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Evaluation of driving risk levels through kinematic, dynamic and psycho-physiological measures

XXXII PhD course

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Abstract

Driver behaviour plays a key role in balancing the interaction between the driver, the vehicle and the road environment. A correct evaluation made by the driver of the potential risks related to the road environment, can improve safety levels and contribute to prevent road accidents. However, risk assessment is a personal and subjective process that can be affected by several factors, which can be classified as internal or external to the driver.

Within this framework, the present PhD thesis aims to understand the effect of these factors on drivers' risk perception by means of an interdisciplinary approach based on driving kinematic-dynamic and psycho-physiological measures estimated in a virtual reality driving simulator environment. In some applications, the driving simulator is used in combination with other tools that aim specifically to detect psycho-physiological parameters.

Five case studies are developed to analyse a number of four human factors. Regarding the internal factors, the present thesis investigates i) the gender difference, ii) the effect of alcohol and iii) the impact of fatigue on driving after a hospital night shift. In regard to the external factors, the effect of using mobile smartphones on the driving performance is studied. To this effect, two applications are carried out considering two different smartphone's activities, social network consulting and messages texting. For each study, a summary of results in terms of risk perception indexes and statistical tests are presented.

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Introduction

Research Motivation

Driving is a complex task, based on a balanced interaction between driver, road environment and vehicle. According to [1], in this relationship, the road safety conditions are assured by proper actions-reactions of the driver. In this regard, the potential risk perception of the road environment, plays a key role.
Relying on the evolution theory of human beings, humans have been capable to identify critical situations due to their ability to predict potential critical scenarios. Therefore, regarding road safety issues, a correct risk perception assessment relates to the behaviour of the driver being adapted to the specificity of the situation, in order to increase safety levels and prevent potential accidents.
The importance of the role and the perception of driver is well-known, and this latter has been given a lot of attention in academic literature review in recent decades [2].
Driving risk assessment is a personal, subjective and complex process that triggers a consequent action. As an example, when a pedestrian crosses down a road, the driver understands the potential risk, estimates the distance from the object and completes the braking maneuver within a sufficient distance assuring safety, both for the pedestrian and to him/herself. In this context, the risk is represented by the pedestrian and the driver's action by the braking maneuver.
However, according to [1] in some cases the risk assessment and the consequent behaviour does not work correctly, exposing drivers to a lack of safety. These refer to scenarios where the risk is correctly perceived, but the behaviour does not match this perception or where the risk does not correctly perceived but it is underestimated.

The human factor has a growing impact on the risk perception assessment causing driver errors that usually lead to crashes. "Error" means the driver did not perform a given task optimally. Misperceptions, slow reactions, and poor

decisions are the products of an impact in the risk perception assessment.
Human factors distort the drivers' perception of the road environment and affect the behaviour by impairing the driving skills. As mentioned by the National Highway Traffic Safety Administration (NHTSA), altered psycho-physiological conditions involve *a lack of attention from the primary task (i.e., the driving task), due to other visual, cognitive, auditory, or bio-metric activities that occur.*
These factors can be internal and external to the driver: internal factors are referred to factors that affect the cognitive and motor skills of the driver as the age, gender, fatigue and the substances assumption; external factors means factors that involve external tasks to the driver, as the smartphone activities that are one of the most cause of distraction.

To date, various efforts from multiple disciplines have been made to obtain understanding of the effect of human factors on driving behaviour by self-report, evaluations, on-road driving observations, computer simulations, etc., with new methodologies constantly emerging to identify and understand the mechanism involved in the altered risk perception due to human factors.
In this context, the scientific research has a crucial role as it can measure the phenomenon by means of indexes and parameters that quantify the impact on driving performances. The support of scientific research can encourage the development of new smart technologies and systems to assist the driver during the driving task and contribute to reduce the number of accidents caused by human factors.
For instance, in November 2017 the European Parliament has approved the proposal to make mandatory the new Advanced Driver Assistance Systems (ADAS) technologies on all the new type-approved vehicles. Some of these are already implemented in vehicles, other are in developing research projects.
All the systems are aimed to alert, highlight, support, and in some case act to fill the potential lack in attention and concentration of the driver during the driving task.

Research Question

In such a framework, the research motivation has pointed out the issue related to the effect of human factor on risk perception. Therefore the research questions could be:

- How much do internal and external factors affect the risk perception assessment process?
- It is possible to stadardise a methodology to be applied in order to analyse different factors with the same analysing method, indexes and tools?
- It is possible to estimate the impact of human factor by quantifying some risk perception indexes?

This PhD project aims to answer to the research questions by taking an interdisciplinary approach and adopting a range of new technologies. A new methodology is proposed to evaluate and estimate quantitatively the driving risk levels by means of a correlation between driving performance and psycho-physiological measures.
To achieve this aim, several virtual reality driving experiment scenarios were created representing the deterioration in risk perception. This study endevours to propose new insights in the drivers' behaviour knowledge paving the way to provide recommendations to specific issues identified.

Gaps in Knowledge

The drivers' behaviour has become one of the main objectives of safety research with a particular attention to the perception and cognition of the drivers. Many road safety studies are developed in the field of human factors, collecting data from several sources that are limited in the depth and quality of information about driving behaviour and performances. Crash reports, questionnaires and historic surveys are some of sources typically used to study and understand aspects related to human factors and consequently to driver behaviour.
Furthermore, in the last decades, analysis based on-road surveys with instrumented vehicles or virtual reality driving experiments have been developed.
Driving simulated data assessment can provide the opportunity to study in details what the drivers really do during a driving test aimed to reproduce a real driving session. Collecting simulated driving data represents a significant evolution in driving research as it allows to study and estimate quantitatively the driver behaviour in terms of objective measures. Drivers' behaviour observed under validated laboratory conditions provide a reliable and accurate reflection of the drivers' natural behaviour performed in an on-road condition. Considering also

the possibility to reproduce in a simulated environment conditions that undermine drivers (that are impossible to reproduce on-road, e.g. alcohol assumption), the benefits of these kinds of surveys are obvious.

Despite an increasing amount of researches on human factors has been done, much effort must be spent in order to standardise the methodology of the investigation of the impact of human factors on risk perception assessment.
A standardisation of the methodology can provide interesting and useful insights to compare from a quantitative point of view different factors by applying the same virtual reality driving simulator procedure and investigating the same literature acknowledged indexes.
This PhD thesis is placed in this context and aims to apply the same specific experimental protocol of a virtual reality driving simulator experiment to different case studies/applications that could involve a potential distortion in risk perception assessment.
Therefore, the present PhD project offers a twofold contribution to the knowledge of the scientific community:

- Individually the case studies represent a single contribution aims to increase the scientific knowledge in the specific research field, that could be the topic related to gender differences, drink and drive issue, driving fatigue after a night shift and driving distraction;
- Generally the application of the same experimental protocol to different case studies allows to investigate and understand in depth how and how much the human factor affects the risk perception assessment in the driving task, by comparing results obtained from different factors.

Obviously, due to the different nature of factors the comparison between them should not necessarily be consider from a numerical point of view between the indexes analysed in the five case studies. Moreover, it could be consider as a qualitative comparison of the results in order to understand and analyse the driving risk levels.

