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Analysis of visual distraction related to smartphone use while driving

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Abstract

Mobile phone distracted driving has been attracting more and more attention in road safety research as evidenced by the consistent number of studies in the field. This paper focuses on the visual distraction effect of mobile phones while driving. Visual distraction is here analyzed concerning several attributes related to the driver (gender, age and driving experience) and the road (weather, lighting, and traffic conditions). The influence of the different attributes on visual distraction is investigated through a simulated driving experiment involving 40 volunteer drivers who were asked to perform four mobile phone tasks while driving: check notifications, read text messages, talk on the phone, write a text message. The experimental results are analyzed using Analysis of Variance (ANOVA) and Covariance (ANCOVA) methods showing that: i) when drivers perceive the worsening of environmental conditions and the related risks, they reasonably focus more on safe driving than on phone activities; ii) older drivers (50-65 years) seem to divert their visual attention from the road more frequently when performing mobile phone tasks. Compared to older drivers, younger drivers look at their phones less when they read a message and drive shorter distances without looking at the road; iii) using the mobile phone to send and read text messages while driving is confirmed to be the most visually engaging and the most demanding activity in terms of concentration required.

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1. Introduction

Mobile phones are today's main tool of communication and an essential device for many people. While at the beginning of the twenty-first century, the common sources of distracted driving were mainly connected to the use of technology on board, such as radio and satnav, or phone conversations, now easy internet access and the innumerable

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available apps have produced a worrying increase in the use of mobile phones while driving. Recent studies, in fact, have highlighted that activities with a high level of distraction for motorists are the use of smartphones, managing children and observing the effects of road accidents (Gazder and Assi, 2022). Being able to access from everywhere to a variety of services, such as social networks, messaging and VoIP services, banking apps, online stores, e-mail boxes and many others, has produced a generation of people dangerously addicted to mobile phones, even when driving. The studies by Albert and Lotan (2018) and Kita et al. (2018) estimate that drivers touch their smartphone screen on average more than 1.6 times per minute, and more than half of the screen-touches are performed when the car is in motion, sometimes at a speed higher than 100 km/h. If on the one side, the perception of the risk related to the use of the mobile phone when driving appears to be generally low, on the other side, many drivers admit to using it albeit aware of the involved risk (Gazder et al., 2019). The main issue seems to lie in the fact that many drivers consider the immediate advantages of using a mobile phone greater than the related risks (Walsh et al., 2008; Ismeik et al., 2015; Yannis et al., 2017; Przepiorka et al., 2018). Based on these elements, the World Health Organization in 2015 defined the distracted driving problem due to the use of the mobile phone as "a serious and growing threat to road safety".

Mobile phone use while driving is widely recognized as one of the main causes of accidents due to distracted driving, and significant relationships have been found between it and the risk of accidents (Kim et al., 2017; Atwood et al., 2018). It is estimated that using the smartphone when at the wheel increases the risk of road accidents by 17.2% for calls, 8.4% for messages, and 54.6% for Internet navigation (Gariazzo et al., 2018). Conversely, a significant number of experimental studies show an increase of risk while texting, but not while phoning (Young, 2017). According to a study by the European Road Safety Observatory (ESCO, 2018), driver reaction times when talking on the phone are 30% slower than when driving with a BAC (Blood Alcohol Content) of 80 mg/100 ml, and 50% slower than driving under normal conditions. To get an idea of the scale of the problem, in the USA, there are around 2,600 deaths and 330,000 serious injuries each year in traffic accidents related to the use of cell phones while driving (Young, 2017). 172,183 road accidents occurred in Italy in 2019 (478 per day, 20 per hour) causing 3,173 deaths and 241,384 injured: mobile phone use was found to be among the major causes of these accidents (ACI, 2019).

To counter the disarming increase in the use of mobile phones at the wheel, many states are now introducing increasingly severe laws into their legislation to prohibit the use of the mobile phone when driving, with the sole exception of hands-free use. For example, since 2009 the European Commission has been investigating the effects of mobile phone use while driving, also analyzing the effectiveness of technological and regulatory interventions aimed at containing it (JBC, 2009). On 16 April 2019, the European Parliament approved new rules requiring life-saving technologies to be installed in new vehicles as from May 2022. Such life-saving technologies may include, among others, intelligent speed assistance, alcohol interlock installation, driver drowsiness, driver distraction warning, and phone lock while driving. The new provisions became mandatory in all member states from 6 July 2022. In 2019, the Government of New South Wales – Centre for Road Safety - launched a program for sanctioning the use of mobile phones at the wheel based on the use of high-definition cameras to detect mobile phone use while driving inside the vehicle. In just one year, more than 100,000 drivers were caught using a mobile phone while driving.

The study presented in this paper is part of a broader line of research carried out by the authors that aims to investigate the disruptive impact of using mobile phones while driving (Fancello et al., 2020). Specifically, this paper focuses on the impact of using the phone while driving in terms of visual distraction. The study intends to provide experimental evidence on the influence that drivers' characteristics (age, driving experience) and external factors (light, traffic, and weather conditions) can have on driving performance when using a mobile phone, both in terms of risk perception and driving activities management. Particularly, this study deeply investigates about the effects on drivers' distraction caused by several tasks that can be performed using a smartphone (checking notifications, reading and writing messages, talking and chatting), highlighting the most dangerous ones for which the risk of accidents increases. So, this research complements the literature on the visual distraction produced by the mobile phone while driving and can provide insights to lawmakers and industry who are working to introduce measures that limit the use and visual distracting effect of the mobile phone while driving. Driving behaviors are investigated through simulated driving tests carried out on an advanced simulator. Results are analyzed using ANOVA (analysis of variance) and ANCOVA (analysis of covariance) methods, integrated with Kolmogorov-Smirnov test and Levene test, to put into light differences in driving behaviors across the various groups of drivers. The paper is structured in six sections: after this introduction, Section 2 discusses a brief review of the literature with a focus on the distracted driving problem

related to mobile phone use. Section 3 describes the performed experimentation and the materials and methods used while Section 4 discusses from an analytical point of view the trial results. The latter are critically discussed in Section 5. Finally, Section 6 concludes the paper illustrating the practical implications and potential contribution of the study outcomes to road safety research.

2. Mobile phone distraction during car driving: a brief literature review

Drivers have traditionally been exposed to several sources of distraction inside the car (radio, satnav, etc.), but it is in recent years that the exponential spread of smartphone applications and development of drivers' multitasking skills have dramatically increased the opportunity for distraction while driving (Young et al., 2007). This latter can be defined as any activity that diverts a person's attention away from the primary task of driving. Texting, calling, or taking selfies while driving are all examples of driver distraction (Choi et al., 2019). Already in 2013, the study by Engström et al. (2013) defined driver distraction as a situation in which "...the driver allocates resources to a non-safety critical activity while the resources allocated to activities critical for safe driving do not match the demands of these activities".

The paper by Bruyas et al. (2017) tried to quantify the use of mobile phones while driving through an online interview involving 3,189 French citizens. 38% of the drivers interviewed declared to use the phone while driving, of which 36% to make a phone call, 27% to read messages, 9% to surf the Internet or use applications, 21% to use GPS, 8% to take photos or selfies, and 7% to use social networks. Although distracted driving is widely recognized as a major cause of road accidents (Sawhney et al., 2018), the use of mobile phones behind the wheel appears to be in uncontrollable and worrying growth (EU statistics, 2019). Particularly, secondary uses of the smartphone while driving, such as chatting, surfing the Internet or browsing photos and posts on social networks, are becoming widespread distractions with negative implications in terms of higher accident risk and reaction times increased up to 204% (Hamilton and Grabowski, 2013; Choudhary and Velaga, 2017a). Over the last years, numerous studies have proven that using mobile phones while driving negatively affects driving performance and safety (Bergmark et al., 2016; Hill et al., 2019; Spyropoulou and Linardou, 2019) and people who use mobile phones at the wheel pay reduced attention to driving (Papantoniou et al., 2015; Hayashi et al., 2017; Van Dam et al., 2019). Several studies have tried to investigate the way in which the specific phone task or the personal features of the driver may affect driving behaviors (Choudhary and Velaga, 2019). These studies include surveys (Gliklich et al., 2016; Raghunathan et al., 2017), simulation experiments (Fancello et al., 2020; Papadakaki et al., 2016; Choudhary and Velaga, 2017b; Oviedo et al., 2018; Siam et al., 2019; Fu et al., 2020), and naturalistic studies (Klauer et al., 2014; Xing and Wang, 2018; Papadimitriou et al., 2019).

