with adult passengers while driving.

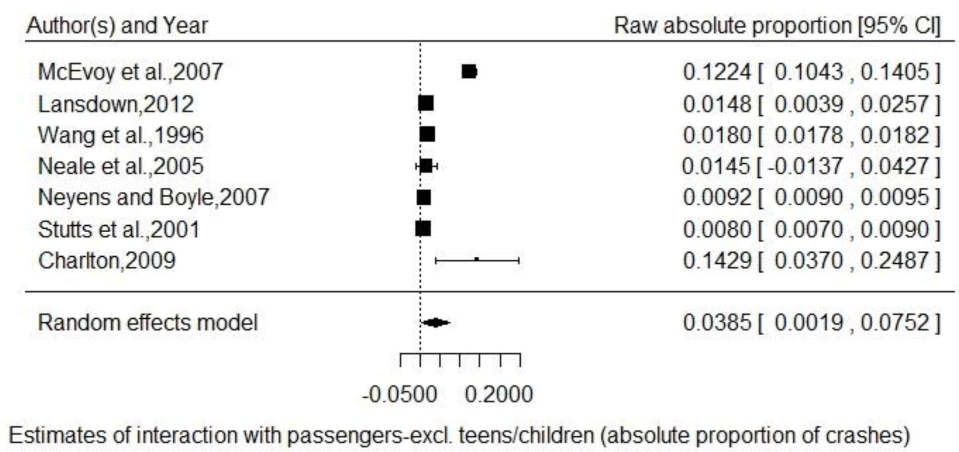

Figure 3: Forest plot for absolute proportion of total crashes that happen due to interaction with adult passengers while driving.

The Q test is significant ($Q_{[df=7]}$ = 3127.0042, p-value < 0.0001) suggesting considerable heterogeneity among the true effects. Therefore, the random effects meta-analysis that was carried out is preferred.

A funnel plot was firstly produced in order to detect potential publication bias (see Figure 4). The regression test for funnel plot asymmetry was not significant at 95% level (p-value = 0.7745), suggesting no evidence for publication bias. There is therefore no need for correcting the estimates.

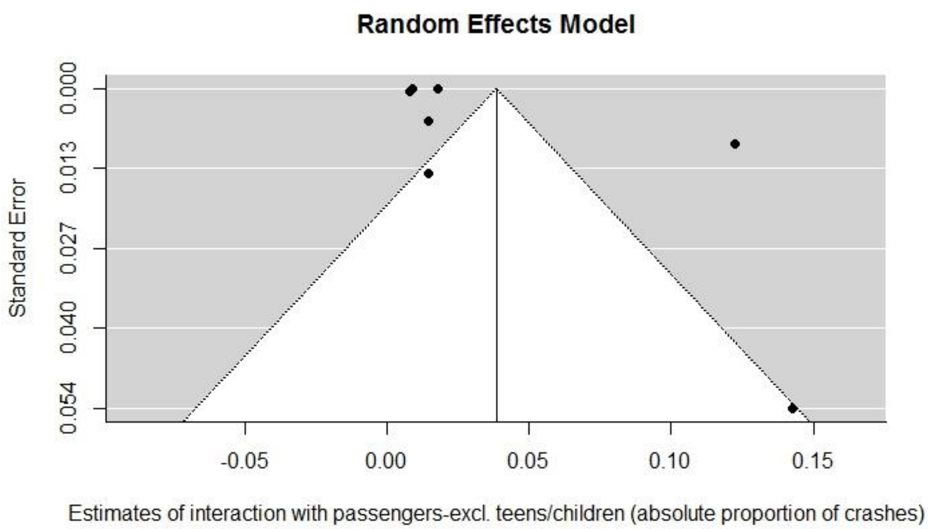

Figure 4: Funnel Plot for absolute proportion of total crashes that happen due to interaction with passengers (excl. teens and children) while driving.

As in the previous analysis, a meta-regression was carried out for adult passengers. The findings are similar, showing a negative correlation between real-crash data and the proportion of crashes due to passenger interaction at a 95% level (estimate = -0.094, p-value = 0.038, R-squared = 0.301). The year of the study showed a non-significant effect as in the previous meta-regression (p-value = 0.381), indicating that there is no time-related effect.

CONCLUSIONS

This research aimed to review and meta-analyze existing findings as regards the effect of conversation with passengers with road safety outcomes. A literature review was carried out and identified two main aspects on which previous research is devoted: the estimation of the proportion of crashes due to interaction with passengers, and the estimation of the effect of interaction with passengers on various driving behavior and safety outcomes. The latter case was early identified as inappropriate for mate-analysis, due to large differences in study methods and outcome measures examined.