Aims, Objectives and Expected Outcomes

This thesis is based on an interdisciplinary approach to study the driver behaviour both in terms of drivers performances by kinematic-dynamic and geometric measures and psycho-physiological measures.
According to this, the existing body of research can be incorporated into a more comprehensive framework and model, in order to evaluate and ultimately improve individual drivers' behaviour and performances.
Therefore, the overall aim is to understand the impact of the human factor on the risk perception assessment via a correlation between kinematic-dynamic and psycho-physiological measures estimated with virtual reality driving experiments.
To achieve this aim, the following objectives are identified:

- To provide a comprehensive literature review in order to identify traditional indexes, methodologies and tools for the estimation of the risk perception;
- To provide a comprehensive literature review in order to identify psycho-physiological indexes, methodologies and tools for the estimation of the risk perception;
- To provide a risk assessment through kinematic-dynamic, geometric and psycho-physiological measures by means of experimental activities in virtual reality driving environment.

Outcomes arising from the completion of the above objectives, will be used as input information to build a more comprehensive profile of driver's behaviour.
In this regard, some expected research outcomes are listed below:

- An enhanced and more comprehensive definition of the characteristics of driving performance decays due to human factors;
- An improvement in the knowledge of the impact of human factors on driver's behaviour;
- New insights contributing to develop recommendations on road safety-related matters.

Tools, Methods and Indexes

A set of tools, methods and indexes are involved in this thesis project to answer to the research questions, achieving goals bridging the interdisciplinary boundaries between driving performance and traffic psychology.

The main research tool is the virtual reality driving simulator (that will be describe more in depth in paragraph 2.1), an advanced system able to reproduce a driving test in a simulated road environment allowing to study and investigate quantitative aspects of drivers' behaviour.
The driving simulator allows to record several geometric and kinematic-dynamic parameters that permit to describe a comprehensive pictures of driver during the driving task.
Furthermore, the driving simulator is able to connect and syncronise with other tools in order to improve the analysis of the driver's behaviour by recording psycho-physiological parameters. The tool that is typically used coupled with the driving simulator is the eye tracking system.
Eye-tracking systems are designed to capture natural visual behaviours in any real or simulated environment. From a hardware point of view, the device uses a type of infrared lighting in combination with high-definition cameras, to project light into the eye and record the direction in which it is reflected by the cornea. This technology allows to study and measure visual behaviour and the eye movements, since the position of the eye can be mapped in frames per second. Through advanced algorithms, it is in fact possible to calculate the position of the eye and determine exactly where the gaze is focused both on a real scenario and on a virtual reality scenario.

A review of scientific literature shows that different methodologies exist to estimate the risk perception and consequently its distortion due to human behaviour alterations. Among these, two sets of methodologies have been selected for the purposes of the present thesis.
First, traditional methodologies are typically based on driving performances analysis in terms of geometric, kinematic and dynamic measures. In addition, surrogate measures are useful indexes in road safety evaluations in order to have a more comprehensive picture of the driver's response during the driving task.
On the other hand, psycho-physiological methodologies involve monitoring of stress and concentration levels due to variations in mental loading during a driving task that is a useful information for the driving behaviour analysis.

Among these methodologies, several risk perception indexes are selected and examined to understand the driving behaviour under investigation. Typical measures are speed, acceleration, pressure on brake pedal, reaction times or blinking, frequency and heart rate for psycho-physiological measures.

Thesis Structure

In this section, the thesis structure will be shown to facilitate readers.
After the introduction that has shown the research motivation, the statement of the problem, the research framework and the thesis' aim and objectives, the literature review and the research framework where the thesis project lies, is proposed in chapter 1.
More in detail a focus on the concept of risk perception is presented taking into account the existing relevant literature review.
Afterwards an explaination of the methodology used (chapter 2) in the case studies is presented looking at the used equipment to carry out the experiments, the recruitment and the validation of the sample of participants, the data collection and processing procedure, the definition of the risk perception indexes and lastly the approach to the analysis of the results.
It should be noted that, since the methodological approach is similar in all the experiments, it was decided to dedicate a specific chapter to the applied methodology before the description of the specific case studies in order to avoid repetitions in all the chapters dedicated to the analysed human factors.
In such a framework, the chapters 3 and 4 show the developed experimental researches aiming to investigate the impact of the internal and external factors on risk perception.
More in depth, in the chapter 3, three studies concerning the internal factors are presented.
The first research (Paragraph 3.1) aims to evaluate the difference in terms of drivers' behaviour of male and female drivers. Parameters analysed is the risk perception in a urban road simulated environment. Three driving performance indexes are studied in terms of average value and standard deviation using two different pavement conditions (wet and dry).
The second research (Paragraph 3.2) aims to quantify the effects of alcohol on driving task by means of driving and psycho-physiological measures. In fact, the driving simulator has been used coupled with an eye tracking systems that has

recorded the blinking and its rate during the overall driving test. The reaction time in approaching to specific events, the driver trajectory, the speed and the baking behaviour are recorded and a comparative analysis with the eye movement measures is performed.
The third study (Paragraph 3.3) deals with the evaluation of the effects of driving fatigue on the driving performance of a sample of medical doctors after experiencing a hospital night shift. The experiment is carried out by using the driving simulator and a sample of ten doctors, nurses and other hospital staff recruited from a Hospital in Rome, Italy. The simulated test was performed twice: firstly in awake condition, in order to record a baseline condition, and afterwards immediately after a night shift.
In the chapter 4 the effects of the external factors on risk perception, as the use of social network and mobile smartphones during driving, are investigated.
The first research (Paragraph 4.1) aims to evaluate whether, when and to what extent the use of mobile phones for social network activities while driving affects the driver's performance and impacts on road safety. A sample of forty-five subjects took part to the experiments and drove the scenarios while involved in different social activities with the smartphone at a growing level of task complexity. The collected dataset was analysed and compared between the scenarios, for each event, in terms of driving performance and surrogate safety measures.
The second research (Paragraph 4.2) deals with the distraction caused by smartphone activity, in particular texting activities. In a virtual reality road environment a specific protocol has managed the alternation of primary task (driving) and secondary task (texting) in order to detect the distraction on the driving task. Furthermore, the effectiveness of in-vehicle applications able to read and write text message are tested.
At the end of case studies presented in chapters 3 and 4, a chapter of general discussions and conclusions is dedicated (Chapter 5). A general summary of empirical results is provided, mapping the achieved results against the set objectives of the research. Furthermore, practical and theoretical implications of the present PhD project are pointed out, highlighting also the limitations of the research emerged from the analysis of the results. Finally, insights for future research developments are proposed to promote improvements in this research area.

Chapter 1

Literature Review and Research Framework

1.1 The concept of Risk Perception

Risk perception has been a topic of wide scientific debate for decades, and still holds as a point of interest for researchers belonging to different disciplines. Indeed, important contributions to the current topic-related knowledge have been produced by scientists operating in a wide range of fields, spanning from geography to sociology, from engineering to political sciences, from anthropology to psychology. As an example, geographical researches have originally focused on understanding human behaviour when facing natural hazards, but over time have broadened their interest up to include technological hazards as well [3].
In the mankind evolution process, individuals have developed the ability to predict (i.e. to foresay whether an event or action is likely to happen in the future, especially as a result of pregress knowledge or experience) the potential evolution of specific critical situations. For instance, we are afraid of falling down from above as, based on our experiences, we know that we would get hurt.
Accordingly, the risk perception assessment is personal, as it is a reflection of the social context an individual finds him - or herself in [4]. In fact, sociological [5] and anthropological studies [6] have shown the perception and acceptance of risk to be rooted in social and cultural factors.
Tackling such a topic, Short [5] argues that response to hazards is mediated by social influences transmitted by friends, family, fellow workers and respected public officials. In addition, Douglas and Wildavsky [6] assert that people, acting within social groups, downplay certain risks and emphasize others as a means of maintaining and controlling the group.

Instead, psychological research on risk perception has been rather focusing on empirical studies concerning probability assessment, utility assessment, and decision-making processes [2].