The use of the mobile phone when driving may produce different types of distraction on the driver. From a conceptual point of view, sources of driver distraction can be divided into three categories (Strayer et al., 2011; Lipovac et al., 2017):

- visual and auditory (external stimuli that reach the driver): eyes off the road and focus on the ringing of the cell phone
- physical/ manual (stimuli introduced by the driver): hands off the wheel to operate the mobile phone
- cognitive: mind off the task at hand (safe driving).

Using the phone while driving involves a combination of multiple types of distraction. For example, auditory and cognitive distractions happen when talking on the phone while visual and manual distractions are mostly combined when typing on the phone. The paper by (Kaber et al., 2012) demonstrated that driver visual and cognitive distractions have independent and combined effects on driver performance, visual behavior and workload. Visual and manual distraction may also depend on how the mobile phone is used while driving, for example, to avoid police control. In this regard, several drivers claim to keep the smartphone under the steering wheel to use it secretly (Oviedo, 2018). Several studies have attempted to measure visual and manual distractions while driving and the distraction produced using the smartphone at the wheel (Louventon et al., 2016; Kujala and Mäkelä, 2018; Née et al., 2019; Victor et al., 2015). Among the others, the study by Knapper et al. (2015) performed a simulation experiment involving 20 volunteer drivers to measure the percentage of time drivers spend looking at the phone and the number of glances on it when performing several mobile phone tasks. According to their results, drivers spend about half the time looking at the phone and not the road when performing smartphone tasks. The paper by Young et al. (2014) focused on what

happens when drivers read or write text messages finding that they reduce the time spent looking at the road by 17% when reading, and by 29% when writing a message. The study by Christoph et al. (2019) explained how the level of distraction and the use of mobile phones seem to largely depend on the self-regulation of the risk by drivers.

An important aspect to consider when studying smartphone distracted driving is the age of the drivers. Younger drivers are usually less experienced in driving but more familiar with the use of mobile phones. The use of the smartphone while driving is more frequent among younger than in more mature drivers (Young and Lenné, 2010), although everyone seems aware of the risks involved (Ismeik et al., 2015; Fancello et al., 2020). In this regard, the recent study by Vollrath et al. (2021) found that although the deteriorating effect of texting while driving appeared objectively less pronounced in highly competent phone users, in the subjective assessment they felt as impaired as drivers with a low texting competence. The study by Fancello et al. (2020) explores the effects of four smartphone usages on driving performance across a range of drivers' ages and experiences, also considering the gender factor. Consistently with previous research, they found that the risk of collision increases for all age groups when using smartphones, and most drivers tend to increase speed when talking on the phone. The results of the naturalistic driving study by Victor et al. (2015) show that some smartphone tasks (such as texting) significantly increase risk. However, a decreased risk was found for talking/listening on a cell phone.

This paper intends to contribute to the existing literature by experimentally investigating the extent to which mobile phone use while driving can impact visual distraction in relation to the age, gender and driving experience of the driver, but also the driving environment (traffic, light, and weather conditions). Moreover, it allows to investigate in deep about the distracting effects caused by each task that characterize the smartphone's use in relation to different drivers' characteristics and several driving environments. To this end, this study focuses specifically on a set of variables that the authors consider representative of the visual distraction due to mobile phone use behind the wheel: (1) the number of looks at the mobile phone, (2) the time required to perform the driving test, (3) the distance travelled without looking at the road during each phone activity, (4) the percentage of time with the gaze on the mobile phone, (5) the average duration of glances on the mobile phone. The study seeks to understand whether behavioral patterns related to visual attention while driving and using the telephone can be identified by type of user or based on the environmental conditions in which they drive. In so doing, this study tries to give an evidence-based answer to the following research questions:

- does the visual distraction effect of the smartphone when driving vary depending on the surrounding driving environment (traffic, lighting, and weather conditions)?
- does the visual distraction effect of the smartphone when driving vary according to the age, experience, and gender of the driver?
- is there a phone activity that impacts visual distraction more than others?

thus, providing a deep understanding of distraction related to mobile phone use behind the wheel.

3. Materials and methods

This section describes the methods, materials and tools used in this experimental research. Specifically, the following elements are described: trial participants, main characteristics of the driving simulator used in the experimentation, experimental design, tools and methods used to collect the trial data, and methods for data analysis.

3.1. Participants

A total of 40 drivers were enrolled in the research on a voluntary basis. Participants were recruited from the population of students and faculty staff at the Transport Department of the Faculty of Engineering of the University of Cagliari (Italy). All participants had to satisfy the following requirements: (1) be aged between 20 and 65 years, (2) have a valid driving license, (3) have at least a two-year driving experience, (4) have prior experience using a smartphone while driving, (5) be familiar with WhatsApp (at least 14 WhatsApp messages sent per day), (6) not to be professional drivers, (7) do not suffer 'simulator sickness' (dizziness, queasiness, and nausea) during the pre-test drive. Before starting with the experimentation, participants were all in-formed about full compliance with the national privacy legislation in processing the data and videos collected during the test. The study was conducted in accordance

with the Declaration of Helsinki and all subjects gave their informed consent for inclusion before they participated in the study.

The sample consisted of 27 men (67.5%) and 13 women (32.5%), divided into the following four age groups:

- group 1: 11 young people (20-29 years old)
- group 2: 11 young adults (30-39 years old)
- group 3: 11 middle-aged adults (40-49 years old)
- group 4: 7 adults (50-65 years old).

For the analysis, the sample was also divided according to the driving experience of the participants (evaluated based on the kilometers driven in the previous year) into the following experience groups:

- 6 low-experienced drivers ($< 5,000$ km)
- 18 medium-experienced drivers ($5,000 < \text{km} < 15,000$)
- 12 experienced drivers ($15,000 < \text{km} < 25,000$)
- 4 very experienced drivers ($> 25,000$ km).

3.2. Driving simulator

Simulated driving tests were performed using an advanced physical simulator that guaranteed a fully immersed driving experience. The used simulator, called BBBus, consisted of a driver's cab with a car seat and safety belt, a pedal board with brake and accelerator, a steering wheel, a motion platform reproducing most of the movements perceptible inside a real car while driving, an immersive video projection system that allows a 180° view, an audio system reproducing all the driving sounds and noises, and a control cabin located in a separate area. The used simulator software is based on Unity version 5.0.2f1 which is a multiplatform graphic engine developed by Unity Technologies also used to create multi-dimensional virtual games.

3.3. Experimental procedure

The experimentation consisted of two monitored driving sessions carried out with a five-minute break from one another. During the two sessions, participants had to drive a simulated road itinerary about 12.5 km long reproducing a real road in the metropolitan area of Cagliari (Italy). The path covered both urban and extra-urban routes. The two driving sessions were characterized as follows:

- session n. 1: driving test under good conditions. It simulates an ideal driving scenario characterized by low traffic, a few pedestrians crossing the road, day driving and perfect visibility conditions (Figure 1a)
- session n. 2: driving test under bad conditions. It simulates an unfavorable driving scenario characterized by more intense traffic, a higher number of pedestrians crossing the road, night driving, fog and visibility up to 150 meters (Figure 1b).

Before performing the two monitored sessions, all participants received a preliminary training session on the simulator to become familiar with the apparatus and its equipment. To reduce a possible learning effect, the training session used a different road scenario to that used in the two monitored sessions.