On the contrary, a meta-analytic approach was proved feasible and has been conducted for the determination of the impact of driver and passenger interaction, in terms of absolute proportion of crashes that occur due to this risk factor. This particular approach has been explored for the first time in the international literature, to the knowledge of the authors. Findings suggest that passenger interaction related crashes appear with a percentage of 3.55% (s.e. = 0.0158) of the total crashes that are reported, while the respective percentage is 3.85% (s.e. = 0.0187) when teens and children are excluded.

This is a considerable proportion, given that in every driving trip where passengers are present in the vehicle, interaction with the driver is bound to occur. This interaction usually takes the form of conversation, but it might develop to something more physical, for instance an argument – as an indication, McEvoy et al. (2007) mention 'dealing with children' in place of interacting, and Eriksen and Gielen (1983) support this as well, by mentioning that well-behaved children decreased the likelihood of crash occurrence. Additionally, this can be examined from a more distant scope; often conversations or even physical activities induce heightened mental workloads to the participants, and sometimes introduce strong emotions to them as well. All the above impose varying levels of distraction on drivers, which, in the context of road safety, are the main causes of the percentage of crashes determined in the previous chapter.

There is a difference when teens and children are removed from the total of passengers examined. It is unclear, however, if the reduction for interaction with adult passengers only is due to the difference in numbers only, or if children and teens impose levels of distraction disproportionately large for their numbers (this is essentially the possibility that one child is more distracting than one adult). This could be investigated in a future study, either a simulator with two groups of passengers (adults and non-adults) or two groups investigated separately in a crash database.

As stated previously, interaction with passengers is only one aspect of driver distraction. Examples of distraction risk factors that can coincide with interaction with passengers could be consumption of goods (e.g. eating, smoking), listening to music, watching objects outside the vehicle, and others. These issues can become quite complex and multifaceted, when other conditions are present as well. Therefore, there is room for further research, as the combined effect of several distracting factors has yet to be examined by means of meta-analysis.

Another important point is that the scope of this research is not to prohibit people to interact in vehicles, which is unrealistic, but rather detect and quantify the impacts of interaction on road safety. Future research could further address the issue by investigating the point at which it becomes a considerable road safety risk factor and set limits to address it.

Moreover, a worthwhile task is the investigation of geographical regions that have not been covered in the literature, especially for low and middle income countries, where high vehicle occupancy is common and interaction with passengers may have stronger or different.

The sample for this meta-analysis is sufficient and lead to relative confidence that the results for driver and passenger interaction are generally transferable, though caution and care against oversimplification are always required, especially between highly different environments.

PRACTICAL APPLICATIONS

Driver distraction comprises a large group of risk factors that are one of the major causes of crashes, and as such needs to be addressed. This research paper is focused on determining the exact causes of one aspect of driver distraction, which is interaction with passengers. The exact effect of crash percentage due to passenger interaction is determined with the use of advanced meta-analytic techniques from the review and evaluation of existing studies. Using this knowledge, stakeholders can make good estimates on future crash numbers and causes, and, perhaps more importantly, take action in order to counter the effects of this risk factor.

It should be noted that conversation with passengers is a part of everyday driving and cannot be entirely eliminated or forbidden. Nevertheless, a series of countermeasures could be designed and targeted specifically, such as public education, driver training, law enforcement, dedicated distraction recognition systems as for other distraction factors etc. As reflected in the international literature, a number of studies mention that passenger restrictions are included as part of the graduated driver licensing programs in many US states in order to mitigate the risk taking behaviors especially of teenage drivers (Chen et al., 2001; Neyens and Boyle, 2008; Shope and Molnar, 2003). In that context, findings from other sources (DG MOVE, 2015) also suggest that education about distraction during driver license acquisition (including professional drivers) could reduce distracting activities. Other potential measures that could contribute to reducing distracted-related crashes could involve the wider use of in-vehicle safety systems such as collision warning systems (DG MOVE, 2015; McEvoy et al., 2007). Furthermore, policy makers can be more accurately informed when making important decisions for transport engineering, such as fund and other resource allocation and prioritization.

ACKNOWLEDGMENTS

This paper is based on work carried out within the SafetyCube research project of the Horizons 2020 programme of the European Commission - INEA (Grant number 633485). The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the INEA nor the European Commission are responsible for any use that may be made of the information contained therein. The authors would like to thank all the partners involved in the "Behaviour" work package of the SafetyCube project for their valuable comments on earlier drafts of this research.

REFERENCES

Aarts, L., & Van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. Accident Analysis & Prevention, 38(2), 215–224.

Aldridge, B., Himmler, M., Aultman-Hall, L., & Stamatiadis, N. (1999). Impact of passengers on young driver safety. Transportation Research Record: Journal of the Transportation Research Board, 1693, 25–30.