In general, the concept of risk perception holds as a very challenging matter, involving various declinations. In fact, on one side, the risk perception at the country scale plays a key role in the economic policies of many nations as a crucial factor affecting acts of leaders and rule-makers, whereas it also concerns psychological personal aspects of the human behaviour.

A widely debated topic in which this latter individual-based risk perception assessment stands as a crucial point is the driving behaviour, i.e. the driver's ability to predict the potential risk of the road environment in order to perform the required maneuvers with promptness. Scientific contributions on the driving risk perception generally aim at understanding and estimating the drivers' risk perception in specific road situations to recognise unsafe conditions and act in order to reduce the relate fatalities [7], [8]. In fact, according to [1] a complex cognitive process between a stimulus and an action, namely, perception – recognition – decision – action has been found.

By referring to a typical road situation, the stimulus might come from the road environment, e.g. an approaching vehicle from the right side that has the left turn signal on, whereas the action would be in this case the braking of the driver to avoid the collision with the approaching vehicle. It is worthwhile noting that a sound risk perception leads the drivers to brake on time, i.e., with the distance with the other vehicle being enough to stop. On the contrary, an impaired or distorted risk perception might affect the braking maneuver, thereby leading to an accident.

1.2 Driving risk perception

As mentioned, the assessment of driving risk perception is a personal, subjective and complex process that induce a consequent behaviour.

According to [4], in order to investigate the evaluation of perceived risk, three levels of risk must be considered: personal, familiar and general risk. The study of Sjöberg aims at defining a mean risk judgment for each levels with respect to 15 classes including the most known risks. Results have demonstrated the class "traffic accident" to hold the highest rating for both personal and familiar risk levels. In addition, the relevant rating differences between the three trends are

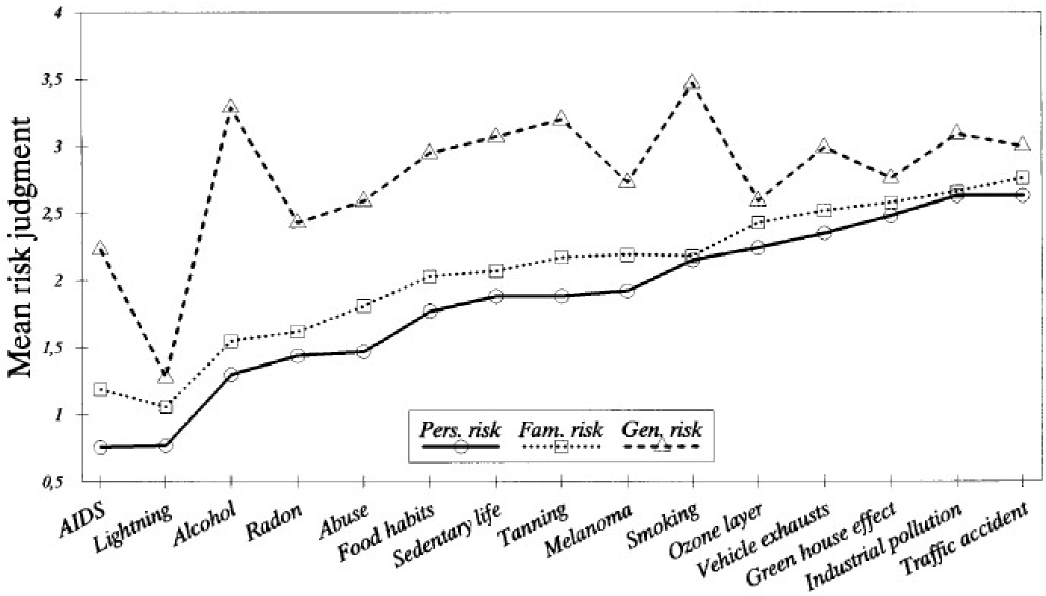

Figure 1.1: Classification of three levels of risk by [4]

observed to be among the lowest.

Accordingly, the definition of a method for effectively estimating the driving risk perception in different road situations is a very complex matter, with very crucial implications.

Based on a topic-related literature review, different techniques have been proposed over time. Some of these are traditional, such as questionnaires and statistical analysis, whilst others are more innovative as the case of virtual reality driving simulator.

Among the traditional methodologies, questionnaires and psychometric models allow to analyse the common driver behaviour through the examination of the users' replies to the queries about their driving habits.

As an example, Slovic [2] has examined the opinion that people expressed when being asked, in a variety of ways, to evaluate hazardous activities by a psychometric paradigm. This research was aimed at developing techniques for assessing the complex and subtle opinions that people have about risk or, in other terms, at assessing what people mean when stating that something is (or is not) "risky," and at determining what factors underpin those perceptions. In addition, Sjöberg [4] has proposed a risk assessment model in which attitude, risk sensitivity, and specific fear are used as explanatory variables. The model offers a different type of psychological explanation of risk perception, and it has many implications, e.g., a different approach to the relationship between attitude and perceived risk, as compared to the usual cognitive analysis of attitude. The author observed that attitude plays a prominent role in such these models.

Regarding the innovative techniques of risk perception assessment, driving simulator is well acknowledged as one of the most effective methods allowing the study of driving parameters typically based on driving performances in terms of geometric, kinematic and dynamic measures. Indeed, it permits to record several measures at a very high frequency, thereby allowing to reconstruct a comprehensive and almost continue picture of the driver's behaviour during a certain route.

Among the measures of driving risk perception typically observed by means of the driving simulator, the Reaction Time (RT) [9] to specific hazardous stimuli (as the presence of a pedestrian that crosses down the road or an intersection or a red traffic light), the Time To Collision (TTC) [10] to evaluate the time required to the driver to reach the point of conflict if he does not change the speed, the Time To Zebra (TTZ) [11] if the point of conflict is a pedestrian crossing and the Post-Encroachment Time (PET) are the most important time-based indicators applied to describe the driver behaviour [10]. In addition, speed values are usually related to the perceived risk as the speed trend is directly influenced by the level of risk perceived by the drivers [12], [13].

Moreover, some parameters allow to understand the driving behaviour with respect to specific maneuvers, as the measure of the Pressure on the Brake pedal (PB) and the deceleration rate (d) for analysing the perceived risk in the braking performances, or the Braking Response Time (BRT) in a typical car-following paradigm [9]. Furthermore, some researchers have defined a synthetic risk evaluation indicator (Risk Perception, RP) to quantify the lane-change risk [7].

Another class of measures describing the driving behaviour, the psycho-physiological parameters can be recorded and synchronised with the driving simulator parameters in order to include the monitoring of stress and concentration levels due to variations in mental loading during a driving task [14].

The stress phenomenon, that has been defined by [15] as a reaction from a calm state to an excited state to the purpose of preserving the integrity of the organism, has an effective impact on the driving behaviour. Two declination of stress are defined: eu-stress is a good stress such as joy, or a stress leading to an eventual state which is more beneficial to the organism; instead, di-stress is a stress with negative bias, which while driving is typically caused by an increase in driver workload [16]. In such a framework, various indicators of stress are known to be highly reliable in the driving context, as the electrodermal activity [17] measured by the skin conductance tool, the heart rate [18] [19], the respiration rate and the electroencephalographic data [20].

Instead, concerning the concentration levels, the eye tracking system is the most used tool to investigate the changes in risk perception due to lack in concentration while driving. Fixation duration [21], blinking duration and blinking rate [22], the variance of fixation position, horizontal or vertical search [23], are the most common indexes.