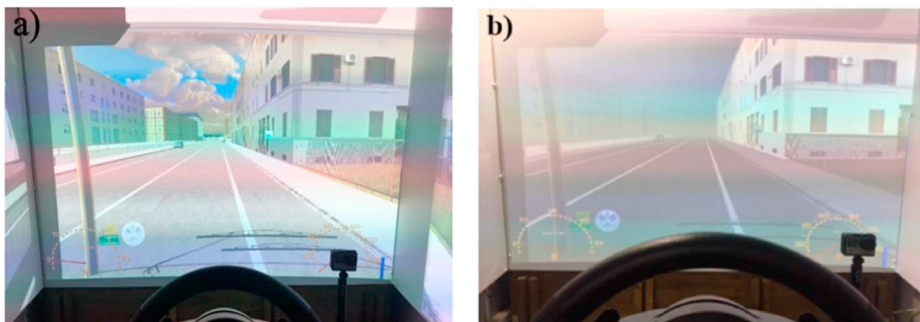


Fig. 1. Driving sessions: (a) test in good conditions; (b) test in bad conditions.

In line with the study by Née et al. (2019), according to which the greatest risks of getting into a road accident derive from visual, manual and cognitive distraction rather than verbal distraction, the experimentation focused on cell phone activities that are most likely to induce this type of distraction. Specifically, all trial participants were asked to drive safely as they normally would while engaging in the following four smartphone tasks:

- check notifications – drivers had to take their smartphone located near the driver seat, check notifications (using only one hand) and finally put the smartphone back in place
- read text messages – each driver had to read aloud four text messages of about 60 characters each. The messages were sent by a member of the research team and contained simple and common sentences, such as: “Would you like to go for a walk downtown this Saturday?”. Participants had to take their mobile phone located near the driver seat, unlock it, read the first text message, lock the mobile phone, put it back in place and then reposition the hand on the steering wheel. Afterwards, they had to repeat the same actions to read the remaining text messages
- talk on the phone (handheld phone conversation) – each participant had to answer a phone call made by the operator who monitored the experiment from the control cabin. Since the content of the conversation is one of the factors that most affect the risk of accident (Zokaei et al., 2020), during the call, each driver had to answer three types of questions taken from “The Rosenbaum Verbal Cognitive Test Battery”. The latter is a cognitive test created by Gail Rosenbaum in 1997 and already used in similar research (Knapper et al., 2015; Waugh et al., 2000; Rakauskas et al., 2015). The test includes questions that are simple but require mental reasoning to provide an answer. The three questions were of the following type: monologue (tell me as much as possible about...), repetition sentence (repeat the following sentence...), verbal puzzle (answer the following questions...)
- write a text message – each volunteer had to write a text message reporting the first four verses of the Italian hymn. The reason for this choice was twofold: (1) to have the same comparable text message for all the participants; (2) to guarantee each participant processed the text by himself.

Both reading and writing tasks were performed using WhatsApp, today’s most used instant messaging app (2.5 billion active users worldwide). It is estimated that drivers open WhatsApp on average eight times while driving, for a duration of 35 seconds (Kujala and Mäkelä, 2018).

To guarantee that all drivers performed the various activities in the same conditions so that to bring out any behavioral difference related to personal attributes, the sequence of mobile phone tasks in both simulations was the same for all drivers. Five minutes after the simulation in optimal conditions, the volunteers performed the test in bad conditions. The order in which the telephone activities were performed was the same in the two tests. The drivers were invited to engage in the specific smartphone task when driving in predefined sections of the simulated route, precisely:

- check notifications at the first kilometer of driving
- read text messages at the third kilometer of driving
- talk on the phone at the fifth kilometer of driving
- write a text message at the ninth kilometer of driving.

In order not to influence their reaction and, consequently, their driving behavior, the drivers did not know that they would be called/texted at a specific time.

The standardization of the procedure ensured that all participants performed the telephone tasks under the same traffic conditions, thus allowing to highlight behavioral differences related to personal attributes.

3.4. Experimental data

The experimental data were recorded and collected in three different moments and ways:

1. During the simulation test, using the BBBuS simulator software, an Eye Tracking device worn by each participant during the test, and two action cameras to videotape the experiment. Specifically, the simulator software recorded the following data:

- the average driving speed (km/h) maintained by each participant during the two driving tests
- the precise distance traveled (km) by each participant during the two tests
- the total time taken to complete each test (minutes)
- the number of collisions and crashes, if any.

The Eye Tracking device was used to record the activity and movements of the drivers' eyes and where they focused their looks during both simulation tests. The two GoPro cameras were positioned behind and in front of the driving seat in order to record the driving behaviors of the 40 volunteer drivers when using the mobile phone during the two tests. The video recordings were post-processed using the raster graphic editor Adobe Photoshop in order to detect "frame-by-frame" where the trial participants looked during the four smartphone tasks and for how long. Based on the frame-by-frame analysis of the video recordings, for each test and each driver, the following data were obtained:

- test start time (the speedometer of the simulator marks $v > 0$ km/h)
- test ending time (the speedometer of the simulator marks $v = 0$ km/h)
- start and end time of each smartphone task
- the precise moments when the drivers shift their eyes from the road to the smartphone to perform the mobile phone task required
- the number of frames elapsed from the moment the drivers move their gaze from the smartphone to the simulator screen during the requested smartphone task (this data is detected for all the times the eye is moved from the phone to the screen and vice versa).

2. At the end of the simulation test, creating a detailed data base finalized to assess driving performances.

To support the analysis, the following dependent variables were elaborated from the data above and considered for analyses:

- total execution time of the test (minutes): it represents the duration of the test from the moment the participants start driving (the speedometer marks $v > 0$ km/h) to the moment they complete the test (the speedometer marks $v = 0$ km/h)
- total execution time of each mobile phone task (seconds)
- number of looks on the mobile phone when performing each smartphone task
- duration of the single glances on the phone (seconds) during each smartphone activity: it is calculated as the difference between the instant in which the drivers shift their look from the road to perform the smartphone activity and the moment in which they return their look on the road. This variable allows evaluating how long the drivers take their attention away from the road every time they look at the mobile phone to complete the requested smartphone task. The smaller the duration, the greater the attention to driving
- percentage of time looking at the smartphone (and not the road) during each task: it indicates how much the smartphone is used during the smartphone activity requested. It is calculated by multiplying by 100 the ratio between the total time spent looking at the phone (sum of the duration of the single glances on the phone) and the total duration of the specific smartphone activity. It indicates how much attention is given to completing the smartphone task compared to safe driving. The higher the percentage of time spent looking at the mobile phone, the lower the driving safety
- distance travelled without looking at the road, during each mobile phone task (meters): it is calculated by multiplying the average speed maintained during the mobile phone task by the total time spent looking on the phone during the task.

3. After completing the simulation test, using a dedicated questionnaire to be filled by each participant.

Each participant was asked to complete a questionnaire consisting of two main parts (Figure 2): the first part concerned driver's personal information (age, gender, employment status, qualification, etc.) and driving experience (use of the car during the past year) while the second concerned questions on the level of perceived effort to carry out the simulation test, personal judgments on the comparison between real and simulated driving, and between phone activities when performed in real and simulated conditions.

Participants were asked to make their judgments on a vertical graduated scale in which each numerical value corresponded to a specific level of effort felt by the driver. Questions 1 and 2 asked respectively to give a score from 1 to 10 on the effort put into simulated driving and the effort put into performing telephone activities during simulated driving compared to real driving.