Austrian Road Safety Fund (2012). Road Safety in Austria Annual Report 2012. Retrieved from: https://www.bmvit.gv.at/en/service/publications/transport/downloads/roadsafety_report2012.pdf

Beanland, V., Fitzharris, M., Young, K. L., & Lenné, M. G. (2013). Driver inattention and driver distraction in serious casualty crashes: Data from the Australian National Crash In-depth Study. Accident Analysis & Prevention, 54, 99–107.

Berkey C.S., D.C. Hoaglin, F. Mosteller & G.A. Colditz (1995). A random-effects regression model for meta-analysis. Statistics in Medicine, 14(4), 395–411.

Caird J. K., Johnston K. A., Willness C. R., Asbridge M., & Steel, P. (2014). A meta-analysis of the effects of texting on driving. Accident Analysis & Prevention, 71, 311–318.

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, 1282–1293

Charlton, S.G. (2009). Driving while conversing: Cell phones that distract and passengers who react. Accident Analysis & Prevention, 41(1), 160–173.

Chen, L.H., Braver, E.R., Baker, S.P., Li, G., 2001. Potential benefits of restrictions on the transport of teenage passengers by 16 and 17 year old drivers. Injury Prevention 7 (2), 129–134.

Consiglio W., Driscoll P., Witte M., & Berg W.P. (2003). Effect of cellular telephone interactions and other potential interference on reaction time in a braking response. Accident Analysis & Prevention, 35(4), 495–500.

DG MOVE (2015). Study on good practices for reducing road safety risks caused by road user distractions - Final report. https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/behavior/distraction_study.pdf.

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. doi: www.pnas.org/cgi/doi/10.1073/pnas.1513271113.

Dingus, T.A., Hankey, J. M., Antin, J. F., Lee, S. E., Eichelberger, L., Stulce, K. E., & Stowe, L. (2015). Naturalistic driving study: Technical coordination and quality control (Transportation Research Board, Washington, DC), (No. SHRP 2 Report S2-S06-RW-1).

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

Drews, F.A., Pasupathi, M., & Strayer, D.L. (2008). Passenger and cell phone conversations in simulated driving. Journal of Experimental Psychology: Applied, 14(4), 392.

Duval, S. & Tweedie, R. (2000a). A non-parametric trim and fill method of assessing publication bias in meta-analysis. Biometrics, 56, 455–463.

Duval, S. & Tweedie, R. (2000b). Trim and fill: a simple funnel plot based method of testing and adjusting for publication bias in meta-analysis. Journal of American Statistical Association, 95, 89–98.

Egger, M., Smith, G.D., Schneider M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. British Medical Journal, 315(7109), 629–634.

Elvik, R. (1994). The safety value of guardrails and crash cushions: a meta-analysis of evidence from evaluation studies. Accident Analysis & Prevention, 27(4), 523–549.

Elvik, R. (2001). Area-wide urban traffic calming schemes: a meta-analysis of safety effects. Accident Analysis & Prevention, 33, 327–336.

Elvik, R. (2016). Association between increase in fixed penalties and road safety outcomes: A meta-analysis. Accident Analysis & Prevention, 92, 202–210.

Elvik, R. (2005). Introductory guide to systematic reviews and meta-analysis. Transportation Research Record 1908, 230–235.

Elvik, R. (2011). Effects of mobile phone use on accident risk: Problems of Meta-Analysis When Studies Are Few and Bad. Transportation Research Record, 2236, 20–26.

Elvik, R. (2013). Risk of road accident associated with the use of drugs: a systematic review and meta-analysis of evidence from epidemiological studies. Accident Analysis & Prevention, 254–267.

Elvik, R. & Bjørnskau, T. (2017). Safety-in-numbers: A systematic review and meta-analysis of evidence. Safety Science, 92, 274–282.

Elvik, R., & Mysen, A.B. (1999). Incomplete accident reporting: meta-analysis of studies made in

13 countries. Transportation Research Record, 1665, 133–140.

Eriksen, M.P., & Gielen, A.C. (1983). The application of health education principles to automobile child restraint programs. Health Education and Behavior, 10(1), 30–41.

Filtness, A.J., Armstrong, K.A., Watson, A., & Smith, S.S. (2015). Sleep-related crash characteristics: implications for applying a fatigue definition to crash reports. Accident Analysis & Prevention, 99(B), 440–444.

Filtness, A. J., Reyner, L. A., & Horne, J. A. (2012). Driver sleepiness—comparisons between young and older men during a monotonous afternoon simulated drive. Biological psychology, 89(3), 580–583.

Fu, C., Pei, Y., Wu, Y., & Qi, W. (2013). The Influence of Contributory Factors on Driving Violations at Intersections: An Exploratory Analysis. Advances in Mechanical Engineering 5 (2013): 905075.