Several factors affecting the driving risk perception might cause a driving error that usually lead to crashes. An error occurs when the driver does not perform the driving task optimally. Misperceptions, slow reactions and poor decisions are the products of an impact in the risk assessment.
Five human factors are selected and investigated in this PhD thesis: in terms of internal factors, the effect of gender, alcohol and fatigue after a night shift have been studied, whereas among the external factors, the use of mobile phone for two kinds of different activities, namely texting and social network consulting, is studied.
In the following section, an overview of the human factors-related scientific literature is reported.

1.3 Human factors influence

Human factors can be sorted into internal and external to the driver. Internal factors are referred to as those factors affecting the cognitive and motor skills of the driver, such as age, gender, fatigue and the substances assumption. On the opposite, external factors involve tasks external to the driver, such as the smartphone activities or limited visibility condition that might affect the distances and road hazards perception.

As far as the internal factors are concerned, it is well known that significant differences in the style of people driving, which reflect in different risky driving behaviour and traffic accident involvement, have been found. Following this assumption, many studies have been conducted to assess the differences in groups of people with similar characteristics, as age or gender. In particular, previous studies [13], [24] have analysed cognitive and psychophysiological differences having significant impacts on the assessment of risk perception while driving.
A recent Italian study [25] shows that the difference in stress levels influences all the various aspect of human behaviour and, in this regard, [26] confirms that

these differences in lifestyles could affect their risk perception, also while performing the driving task.
According to several sociology researches the stress levels are different between genders and, specifically, women are found to be affected by higher stress levels than men. In particular, [27] have represented the trend of stress levels along a day and has underlined a different trend between genders, almost opposite, with two main peaks for women's trend in two different moments of the day [28]. Concerning the matter, in [14] authors have demonstrated that driving performance and control capabilities may vary significantly depending on the gender-related stress levels. From a general point of view, further topic-related researches [29], [30] claim that, due to biological causes, females perceive risks as greater than males do.
Major goal of this research field is to understand the magnitude of this difference in terms of risk perception while driving. In this regard, the driving simulator represents a viable solution to record kinematic and dynamic parameters to provide an objective measure of perception of risk.

As well addressed, gender is an intrinsic internal human factor, that have a biological and life-style nature and, as demonstrated by several studies, necessarily has an impact on the driving style and risk perception. Nevertheless, other internal factors affect the risk perception assessment by impairing the ability of recognition, the space and time perception and the reflexes, in specific driving conditions. Among the other, alcohol is one of the most acknowledged cause of accidents.
Drink-and-drive phenomenon is a widely debated topic, which is the at the base of social and political issues. Despite the effects of alcohol is well known, in many country the use of alcohol in everyday habits has become a deeply rooted cultural practice not only for young drivers, but also middle-aged drivers that always had different drinking habits. World and European data depict the alcohol as the cause of many road accidents, declaring that 5% of deaths in the world are caused alcohol-relatedby accidents [31].
Indeed, alcohol affects various brain functions, compromises the psycho - motor skills and impairs the capabilities of perception, attention, processing and evaluation.
From a road safety point of view these effects are extremely worrying, as alcohol is identified by several studies [32] as the most important human factor responsible for the alteration of risk perception. In detail, alcohol assumption represents a hazard for road safety not only as impairs the driving risk perception, but also

as it reduces the perceived negative consequences of risk-taking [33] and alters decision-making processes while driving. Accordingly, who drives under the effect of alcohol is not aware of exposing himself and the others users of the road to high risk, and of the potential consequences of such a risk [34], [35].
The statement of the problem seems extremely serious; hence, many awareness campaigns and research studies are aimed to study more in depth the phenomenon in order to promote the consciousness of drink-and-drive, as in the French case of study [36].

Similar effects to the alcohol impairment on driving are caused by fatigue. Fatigue is a gradual and cumulative process associated with a disinclination towards effort, eventually resulting in reduced cognitive performance efficiency [37] that reflects on the driving performances as well [38].
A report of the European Commission [39] highlights that a person who drives after being awake for 17 hours has twice the risk of crashing than the baseline condition (i.e. rested driver), which is equivalent to the risk at which he/her would be subjected if driving at the 0.5 Blood Alcohol Concentration (BAC %). In fact, this phenomenon is another main cause of road accidents and, as reported by [40], in Europe it causes from 1 to 4% road accidents.
The fatigue has attracted researchers' concerns with particular reference to the drivers usually working along night shifts. In fact, people exposed to shift-work can have major disruptions in sleep and circadian rhythms [41], [42]. Circadian disruption and sleep deprivation can also lead to reduced waking alertness, impaired performance, worsened mood and fatigue [43].
Therefore, the fatigue phenomenon is not only a major concern for work safety but also for traffic safety. Indeed, traffic accidents in work-to-home routes is one of the major causes of injuries and deaths among workers [44], [45].
Some previous studies have analysed the complex challenge that who has to stay awake for many hours has to face while driving [38], [46]. In fact, working under sleep deprivation increases fatigue and risk of driving errors [47].
Although the phenomenon has been already widely investigated, more scientific evidence is needed to evaluate the exact quantitative relationship between fatigue caused by a night work shift and risk perception decay while driving.
In this thesis, with the aim of investigating the effect of the shift-work on the driving performances, a sample of nurses, doctors and sanitary staff from a Hospital in Rome were subjected to the analysis of their driving fatigue after a night shift, by means of the driving simulator.

As mentioned, internal factors affect the risk perception by acting on the driver cognitive skills, whereas external factors concern something that is external to the driver that may cause a shift of attention from the primary task, i.e. the driving task. These external factors can affect the risk perception assessment by distracting or diverting the driver's concentration on something else.

Today the smartphone is an agglomeration of technological devices, more similar to an assistant than a simple device designed to call and text. Smartphones contain not only the phone, but also camera, navigator, radio, videogame console, and allow either Internet access that carries out all the operations performed by a PC. Moreover, a smartphone is typically a device of entertainment with the largest number of applications available for downloading, some of which are social networking apps.

For these reason, the smartphone is one of the main sources of distraction for driving users, as also documented by data provided by WHO [48] stressing out that more than one million of death per year are caused by distraction. In Italy, the ACI - ISTAT data for 2017 report that in the extra-urban context, 40.8% of the accidents occurred (about 175,000) are due to incorrect driving behaviour, incorrect use of the rules, and distraction to driving [49]. Even though the use of the smartphone while driving increases the chances of accidents, in many countries the distracted driving due of smartphones remains a growing issue that call on the legislators to ban its use with the penalty of withdrawal of the driving license.

Many studies have been focused on the evaluation of smartphone use on-hand or hand-free mode, both for calling and texting. The hand-free mode typically requires a vocal assistant that through specific commands guide the user. According to Mehler [50] the vocal assistant reduces the mental workload, visive and tactile distraction of the driver in these activities. However, the vocal assistant design must be very accurate in order to have an efficient recognition, quick, fluid and without errors in understanding. Otherwise, as demonstrated by Tsimhoni [51], each misunderstanding lead to an increasing of the required time to complete the task, thereby increasing of driver's frustration and driving performances deterioration.

Nowadays, most of the scientific studies on the effects caused by the use of the smartphone while driving focus on two device's functions: talking and texting [52], [53], [54] [55], [56], [57] [58].

Some studies have tackled the texting task in order to evaluate the difference between smartphones with keyboard and touch screen smartphones. In this re-

gard, as resulted by [52], touch screen smartphones deteriorate the texting performances in terms of time-consuming and collected errors. Main causes are the smartphones' dimensions which make it difficult to handle and the keys recognition by touch. However [61] have highlighted the main factors of the deterioration of the texting performances in the messages length and the complexity of the assigned task.
In this regard, in the present thesis the driving performances recorded by the driving simulator have been analysed to understand the effect of the WhatsApp texting (both audio and text message) and the effectiveness of the AndroidAuto vocal assistant.