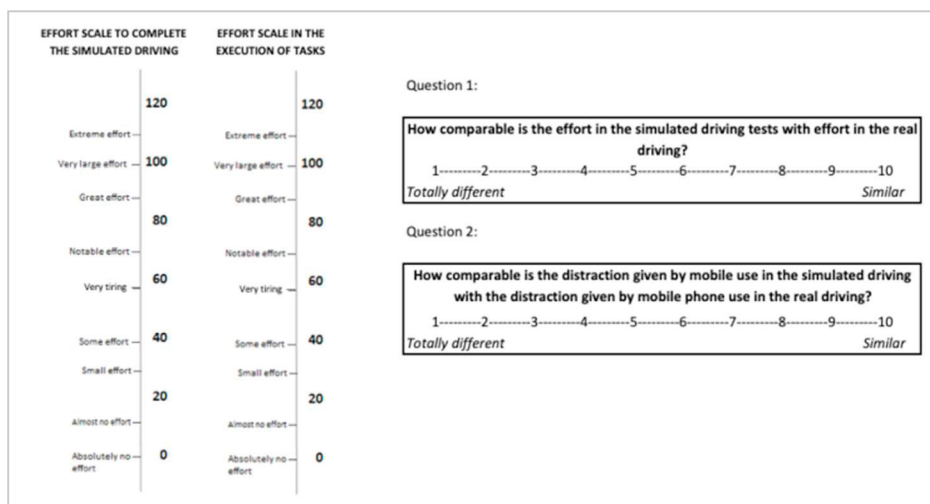


Fig. 2. Questionnaire judgement scale.

3.5. Data analysis

Experimental data were analyzed using both descriptive and inferential statistics:

- descriptive statistics were used to explore and preliminarily interpret data from questionnaires and video-processing
- the presence of a significant statistical relationship between the variables was investigated using ANOVA, ANCOVA and regression models.

ANOVA is typically used to check whether the means of two or more independent groups are significantly different from each other. The null hypothesis states that all group means are equal while the alternative hypothesis states that at least one is different. ANOVA works by comparing the variance between group means versus the variance within groups as a way of determining whether the groups are all part of one larger population or separate populations with different characteristics. The result of the ANOVA test is the F statistic, also called the F-ratio. When the F-ratio statistic is close to 1, there is no real difference between the groups tested and the null hypothesis is verified. ANOVA requires data from approximately normally distributed populations with equal variances between factor levels (i.e., guaranteed homoskedasticity). In this application, the Kolmogorov - Smirnov Test was used to verify the first requirement while the Levene Test was used to verify homoskedasticity.

ANCOVA is normally applied to determine if there are any significant differences between two or more independent groups on a dependent variable. ANCOVA is a general linear model which combines ANOVA and regression analysis. Compared to the one-way ANOVA, the ANCOVA method has the additional benefit of allowing statistical control for a third variable, the so-called covariate, which is believed to affect the results. This method of statistical investigation aims to analyze the relationships between two variables. This relationship can be defined as linear when it can be represented by a common regression coefficient (the influence of the covariate is the same in all groups). In other words, the regression coefficients of the various groups must be similar and therefore produce parallel lines. A second-order polynomial regression method was used to verify the presence of a correlation between the variables, as it has a better adaptation to the data distribution (defined with the evaluation coefficient R^2).

4. Results

4.1. The Experimentation results

From the "frame by frame" analysis of the GoPro videos using Adobe Photoshop, it emerged that:

- in both tests, the highest (average) percentage of time with the gaze on the smartphone was recorded when participants were writing text messages: 48.9% during the simulation test in good conditions and 48.2% during the test in bad conditions (Figure 3)
- the percentage of time with the gaze on the phone decreased during the simulation test in bad conditions compared to the test in good conditions (Figure 3)
- in both tests, the longest average distance travelled “in the dark” (without looking at the road but at the mobile phone) was recorded when participants were writing text messages: 750 meters during the simulation test in optimal conditions, and 587 meters during the test in bad conditions (Figure 4)
- the distance travelled without looking at the phone during each smartphone task was always shorter during the simulation test in bad conditions (Figure 4).

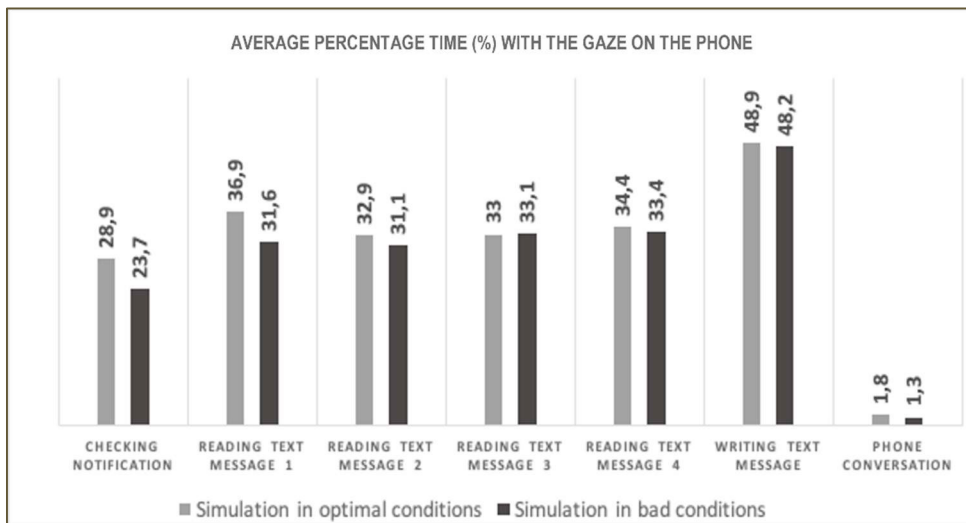


Fig. 3. Average percentage of time looking at the mobile phone during each activity (%).

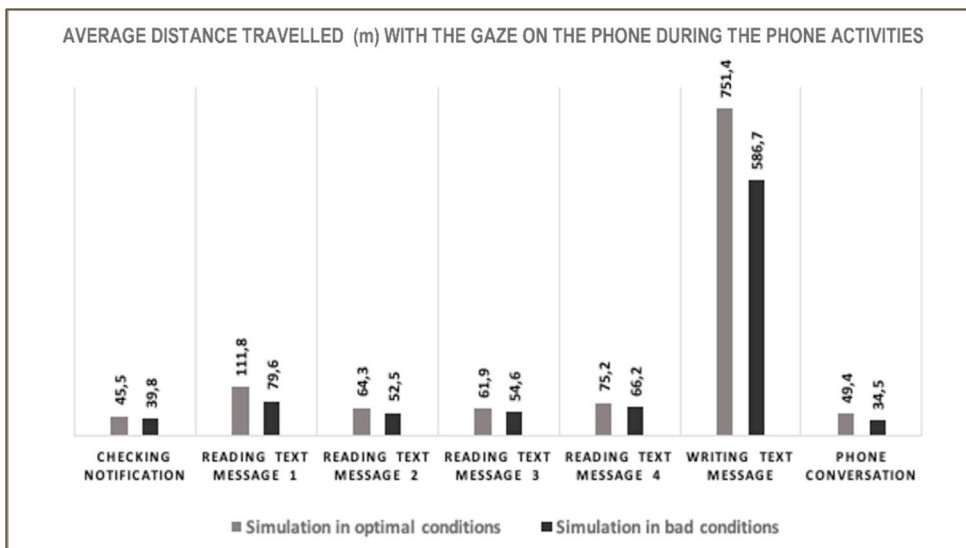


Fig. 4. Average distance travelled looking at the mobile phone and not the road during each activity (m).

4.2. Inferential statistics

Inferential statistical analyses were performed to investigate the influence of gender, age and experience on drivers' behaviors. Analyses were performed using XLSTAT version 2016.02.28451 developed by Addinsoft. ANOVA was used to identify differences across groups of drivers. In particular, the following variables were compared in the two simulation tests:

- text execution time to carry out the two simulations
- distance traveled without looking at the road during each mobile phone task
- percentage of time looking at the mobile phone during each telephone activity
- average duration of the single glances on the phone to carry out each mobile phone task.