Green, J., Ayrton, R., Woodall, J., Woodward, J., Newell, C., Cattan, M., & Cross, R. (2008). Road Safety Research Report 102 Child–Parent Interaction in Relation to Road Safety Education: Part, 2. The Centre for Health Promotion Research, Faculty of Health, Leeds Metropolitan University Department for Transport: London.

Hedges, L.V., & Olkin, I. (1985) Fixed-and random effects models in meta-analysis. Academic

Press, San Diego, CA.

Klauer, S. G., 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. National Highway Traffic Safety Administration, https://vtechworks.lib.vt.edu/bitstream/handle/10919/55090/DriverInattention.pdf.

Koppel, S., Charlton, J., Kopinathan, C., & Taranto, D. (2011). Are child occupants a significant source of driving distraction?. Accident Analysis & Prevention, 43(3), 1236–1244.

Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). Effects of passenger and cellular phone conversations on driver distraction. Transportation Research Record: Journal of the Transportation Research Board, 1899, 109–116.

Lam, L.T. (2002). Distractions and the risk of car crash injury: The effect of drivers' age. Journal of Safety Research, 33(3), 411–419.

Lansdown, T.C. (2012). Individual differences and propensity to engage with in-vehicle distractions – A self-report survey. Transportation Research Part F, 15, 1–8.

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.

McEvoy, S.P., Stevenson, M.R., & Woodward, M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. Accident Analysis & Prevention, 39(3), 475–482.

Neale V., Dingus T., Klauer S., Sudweeks J. & Goodman M. (2005). An Overview of the 100- Car Naturalistic Study and Findings. Paper 05-0400, 19th International Technical Conference on Enhanced Safety of Vehicles, Washington, DC, United States, June 2005.

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(1), 254–259.

Neyens, D. M., & Boyle, L. N. (2007). The effect of distractions on the crash types of teenage drivers. Accident Analysis & Prevention, 39(1), 206–212.

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. Proceedings of the 6th European Transport Research Arena Conference, Warsaw, April 2016.

Phillips, R.O., Ulleberg, P., & Vaa, T. (2011). Meta-analysis of the effect of road safety campaigns on accidents. Accident Analysis & Prevention 43, 1204–1218.

Rothstein, H.R., Sutton, A.J. & Borenstein, M. (2005). Publication bias in meta-analysis: Prevention, assessment, and adjustments. John Wiley & Sons, Chistester, England, 2005.

SafetyCube (2016). Preliminary guidelines for priority setting between measures. Part 1: outline and theoretical background, Deliverable Number 3.4(1) of the H2020 project SafetyCube.

Shope, J.T., Molnar, L.J., 2003. Graduated driver licensing in the United States: evaluation results from the early programs. Journal of Safety Research 34, 63–69.

Stevens, A., & Minton R. (2001). In-vehicle distraction and fatal accidents in England and Wales. Accident Analysis and Prevention 33, 539–545.

Stutts, J.C., Reinfurt, D.W., Staplin, L., & Rodgman, E.A. (2001). The role of driver distraction in traffic crashes. AAA Foundation for Traffic Safety. https://www.aaafoundation.org/sites/default/files/distraction%20%281%29.pdf

Sterne, J.A.C., & Egger, M. (2001). Funnel plots for detecting bias in meta-analysis: Guidelines on choice of axis. Journal of Clinical Epidemiology, 54(10), 1046–1055.

Sullman, M.J. (2012). An observational study of driver distraction in England. Transportation Research Part F, 15(3), 272–278.

Trigoso, J., Areal, A., & Pires, C. (2016). Distraction and fatigue. ESRA thematic report no. 3. ESRA project (European Survey of Road users' safety Attitudes). Lisbon, Portugal: Prevenção Rodoviária Portuguesa. http://www.esranet.eu/sites/default/files/ESRA2015ThematicReportNo3DistractionANDFatigue_0.pdf

US Government Official Website for Distracted Driving, distraction.gov, (2016). Facts and Statistics. Available online at: http://www.distraction.gov/stats-research-laws/facts-and-statistics.html.

Van Houwelingen, H.C., Arends, L.R., & Stijnen, T. (2002). Advanced methods in meta-analysis: multivariate approach and meta-regression. Statistics in Medicine, 21(4), 589–624.

Viechtbauer, W. (2010). Conducting Meta-Analyses in R with the metafor Package. Journal of Statistical Software, 36(3), August 2010.

Wang J. S., Knipling R. R., & Goodman, M. J. (1996). The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. 40th annual proceedings of the Association for the Advancement of Automotive Medicine. Vol. 377. 1996. http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/oldWang.pdf.

Yannis, G., Papadimitriou, E., Bairamis, C., & Sklias, V. (2011). 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.