Furthermore, although the effect of the use of the smartphone while driving is quite explored, typically in terms of reading, talking and texting, much effort must be oriented to the distractions due to social networking with the smartphone while driving.
In fact, only one published research [60] focuses on the use of social applications while driving (e.g. Facebook, Instagram, SnapChat) and shows that Brake Reaction Times and Time Headway significantly increases in the social-condition compared to the baseline. Furthermore, a questionnaire realised by Basch et al. in 2018 [61] has been subjected to a sample of university students on the custom to use the social network while driving. First results show that about 43% of the 324 interviewed students admitted to scroll the home page of the social network, to read posts and articles, and also to post thoughts and photos on social media while driving. The lack in knowledge on quantifying the effect social activities on driving highlights the need for investigating more in depth the phenomenon by means of an advanced tool as the driving simulator.

Chapter 2

Methodology

This chapter explains the common methodological approach that is used in each of the following studies. It includes the equipment used in the experiments and its validated reliability, the validation method of the sample of participants, the data collection and processing stages, the choice of the indexes that allow to investigate the risk perception and finally the approach to the results analysis with the statistical validation.
As mentioned before since the methodological approach is similar in all the experiments, it was decided to dedicate a specific chapter to the applied methodology before the description of the specific case studies in order to avoid repetitions in all the chapters. For these reason all the common aspects of the method will be addressed in this chapter, while the specific features will described in the specific case study section.

2.1 Equipment

The equipment used for the experiments of this thesis is mainly based on the virtual reality driving simulator.
The virtual reality driving simulator is an advanced tool that allow to study the drivers' behaviour in terms of driving performance.
This tool has many advantages: first, the driving simulator allows to avoid all the risks of field studies permitting to study such topics in a dedicated environment that could be investigated otherwise. Moreover, the driving simulator can control all the aspects of a driving test assuring the same simulated road environment with the same boundary condition (e.g. road geometry, traffic flows, weather conditions, pavement friction, etc.) as many times as required for each driver

that performs the test. It allows accurate statistical validations. Lastly, it allows to collect many parameters that describe all the aspects of the driving test with a frequency up to 10 data per second.

Thanks to this technology, it is possible to carry out effectiveness and reliable scientific analysis avoiding any risk for the participants to the test.

The driving simulator provided by the DriveSimSolution company is located in the Road Safety Laboratory of Roma Tre University, Engineering Department and it is made up of two part, an hardware and a software part.

From an hardware point of view, it is a real vehicle is converted in a driving simulator by removing all unnecessary mechanical parts and replacing it with others connected with the workstation. A mechanism allow to transfer the force feeling defined by the software to the driver controllers (e.g. wheel, pedals and gear) and a speakers system reproduce the sound of a real road environment in the hood of the vehicle to simulate a real driving feel at the best. The high-quality wide image is reproduced in front of the car on a curve wall for a visual angle of 180 degree to assure the frontal and peripheral views. The simulated scenario is projected with lateral and rear-view mirrors.

From the software point of view, the workstation manages and controls all the parts of the simulation, from the scenarios design, images generation, numeric equations, simulation run, driver controllers amng others. It is a performing computer where the simulation software Stisim Drive is installed.

Using the software capabilities, road scenarios are built with objects of Stisim library or by modeling any object with a commercial 3D modeling software. The scenario design process uses a specific language based on events. "Event" is considered each object insert in the scenario, as trees, vehicles, buildings, pedestrian, signs, etc. Scenarios are built by means of three types of files: a configuration file, an event file and a sub-event file that allows to organise the structure of the main event file.

The configuration file permits to define several parameters: the vehicle dimension, the background features, the position of the lateral al rear-view mirrors, the wheel and the pedals feedback, the dynamic aspects of the driving as the pavement friction value and the sound files of the simulation.

Instead, the .evt file, written in a text file, is made up by lines where each line corresponds to an "event" with all the characteristics that specify the position (longitudinal, transversal respect to the driver) and the movement (if the event is dynamic).

The .pde file is a sub-event file that is built with the same rules of the main event file.

This design process assure a high level of realism of the road environment allowing to feel the driver comfortable with direct consequences on the drivers feedback and performances reliability.
More than fifty parameters are recorded in an output file with a very high frequency in terms of time or space, typically 0.1 seconds, that means 10 data per second. The parameters describe, almost continuously, the driving behaviour through the driver controller feedback and the driving performances. The measures is typically speed, acceleration, deceleration described in longitudinal and transversal components, center of the vehicle position on the lane, pressure on pedals, gears, steering wheel angle, etc.
The application fields of the virtual reality driving simulator is typically focused on the geometric elements design, road safety audit, advanced technologies development and the psycho-physiological conditions analysis.
For the psycho-physiological conditions application where the thesis lies, in order to look into the effects of human factors on driver behaviour, the driving simulator is integrated with other tools that allow to monitor the driving performance in terms of kinematic and dynamic measures with a psycho-physiological analysis of the condition of the participant during the test.

2.1.1 Driving simulation reliability

To rely on the driving simulator, it must be correctly validated.
Usually, the validation is based on two levels of validity: absolute and relative. Absolute validity refers to the numerical correspondence between behaviour in the driving simulator and in the real world. Relative validity refers to the correspondence between effects of different variations in the driving behaviour.
According to [62] the relative validity of a simulator is necessary to be a useful research tool. Instead, absolute validity is not essential since research questions typically deal with matters relating to the effects of independent variables, rather than seeking to determine absolute numerical measurements of the driver behaviour.
A great deal of research has demonstrated the relative validity of the driving simulator as a suitable alternative to field studies. Several positives are pointed out as the efficiency, low expenses, safety, experimental control and ease of data collection.
A remarkable amount of research activities has demonstrated that they can be an effective tool for research [63], [64], [65].

More specifically, several findings from the Road Safety research group of Engineering Department of Roma Tre University [66], [67], [68] have proven that the values carried out by simulation tests are representative of real driving conditions. Many previous studies have ascertained the driving simulator validation in different road geometry elements too, as along horizontal curves [69] or performing a deceleration lane [70].
The validation aimed to understand if the driving simulation lead to the same reaction of the drivers behaviour, as in performing a specific maneuver [71], or in limited visibility condition [72], or in a specific case such as during a phone conversation [73].
In particular, the speed as one of the main parameters that describe the driver's behaviour is validated by way of comparison between a field study and a driving simulator study. The comparison between real speeds and the simulated speeds led to the validation of driving simulator as a reliable tool for the analysis of speeds in several different areas.
According to [74] the validation procedure has followed the three steps listed below:

- Field study to collect speed measurements;
- Reconstruction in virtual reality of the real world, using the driving simulator and subsequently running driving tests in virtual reality;
- Comparative and statistical analysis of the field speeds and of the simulated speeds from driving simulation.

In particular, the following conclusions were reached:

- The simulated speeds are slightly different from the field speeds (<1%);
- The maximum negative difference between the real speed and the simulated speed is -7.6 kph, whereas the maximum positive differences +5.6 kph;
- The mean percentage deviation is -4.5%. The difference between the observed speed and the simulated speed were not statistically significant;

The achieved results allow to use the driving simulator as an advanced and efficient tool to developed research studies on drivers' behaviour. Obviously, an

Figure 2.1: Virtual Reality Driving Simulator of Roma Tre University

improvement of the reliability of the simulator, by implementing a moving base system to effectively simulate motion cues, could help to lower the high speed induced by a lower risk perception as well as reduce the greater difficulty in maneuvering in driving simulator.