Table 1 shows the results of the one-way ANOVA related to the variable "Exact duration of the driving tests". The table lists the size of the sample, the sum of the values of the variable, the average value, the variance, the sum of the squares, the degrees of freedom, the mean of the squares, and the value of the Fisher-Snedecor variable F along with its significance and critical values. $F > F_{crit}$ ($F\text{-ratio} > 1$) implies the rejection of the null hypothesis and indicates the existence of statistically significant differences in the sample between the two simulations characterized by different light, weather and traffic conditions.

Table 1. ANOVA results: comparison between the simulations.

Total execution time to carry out the driving tests						
Groups	Count	Sum	Average	Variance		
Simulation in good conditions [s]	40	29,266	731.650	13,677.567		
Simulation in bad conditions [s]	40	32,681	817.025	25,948.538		
ANOVA results						
Origin of the variance	<i>SQ</i>	<i>df</i>	<i>MQ</i>	<i>F</i>	<i>P-value</i>	<i>Fcrit</i>
Between groups	145,777.813	1	145,777.813	7.358	0.008	3.963
Within groups	1,545,418.075	78	19,813.052			
Total	1,691,195.888	79				

Table 2 shows the results of the ANOVA related to the variable "Distance traveled without looking at the road" for the mobile phone tasks for which $F > F_{crit}$ and the hypothesis of homoskedasticity and normal distribution was verified (only "Texting" and "Talking on the phone" tasks). According to these results, changes in light, visibility and traffic do have an influence on the total execution time in the two simulations and on the distance traveled without looking at the road while texting or talking on the phone.

ANOVA was also applied to the sample divided according to the personal characteristics of the drivers to investigate if and how the presence of external factors related to traffic, light and weather conditions combined with the personal characteristics of the driver (gender, age and driving experience) may affect driving performance when using the mobile phone. The analysis was not applied to telephone conversation activities as the duration of glances on the phone during calls was limited to call acceptance and closure operations, with a value not comparable to other smartphone activities.

Table 3 summarizes the results of the ANOVA, reporting the value of the Fisher-Snedecor variable F together with its critical value and significance values for the analyzes that verify the $F > F_{crit}$ condition, thus suggesting statistically significant differences in the behavior of the sample divided by age, gender and driving experience in the two simulation tests.

Considering the variable "Percentage of time looking at the mobile phone" while reading text messages, the value of F compared to the value of F_{crit} shows how females and younger drivers (aged between 20 and 29 years) have behaviours statistically different in the two tests. Similarly, when checking notifications, participants who reported between 5,000 and 15,000 km driven in 2017, appear to be looking at the phone for a statistically different percentage of time in the two simulation tests. As for the variable "Distance traveled without looking at the road", it emerged that males, younger drivers (20-29 years-old) and mature drivers (50-65 years-old) show statistically significant

differences in the two simulation tests while, respectively, sending text messages, checking notifications and reading messages.

Table 2. ANOVA results: comparison between the mobile phone tasks with $F > F_{crit}$ in the two simulation tests.

Distance traveled without looking at the road						
Texting						
Groups	Count	Sum	Average	Variance		
Simulation in good conditions [m]	40	30,054.090	751.352	152,776.974		
Simulation in bad conditions [m]	40	23,468.274	586.707	63,720.157		
ANOVA results						
Origin of the variance	SQ	df	MQ	F	P-value	Fcrit
Between groups	542,162.122	1	542,162.122	5.008	0.02807	3.963
Within groups	8,443,388.077	78	108,248.565			
Total	8,985,550.199	79				
Talking on the phone						
Groups	Count	Sum	Average	Variance		
Simulation in good conditions [m]	40	1,974.371	49.359	1,169.203		
Simulation in bad conditions [m]	40	1,380.748	34.519	464.609		
ANOVA results						
Origin of the variance	SQ	df	MQ	F	P-value	Fcrit
Between groups	4,404.853	1	4,404.853	5.392	0.02283	3.963
Within groups	63,718.667	78	816.906			
Total	68,123.520	79				

Table 3. ANOVA results: comparison between the four mobile phone tasks in the two simulations in relation to gender, age and driving experience.

Variable	Mobile phone task	Part of the sample	F	P-value	F crit
Percentage of time looking at the mobile phone	Checking notifications	Group 2: 5K < km < 15K	4.748	0.036	4.130
	Reading text messages	Gender: Female	4.555	0.035	3.934
		Age class 1: 20 - 29 years	5.336	0.023	3.952
Distance traveled without looking at the road	Checking notifications	Age class 4: 50 - 65 years	9.064	0.011	4.747
	Reading text messages	Age class 1: 20 - 29 years	6.800	0.012	3.952
		Group 2: 5K < km < 15K	4.353	0.039	3.908
		Group 3: 15K < km < 25K	7.650	0.007	3.942
	Texting	Gender: Male	4.853	0.032	4.027

Cohen's d Test was used to analyze the effect size of one-way ANOVA results by applying it to pairs of groups that have similar standard deviations and same size. Cohen's d provides a quantitative measure of the magnitude of the study effects, and it is calculated as the difference between the means of two groups divided by the standard deviation of the population from which the groups were sampled. The values of the Cohen's d test are interpreted as follows:

- $d < 0.2$ trivial effect
- $d = 0.2$ small effect
- $d = 0.5$ medium effect
- $d = 0.8$ large effect
- $d > 1$ giants.

Table 4 shows the values of the Cohen's d Test for the comparisons that verified the $F > F_{crit}$ condition. The results confirm that the magnitude effect is relevant for all the comparisons reported.

Afterwards, ANCOVA was applied to the sample divided into groups based on age and driving experience, as previously detailed in Section 3.1. ANCOVA was used to evaluate the possible relationships between the percentage of time spent looking at the smartphone during each smartphone task and the average duration of single glances on the mobile phone.

Table 4. Cohen's d test – Effect size.

Total execution time to carry out the driving tests [s]						
Reference sample	Activity	Groups*	Mean	SD	Sample size (n)	Cohen's d
Whole sample	Entire test	Test n.1	731.650	116.951	40	> 1
		Test n.2	817.025	161.085	40	
Percentage of time looking at the mobile phone [%]						
Reference sample	Activity	Groups*	Mean	SD	Sample size (n)	Cohen's d
5K< km <15K driven in 2017	Checking notifications	Test n.1	32.778	13.554	18	0.724
		Test n.2	23.833	11.031	18	
20 - 29 years	Checking notifications	Test n.1	36,023	11.048	44	0.493
		Test n.2	30,818	10.063	44	
Females	Reading text messages	Test n.1	34.846	12.648	52	> 1
		Test n.2	30.250	9.010	52	
Distance travelled without looking at the road [m]						
Reference sample	Activity	Groups*	Mean	SD	Sample size (n)	Cohen's d
20 - 29 years	Checking notifications	Test n.1	84.205	59.616	44	0.493
		Test n.2	58.432	27.269	44	
50 - 65 years	Checking notifications	Test n.1	62.577	31.556	7	> 1
		Test n.2	22.569	15.504	7	
5K< km <15K driven in 2017	Reading text messages	Test n.1	81.972	72.798	72	0.348
		Test n.2	61.789	37.913	72	
15K<km<25K driven in 2017	Reading text messages	Test n.1	83.244	37.521	48	0.565
		Test n.2	64.023	30.171	48	
Males	Texting	Test n.1	824.188	434.124	27	0.600
		Test n.2	610.852	254.429	27	

*Test n.1: Driving test in good conditions; Test n. 2: Driving test in bad conditions.

Observing the graphs in Figures 5 and 6 resulting from the ANCOVA analyses, it emerges that the regression lines are all parallel, thus suggesting that the influence of the "age" or "driving experience" covariate is the same for all groups. The dispersion of the points and the position of the straight line that characterize the behavior of elderly drivers when texting is higher than those of other age groups. This means that with the same percentage of time looking at the mobile phone while texting, older participants (50–65 years old) look at the phone each time for an increasing amount of time, and this happens in both simulation tests (Figure 5c and 5d). Older drivers seem to focus more on texting rather than safe driving with the eyes on the road. For example, comparing the driving behaviors of younger (20–29 years) and older (50–65 years old) drivers in the simulation in good conditions, it emerged that with the same percentage of time looking at the mobile phone (40%), the average duration of the looks on the phone of young drivers is 0.75 seconds, that of the older drivers is 1.5 seconds (Figure 5c).