2.2 Sample of participants

This section aims to explain the method by means of the sample of participant has been selected and validated. This two phases have involved two different statistical methods: the mean stability method [75] and the Chauvenet criterion [76].

The mean stability method allows to evaluate the mean stability on an increasing number of measures in order to define the minimum sample size that ensure the stability of the measures, with variations less than 1%. Typically, speed values are analysed with this method as they are a reliable index of driving behaviour. The Chauvenet criterion, instead, allows to validate data by removing outliers by determining the reliability of a data that belong to a distribution function. The criterion is based on a chosen measure that is representative of the specific investigated factor.

Figure 2.2: A participant during the virtual reality driving test

Figure 2.3: Another participant during the virtual reality driving test

Figure 2.4: A view inside the simulator

Considering N measures of the same variable (x1, x2, x3,...,xn), the average μ and the standard deviation σ. For each values, the difference between that value and the average is quantified in terms of standard deviations, using the following equation:

$$ni = \frac{(xi - \mu)}{\sigma}$$

The probability that a measure differs from the average μ, σ times is determined and the number of expected anomalies equal to n is calculated as the product between this probability and the total number of measures:

$$n = P * N$$

The Chauvenet criterion establishes that the anomalous measure must be rejected when the expected number of anomalous measures n is less than 0.5.
In each case study, the features of each recruited sample in terms of age, gender, demographic characteristics, etc and the result of the Chauvenet criterion will explained thoroughly.

2.3 Data collection and processing

The outputs of a simulation test is collected in a text file .dat, where each parameters has been reported for the overall ride at a specific frequency. More than fifty parameters can be collected in order to describe the driving behaviour of each participant.
From the .dat output file, data are usually processed on an Excel file or by means of an *ad hoc* Matlab code. The result of the processing is typically a series of graphs where the main parameters are in relation with the time or the space.
Some parameters are analysed as they are recorded by the simulator (e.g. speed, acceleration or lateral position), while others are derived by a calculation (e.g. surrogate measures as TTC or reaction time).
As an example, the Time To Collision (TTC) is a derived parameter that allows to evaluate the time required to the driver to reach the point of conflict if he/she does not change the speed. It is obtained by the following calculation:

$$TTC = \frac{Vi}{LVi}$$

where Vi i the initial speed and LVi is the distance between the driver and the obstacle that impose the brake to the driver, at the moment when the driver has Vi as speed, before decelerates.
Moreover, the reaction time is an other derived parameter that allows to calculate the time elapsed from the moment when the driver perceives something and the moment when he/she acts. The reaction time compared to a pedestrian crossing is the time elapsed from the moment when the pedestrian start to cross and the moment when the driver start to press the brake. It is calculated with:

$$RT = Tp - Ta$$

where Tp is the time correspondent to the perception and Ta is the time correspondent to an action.
Furthermore, the simulation system allows to record also some error the driver make during the driving test. As an example, the number of overcoming of the center line and of the edge line, the percentage of the overall ride where the driver overcome the speed limit, the total number of off roads and crashes with other vehicles or pedestrians.

2.4 The selected indexes

Based on the literature review, some indexes are selected in order to estimate and quantify the drivers's behaviour in the considered psycho-physiological impaired conditions.
Two kinds of measures have been recorded and studied: the driving performance-based measures derived from the driving simulator outputs and the psycho-physiological measures by the used-coupled of the driving simulator with the eye tracking system.
The first ones are typically based on driving performances analysis in terms of geometric, kinematic and dynamic measures. Many previous studies [77] have investigated the effects of psycho-physiological conditions on driver performance, as speed, acceleration, deceleration, lateral position and steering wheel movements. These measures are significantly affected by drivers' state and can be considered as the indicators for detecting fatigue, drunk driving and other impaired psycho-physiological condition.
More in details in the further studies, the measures that have analysed are the speed [12] as one of the most reliable index of driving risk levels, typically in terms of average (AvS) or, respect to a braking, the Difference of Speed (DS) or the Initial value of Speed (Si). The Reaction Time (RT) to some hazardous stimuli specifically designed in the driving scenario in order to stimulate the driver's reaction. Furthermore to understand the impact of human factors on the trajectory, two indexes are examined: the average lateral position or the average of the trajectory (AvT) to understand the trajectory kept by the driver on average on the entire route, or some interesting parts of it; and the Standard Deviation Lateral Position (SDLP) index that take into account the lateral oscillations of the trajectory around the average. A high value of SDLP can be lead to heeling phenomenon.
Moreover, some specific maneuvers have been examined to study more in depth the kinematic and dynamic parameters of the driving behaviour. The stopping maneuver has been forced in the simulated scenarios by means of different obstacles that lead to a braking, in order to record the average and standard deviation value of deceleration (d), the Pressure in Brake pedal (PB) that is a reliable index of risk perception [78], and the Slip Ratio (SR) [79] that allows to understand when the driver performs a braking with a friction value over the maximum limit of fiction.
The overtaking maneuver is studied in terms of number of overtaking in percentage (O%) on the entire route respect to the baseline recording to understand the

effects of the considered human factors on the behaviour.
The car-following maneuver are typically implemented in the simulated scenarios with a leader vehicle with a speed about 10% lower than the driver, that after a fixed space (between 500 and 1000 meters) suddenly brakes in front of the driver. The measures car-following related usually analysed are, besides the RT values at the moment of leader braking, the initial, minimum and the average distance between the leader and the driver (Di, Dmin and Dav).
Finally, the pedestrian crossing, both legal and illegal, respectively if the pedestrian is on the proper zebra sign or not, in terms of Time To Collision (TTC) or Time To Zebra (TTZ), deceleration and initial speed. In addition the Speed Reduction Time (SRT) is analysed. In fact, surrogate measures are useful indexes in road safety evaluations [10]. TTC is the most important time-based indicators used to describe the driver behaviour [80] as it allows to estimate the time since driver perceives the obstacle, removes the accelerator pedal and starts to brake until the obstacle itself. Therefore, it deals right with the driver's perception and action.
Moreover, the psycho-physiological measures, recorded by the eye tracking system, allow to investigate the changes in risk perception due to lack in concentration while driving task. According to literature [81] [82], eye-related indexes are a quite direct reflect of specific cognitive processes. Moreover, in order to understand how much the considered human factors affect the eye movement and the ability of concentration, the blinking and its rate [22] are calculated taking into account the baseline values. Moreover, the variance of fixation position, both horizontal and vertical search [23] is examined in relation to the available simulation view.

2.5 Statistical validation of results

Before the interpretation of the results, on the basis of the defined indexes to be investigated, a statistical validation is required.
Typically, in a driving simulator study, the aim is to evaluate the correlation between some characteristics or to understand if by modifying a specific variable, it is possible to change specific parameters.
The statistical test usually used are those that allow to accept and reject an hypothesis. Based on all test, the null hypothesis means that no relationship between the investigated variables is found. Moreover, the aim of each statisti-

cal test is to accept or reject the hypothesis. Rejecting the null hypothesis the alternative hypothesis is accepted, i.e. a relationship between the test variables is observed. In each study, although the sample is representative of the overall population from a statistical point of view, the sample could not be the overall population regardless of the dimension of the study. In addition, results of a statistical test are expressed always in terms of probability.
In other words, an error can occur in accepting or rejecting the null hypothesis. However, if the probability to have an error is very low, it is possible to assume correct the achieved interpretation of results. The probability is expressed as p-value and the threshold usually used for the p-value is < 0.05, therefore, the null hypothesis is rejected and consequently the alternative hypothesis is accepted whenever the p-value is less than or equal to 0.05.
Statistical tests can be divided in two groups, i.e., parametric tests and non-parametric tests.
The first category is based on the average and the standard deviation of the values and they must be applied when the normality of the sample is verified and the variable is continue. Instead, when the normality is not verified and the variable is not continue, the non-parametric tests must be used. The non-parametric tests are based on observations ranks and not on real values. Observation are organised in ascending order and at each observation, a number correspondent to the position in the order (rank) is assigned.
The non-parametric tests are based on the comparison between the sums of the ranks and not on the real values.
Main types of test, typically used for the analysis of simulator data are:

- Analysis of variance (ANOVA) to compare the effects of a independent variable on a group of dependent variables. To apply the ANOVA test the sample must satisfied two condition: the normality and the homoscedasticity.

- Kruskal-Wallis test if the normality condition is not satisfied, but homoscedasticity is satisfied;

- Brown-Forsythe procedure if the normality condition is satisfied, but homoscedasticity is not satisfied;

- Median test if both the normality and the homoscedasticity are not satisfied.

To summarise, considering a sample of data, if the normality and the homoscedasticity are fulfilled, the ANOVA test is applied. If the assumption of

normality is violated, but the assumption of homoscedasticity is satisfied, a non-parametric homoscedastic ANOVA, better known as the Kruskal-Wallis test, is applied. This method is the non-parametric test correspondent of the ANOVA test where data are replaces by their rank.
Furthermore, if the hypothesis of normality is validated and the hypothesis of homoscedasticity is not verified, it is possible to proceed with a homoscedastic ANOVA through the Brown-Forsythe procedure. This analysis is a statistical test for the equality of group variances based on the execution of an ANOVA, on a transformation of the response variable.
Finally, if both requirements are not satisfied, the median tests are applied. The median test is a non-parametric test in which the null hypothesis that the medians of the populations of two statistical samples are identical, is tested.

Chapter 3

Internal Factors

3.1 Gender differences on road safety

3.1.1 Background

For decades, researchers have highlighted significant differences in gender and age groups in terms of driving behaviour.
Several studies, concerning gender tackle the different perceptions of risk, traffic accident involvement and risky driving. In particular, as confirmed by several medical studies, the gender difference involves cognitive and psycho-physiological differences, which have a significant impact on the assessment of risk perception while driving. Driving performance and control capabilities are different depending strongly on the gender. A research [83] analyses the force control capabilities (FCCs) as indicator of motor performance. Differences in FCCs can influence driving performance and control capabilities. It is highlighted that the gender has a significant impact on FCCs and in particular, male performance was found to be significantly better than female performance in all the FCCs. This difference in term of motor performance between gender leads to difference in driving behaviour and road safety. In term of driving behaviour, many studies confirm that male drivers have a more aggressive driving attitude [26] and violation of road laws [84] [85]. Otherwise, recent studies report that female drivers are more involved in crashes compared to males, due to different reasons (errors in yielding, gap acceptance, and speed regulations) [86] [87] [88]. Furthermore, recent studies [89] have analysed the correlations between gender differences and the accident data, in relation to different variables, such as alcohol consumption, drugs consumption, social characteristics, etc. These studies were conducted with the use of questionnaires. In the recent years, many studies in the field of road safety

were conducted with the use of driving simulator in virtual reality. These kinds of instruments provide many advantages in terms of analysis, such as, for example, the repeatability of the scenarios in the same conditions. These fact gives the possibility to correlate the dynamic and kinematic characteristics of the vehicles with the different design parameters of the simulated scenarios (traffic flow and road geometry). These tools have also been adopted to characterise the driving behaviour and road safety in age, experience and gender studies. For instance, some research has been conducted to analyse and evaluate the road safety training programs [90] [91] [92]. A research [93] conducted using a driving simulator and an eye-tracking system, has pointed out that age and gender influence drivers' distraction during driving. This is crucial issue due to impacts on road safety. Furthermore, in terms of risk perception, researchers from TU Delft [94] have studied the difference in driving behaviour between males and females in the approach of overtaking. Results show that male drivers overtake more than female drivers, maintain smaller following time gaps from the front vehicle before initiating on overtaking maneuver and have smaller critical gaps. These behaviours contribute to increase the accident risk. In fact, it is well-known that significant differences of drivers' behaviour have been found according to gender due to different levels of stress related to working conditions, family responsibilities and consequent care activities. In this regard, it appears that stress levels are different between genders habits. In fact, at different stages of the day [27] stress and fatigue affect women more than men in the workplace for causes often linked together (including difficulties in reconciling life-work and the unfair distribution of family-care tasks [28]). The differences in roles, fields, professional activities, situations of distress linked to harassment or bullying attitudes[95]. Several studies show that the difference in behaviour is reflected in the different risk perception also due to psychosomatic disorders that may arise due to high levels of stress [25]. A point of interest is to understand the magnitude of this difference on drivers' behaviour through indicators measuring risk perception (simulator, eye tracking system, etc).
These studies were very important in terms of road safety as they allowed the Italian and European Authority to plan specific countermeasure.

3.1.2 Objectives

The aim of this research is to estimate and quantify gender differences in term of risk perception indexes in performing a braking maneuver. The different risk perception of males and females is the cause of different driving styles, driving behaviours and consequently risky maneuvers. Therefore, the purpose is to understand through kinematic and dynamic indicators of the driving performances, what the differences of the males and females behaviour are in approaching and performing a braking maneuver.

3.1.3 Method

The above mentioned methodology of a virtual reality driving experiment is applied and further features of the simulated scenario, sample of participants and data collected are explained in the following paragraph.

Simulated scenario

Firstly, a road simulated scenario is designed (Figure 3.1) to reproduce a typical urban road environment. The road segment was characterised by 10 kilometers length and a cross-section of two 3.50 meter lanes and both-side sidewalks 4.00 m wide. The horizontal road alignment is typically flat. The simulated scenario was implemented according to the Italian rule and regulation the Italian Highway Code (Ministry of Infrastructures and Transports, 1992). Other vehicles are implemented in the scenario with a low level of traffic flow to not affect the driver's behaviour. The real roadside elements, markings and signs were accurately reproduced in simulation environment. Urban buildings, sidewalks, intersections, vehicles and vertical signs are recreated to simulate a real urban environment providing the most realistic conditions. Speed limits were 50km/h as the rules and regulations of an urban context impose.

Moreover, typical events of an urban context were implemented in order to impose to the drivers different brakings where the bahaviour of females and males are studied.

In more detail, two pedestrian crossings and two intersection without the signal lights were implemented. The pedestrian crossing sign was designed in accordance with the Italian Code and previous studies ([96], [97]) with 1.50 m long strips of crosswalks, 0.50 m wide and spaced 0.50 m between each other. At each crossing the pedestrian movement (1.50 m/s) was activated when the driver reached 60 m before the zebra crossing.

Intersections were implemented as a T-sharp intersection with another road with the same geometric characteristics, without traffic lights and at each intersection a vehicle cross the road with a speed of 50 km/h when the driver reached 70 m before the intersection.

Furthermore, in order to study more in depth the different braking performance of male and female drivers, two pavement conditions are reproduced by providing as input to the software a friction value of the pavement. It is imposed equal to 0.8 for dry pavement and 0.4 for a wet pavement ([98]). With this variable, the male and female braking behaviours are studied also respect to the perceived pavement risk.