Similarly, ANCOVA results for the sample divided by driving experience show that, with the same percentage of time looking at the mobile phone while texting, more experienced drivers look at the mobile phone for a shorter time, every time they move their gaze from the road (Figure 6c and 6d).

Looking at the four graphs in Figure 6, the lines of more experienced drivers (groups 3 and 4) are lower than those of less experienced drivers (groups 1 and 2) in both simulations, both when checking notifications and when writing text messages. By way of example, considering 40% of the time with the gaze on the phone while checking notifications, more experienced drivers look at the phone each time for about one second while less experienced

drivers for 1.2 seconds. The same behavior occurs when writing text messages. A reduction in the average time of single glances on the phone emerges for all driving experience groups during the simulation in bad conditions. As an example, when moving their gaze to the phone for reading text messages, more experienced drivers look at the phone each time for about 1.10 seconds in the simulation under good conditions, this time is reduced to 0.8 seconds in the simulation in bad conditions (Figure 6c and 6d).

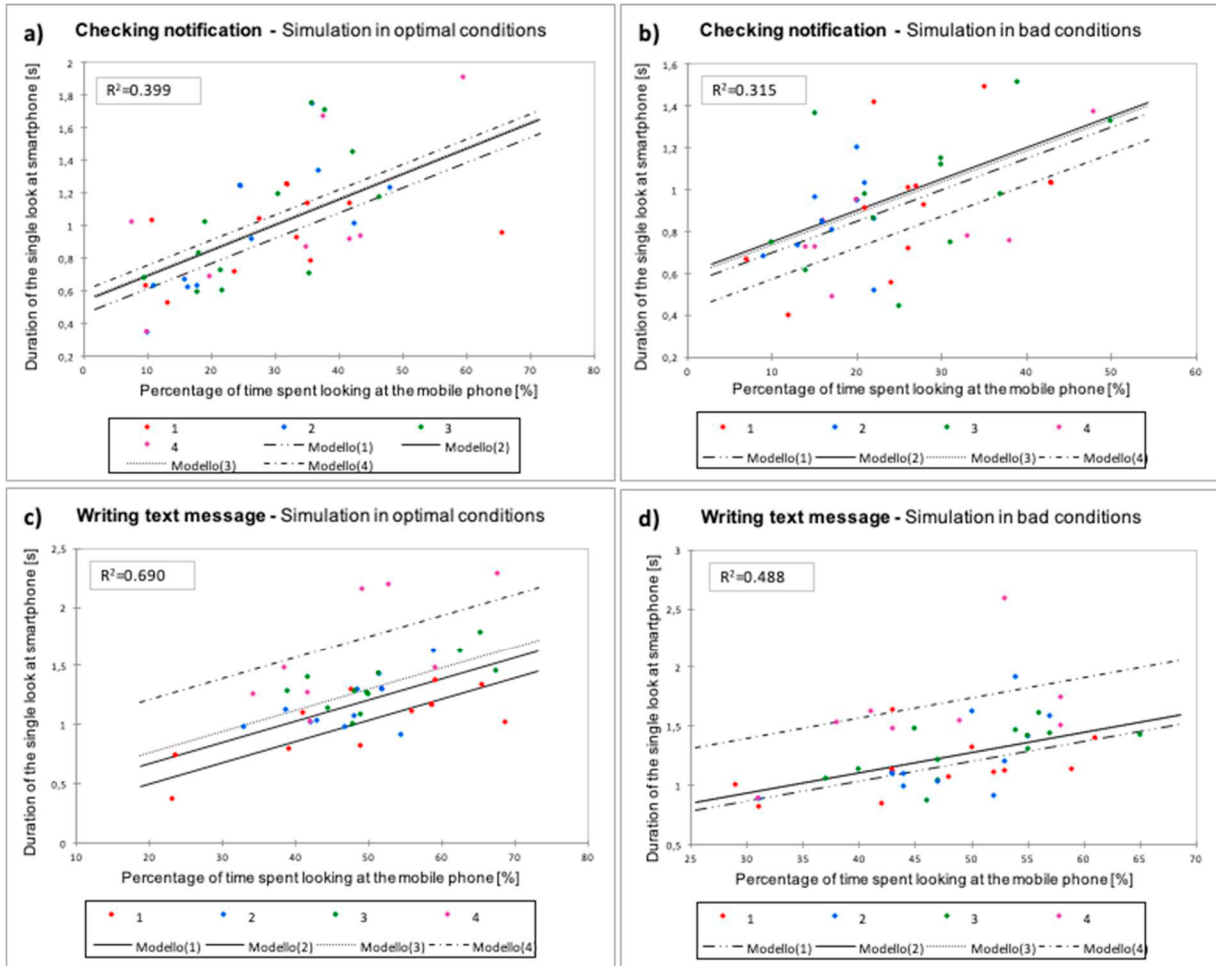


Fig. 5. Checking notification and texting - Age classes.

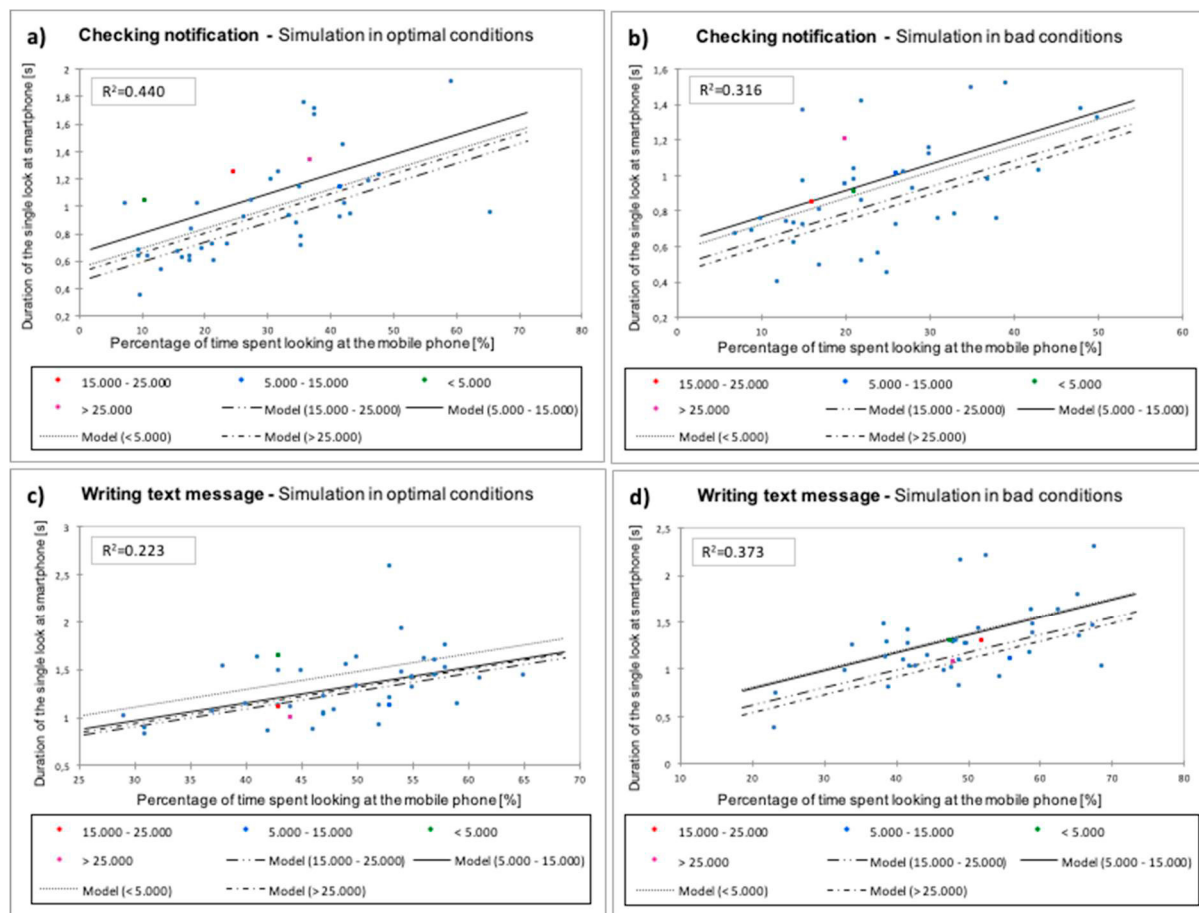


Fig. 6. Checking notification and texting – Driving experience.

4.3. Results of the questionnaires completed after the simulation test

Although the use of a high-fidelity driving simulator like the one used in the experimentation may reduce the degree to which driving tasks are perceived as artificial, it does not guarantee the complete elimination of the fictional effect. The questionnaire submitted to the drivers at the end of the two simulation tests was aimed at evaluating the perceived differences between real and simulated driving. The answers provided by the 40 participants led to the following results:

1. Comparison between simulated and real driving:

- the average score assigned by the drivers to the comparison between simulated and real driving was 4.9 on a scale from 1 (totally different) to 10 (very similar). 62.5% of the drivers assigned to the comparison a score equal or superior to 5, on a scale from 1 (totally different) to 10 (very similar), which means that they considered simulated driving quite similar to real driving. Nobody considered the two types of driving to be truly similar (Figure 7)
- the effort required by the simulated driving (Figure 8) was evaluated with an average score of 50.03, in an intermediate position between "Some efforts" and "Very tiring" in the scale shown in the questionnaire.

2. Comparison between mobile phone use in simulated and real driving:

- 72.5% of the drivers considered smartphone activities to be quite similar in simulated and real driving
- nobody perceived the commitment necessary to perform the smartphone task required during the simulated test totally different from the commitment necessary to perform the same activity during real driving (Figure 9)

- the drivers assigned an average score of 61.35 to the perceived effort in carrying out the smartphone activities requested, which represents a "very tiring" effort (Figure 8).

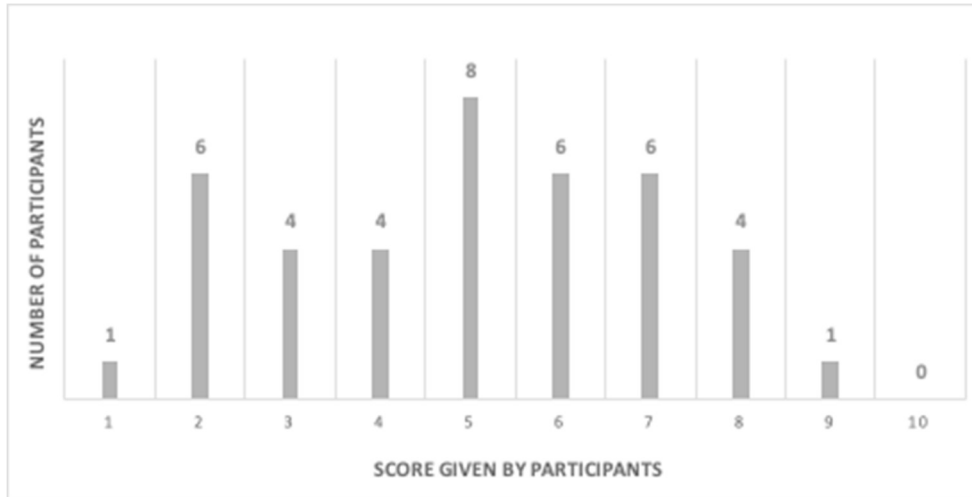


Fig. 7. Frequency distribution of the scores given by the drivers to the comparison between real and simulated driving efforts.

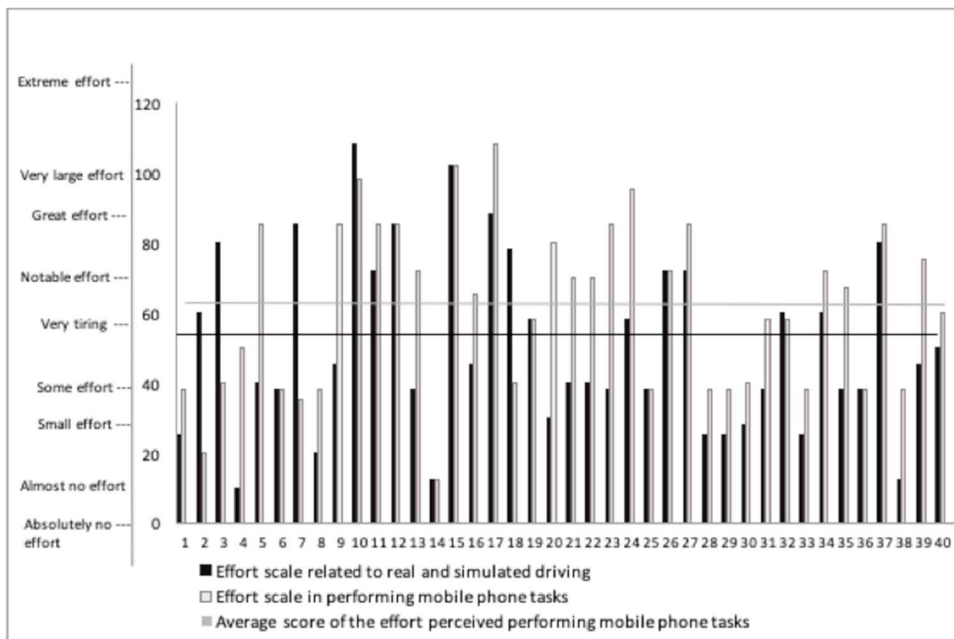


Fig. 8. Level of effort perceived during simulated driving compared to real driving (dark grey), and level of distraction given by the smartphone use in simulated driving compared to real driving (light grey).

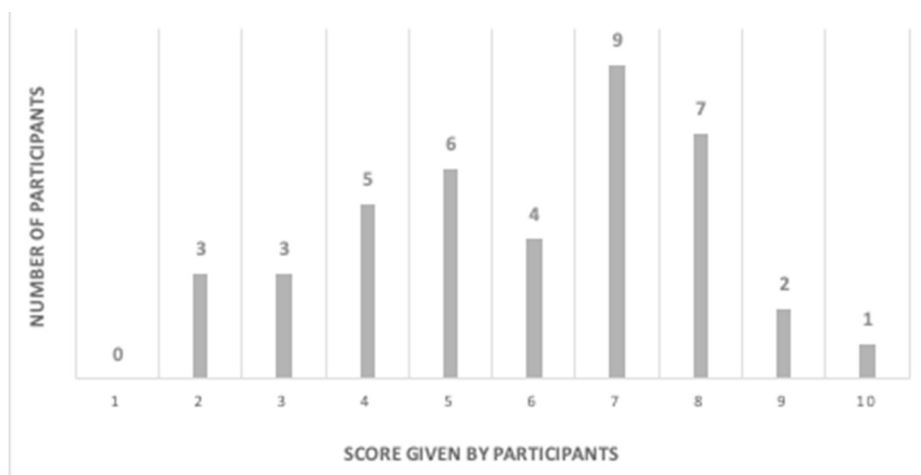


Fig. 9. Frequency distribution of the scores given by the drivers to the comparison between the perceived level of distraction due to smartphone use in real and simulated driving.

5. Discussion

Based on the results of the performed descriptive and inferential analysis, this section attempts to give an answer to the three research questions introduced in Section 2.

Before entering the discussion, some considerations on the limits of simulated driving studies are appropriate to transparently read the importance of the results in relation to the often-criticized lack of realism of simulated driving compared to real-world driving (Svenson and Patten, 2005). It is a widespread opinion, also shared by the authors, that a highly immersive virtual environment can help make the driving experience more real but cannot completely undo the different sensitivity of the driving instrumentation of the simulator (steering wheel, pedal without clutch and automatic transmission) as well as the awareness of driving in simulated conditions. In fact, even the drivers who took part in this experimental research highlighted some difficulties in associating virtual driving with real driving (on the other hand, they perceived the level of distraction and the effort related to carry out telephone activities in simulated driving as quite similar to those experienced in real life). It is worth pointing out that simulation limits such as those mentioned above are largely offset by several key advantages that only driving simulator studies can guarantee, two above all: control of driving parameters and safer conditions for participants (Oviedo et al., 2016; Collet et al., 2010).

In this research, without renouncing the fundamental characteristics of the phenomenon, a small share of realism was given up in favor of a risk-free analysis for drivers and third parties both from the point of view of road safety and compliance with road regulations (the use of mobile phones while driving is prohibited by law).

5.1. RQ 1: Does the visual distraction effect of the smartphone when driving vary depending on the surrounding driving environment (traffic, lighting, and weather conditions)?

Important information was derived from the experimentation regarding the influence that traffic, lighting, and weather conditions can have on driving performance. The average percentage of time looking at the smartphone was found to decrease during the driving test in bad conditions. It appears that when drivers perceive the worsening of environmental conditions and the related risks, they reasonably focus more on safe driving than on phone activities. Similarly, the reduction recorded for the variable “Distance travelled without looking at the road” during the driving test in bad conditions confirms the greater attention drivers devote to the road in the presence of adverse environmental surroundings. The reduction in the percentage of time with the gaze on the mobile phone and the distance traveled without looking at the road during the simulation in bad conditions proves that drivers adjust the visual-manual activities at the phone in relation to the perceived driving context (Christoph et al., 2019).

The statistical significance of these results was confirmed by ANOVA and ANCOVA. ANOVA confirmed statistically significant differences between the two tests in good and bad conditions, thus indicating that worsening lighting, traffic and weather conditions induces more cautious driving behavior and a reduction in speed (Table 1). A strong contribution provided by this work is given by ANCOVA, because it investigated the relationship between age, driving experience and percentage of time spent looking at the smartphone. ANCOVA confirmed that the surrounding driving conditions statistically influence the distance traveled without looking at the road, especially during phone conversations and texting (Table 2).

5.2. RQ 2: Does the visual distraction effect of the smartphone when driving vary according to the age, experience and gender of the driver?

This is the main contribution that this work provides to the literature because it investigates in depth the topic of distraction, finding the relationships between the different tasks that can be carried out using a smartphone and some driver characteristics, such as age, gender and driving experience. Previous studies have investigated specific or single tasks (Rumschlag et al. 2015), but none have analyzed them all together and compared.

Several information on the influence that the driver's age, experience, and gender may have on visual distraction derived from the experimental study. Based on the analysis of the "average number of the looks on the mobile phone" variable, especially age seems to influence distracting behaviors related to the use of the smartphone behind the wheel (Figures 5 and 6). According to the results of the simulation tests performed, older drivers (50-65 years) seem to divert their visual attention from the road more frequently when performing mobile phone tasks.

ANOVA results confirmed from a statistical perspective the influence that age and gender can have in carrying out telephone tasks while driving, especially reading text messages. Female and younger drivers (aged between 20 and 29 years) performed statistically differently in the two tests when reading text messages. They seem to feel more the worsening in surrounding driving conditions and consequently focus their attention more on the road than on the phone while reading text messages. Compared to older drivers, younger drivers look at their phones less when they read a message and drive shorter distances without looking at the road.

When texting, older drivers (50 - 65 years) focus on their smartphone screen for a longer time than younger drivers in both simulated driving conditions. This result confirms previous studies according to which sending WhatsApp messages while driving produces a general deterioration in driving performance for all drivers, but more for elderly drivers. The visual distraction associated with the use of a mobile phone behind the wheel also appears to be influenced by the driving experience, which in this study was considered in terms of kilometers driven in the previous year. The parallel lines in Figure 6 suggested markedly different behavior between more experienced and less experienced drivers. When checking notifications or texting, more experienced drivers give the phone shorter looks than less experienced drivers. A possible explanation could lie in the fact that more experienced drivers, by spending more time behind the wheel, are more likely to use the phone while driving, thus getting used to fast use.

5.3. RQ 3: Is there a phone task that impacts driving distraction more than others?

The answer to the third research question is partly included in the two previous questions. Using the mobile phone to send and read text messages while driving is believed to be the most visually engaging and the most demanding activity in terms of concentration required (Knapper et al., 2015; Ortiz et al., 2018). This belief found further experimental evidence in this study. The variables "percentage of time with the glance at the phone", "distance traveled without looking at the road" and "duration of individual glances at the phone" while writing and reading text messages showed the greatest and most significant variations, both based on driving conditions and personal characteristics of the drivers. In particular, the longest distance traveled without looking at the road was recorded for older drivers when writing text messages. Compared to younger drivers, older drivers need to focus longer on their smartphone screen to write text messages. This may be justified by the less familiarity older drivers have with smartphones, which means they must visually focus on the phone more than young drivers to do the required task correctly, thus taking their attention off the road more often and for longer.

6. Conclusions

This experimental study investigated the visual distracting effect of mobile phone use while driving, in relation to several attributes related to the driver (gender, age and driving experience) and the road (weather, lighting and traffic conditions). The influence of the different attributes on visual distraction was investigated through a simulated driving experiment involving 40 volunteer drivers of different gender, age, and driving experience. Drivers were asked to carry out four mobile phone activities (check notifications, read text messages, talk on the phone, write a text message) during two simulated driving tests, one in good traffic and weather conditions and one in bad conditions.

The variables analyzed in the study were considered representative of the visual distraction due to mobile phone use behind the wheel and include: (1) the number of looks at the mobile phone, (2) the time required to perform the two driving tests, (3) the distance travelled without looking at the road during each phone activity, (4) the percentage of time with the gaze on the mobile phone, (5) the average duration of glances on the mobile phone. Analysis of experimental data using the ANOVA and ANCOVA methods confirmed that the visual distraction effect of the smartphone while driving varies according to the surrounding driving environment (traffic, lighting, and weather conditions) and the age, experience, and gender of the driver:

- bad driving conditions generally induce more cautious driving behaviors and a reduction in speed, and affect the distance traveled without looking at the road, especially during phone conversations and texting
- older drivers (50-65 years) seem to take their visual attention off the road more frequently when performing mobile phone tasks. When texting, older drivers focus on their smartphone screen for a longer time than younger drivers, both in the test in good driving conditions and in the test in bad conditions
- when reading text messages in bad driving conditions, female and younger drivers (aged between 20 and 29 years) seem to perceive more the worsening of the surrounding driving conditions and consequently focus their attention more on the road than on the phone
- when reading a text message, younger drivers look at their phones less, and drive shorter distances without looking at the road than older drivers
- when checking notifications or texting, more experienced drivers (more than 15,000 kilometers driven in the previous year) give the phone shorter glances than less experienced drivers.

The results provide experimental evidence on the influence that drivers' characteristics (e.g., age) and external factors (light, traffic, and weather conditions) have on driving when using a mobile phone. This influence was found both in terms of risk perception and driving activities management, also highlighting to what extent the experience in the daily use of mobile phones must be considered in the evaluation of driving performance.

The findings could support both EU legislators and the automotive sector which are currently working to introduce effective measures to counteract the increasingly worrying phenomenon of smartphone use behind the wheel, and to improve the instruments that limit the use and visual distracting effect of the mobile phone while driving.

The authors plan to expand the research by investigating driving performance when using voice messages instead of phone calls, and smartwatches to read notifications instead of the phone. Furthermore, analysis for single age groups will be performed to investigate the specific variability of driving behaviors of homogeneous groups of users as a function of the specific characteristics of the road layout.

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