Sample features

A homogeneous sample of subjects was selected. Furthermore, to avoid biasing of results induced by driver attitude, experience in driving, age, stress phenomena, emotional state or neuro - cognitive status or by other subjective factors, the same driving conditions were generated for each driver. The sample is made up by 40 subjects, 20 women and 20 men, 35 years old on average (ranging from 21 and 43 years), recruited via direct contact as volunteers from the Department of Engineering at the University of Roma Tre. None of the subjects had previous experience with driving simulators. None of the drivers had perceived simulation sickness such as to stop the test.
Through Chauvenet statistical criterion, the number of participants were assessed as significant from a statistical point of view, that assures a correct statistical data interpretation. According to the Chauvenet criterion, no data were rejected.

Procedure

Each driver performed the simulated scenario once and the driving performances of four brakings are recorded. Each session consisted in the driving test and lasted for about 30 minutes.
The test protocol provided a preliminary explanation of the training scenario in order to get familiarisation with the tool, a before-driving questionnaire with driver general information, and the training itself. After the driving test an after-driving questionnaire was provided and finally drivers were requested to fill a questionnaire about the eventual simulation sickness perceived.

Data collection

Three risk perception indexes are selected and studied during a braking maneuver, from the time when the driver starts to brake until the end of braking

when the vehicle stops. The analysed indexes are: time to collision (TTC), the maximum pressure on brake pedal (PB) and the slip ratio (SR).
According to Hayward [99] the time to collision is the time required for two vehicles to collide if they continue at their present speed and on the same path. Moreover, according with Van der Horst [80] TTC at the onset of braking, TTCbr, represents the available maneuvering space at the moment the evasive action starts. TTC allows estimating the time since driver perceives the obstacle, removes the accelerator pedal and starts to brake until the obstacle itself. Moreover, it deals with the time that driver estimates to have before the collision with the obstacle. In this regard, it is calculated as the average value of the TTC calculated for each braking events, that are the two pedestrian crossing and the two intersection that impose to brake to the driver.
High values of TTC indicates a good perception of risk and cautious behaviour, on the contrary a low value indicates a poor risk perception and a higher risky behaviour. In this case, TTC values are measured with respect to each of four events.
The PB is the maximum value of the pressure during the overall braking. It is measured in pounds and is an indicator usually used to estimate driving risk perception [78]. The value is the maximum value of pressure measured during braking due to the obstacle. A high maximum value of pressure could correspond to a low risk perception. The driver due to the obstacle has slowed suddenly, with high deceleration values. On the contrary, a calibrated braking does not require a high value of pressure on the accelerator pedal and therefore the maximum value of pressure recorded is low.
Finally, SR represents the ratio between the value of friction applied during braking, and the value of friction imposed on the pavement by simulator (0.8 or 0.4 in accordance with the condition of the surface of the pavement). Values greater than 1 represent condition of loss of friction at the contact point between the road and the wheel. This condition can be related to poor risk perception that led drivers to brake unsafely.

3.1.4 Results

ANOVA results

All the results are statistically validated with the Analysis of Variance (ANOVA). According to findings in literature [100] [101], the ANOVA test is typically used to highlight the statistical significance of the indexes' values.

Figure 3.1: Driving scenario

In this specific case, as shown in (Tables 3.1, 3.2) the test showed that the variation of the average for the gender factor is always significant (between 95% and 99%) with the exception of TTC in dry conditions. With reference to the friction conditions, the variation has validity lower than those recorded on the gender factor. Generally, the variation ranges between 99% and 90%, with the exception of TTC in men, where the variation of TTC are not statistically validated.

Index	Wet	Dry
Time To Collision - TTC [s]	$F(1,38)$; $p<0.01$	$F(1,38)$; $p=0.70$
Pressure on Brake - PB [pounds]	$F(1,38)$; $p<0.01$	$F(1,38)$; $p<0.01$
Slip Ratio - SR	$F(1,38)$; $p<0.01$	$F(1,38)$; $p=0.05$

Table 3.1: ANOVA test results on gender factor

Index	Female	Male
Time To Collision - TTC [s]	$F(1,38)$; $p=0.10$	$F(1,38)$; $p=0.55$
Pressure on Brake - PB [pounds]	$F(1,38)$; $p=0.08$	$F(1,38)$; $p=0.05$
Slip Ratio - SR	$F(1,38)$; $p<0.01$	$F(1,38)$; $p=0.10$

Table 3.2: ANOVA test results on friction factor

Time to Collision (TTC)

The results about TTC showed a more cautious behaviour for women that begin to slow down before, having the time available for stopping. On the contrary, the values recorded about men are lower than women.

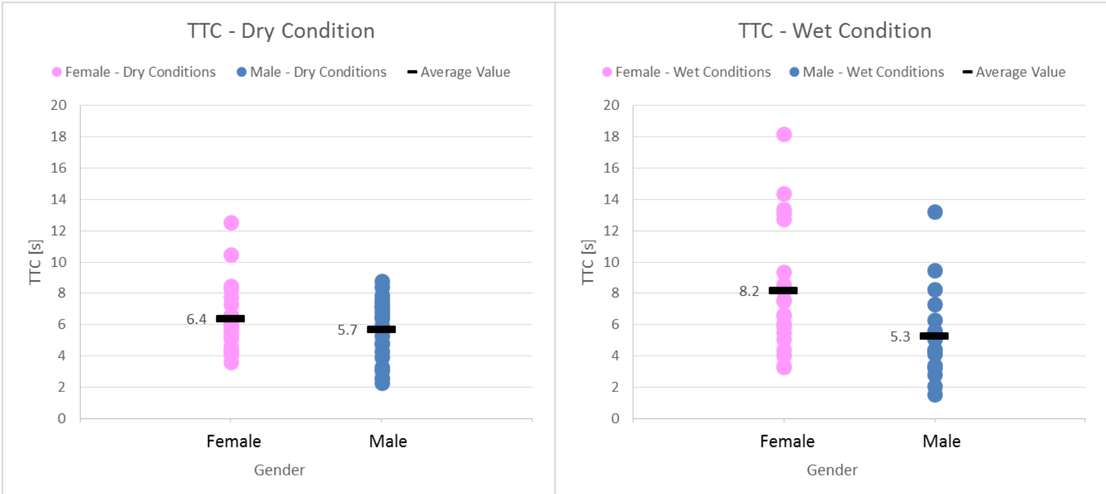

Figure 3.2: Time to collision - TTC

In addition, women estimate in a proper way the risk from the pavement conditions, taking more time where the pavement appears wet and the values of actual friction is low. Instead, men did not change their behaviour as a function of the pavement conditions, exposing themselves to more dangerous conditions in the case of wet pavement.

In terms of percentage differences, gender differences in dry conditions are less in terms of TTC. The TTC will increase about 12% from the calculated value for men. Instead, in wet conditions, gender differences are higher, with 55% increases for women more than for men (Figure 3.2).

According to the output provided by ANOVA test, there was a statistical significance of 90% in wet conditions to varying gender. In dry conditions, the statistical significance is lower with values approximately equal to 70%. On the contrary, from the analysis of the gender as a function of the conditions of friction, it can be noted a very high statistical significance for the female gender, higher than 90%. On the contrary, the difference between dry and wet conditions does not seem to have a statistical significance for the male gender.

Pressure on Brake pedal (PB)

Although women start to brake earlier, as shown by TTC values, results recorded for PB show women braking very heavy, with a significant pressure on the brake. This can be related to a lack of confidence on completing the stopping maneuver successfully. Such behaviour could expose female drivers to an accidental event more than male drivers.

Conversely, men perform braking with a lower pressure on the pedal, calibrating the braking. Brake pedal results in terms of gender are in agreement with

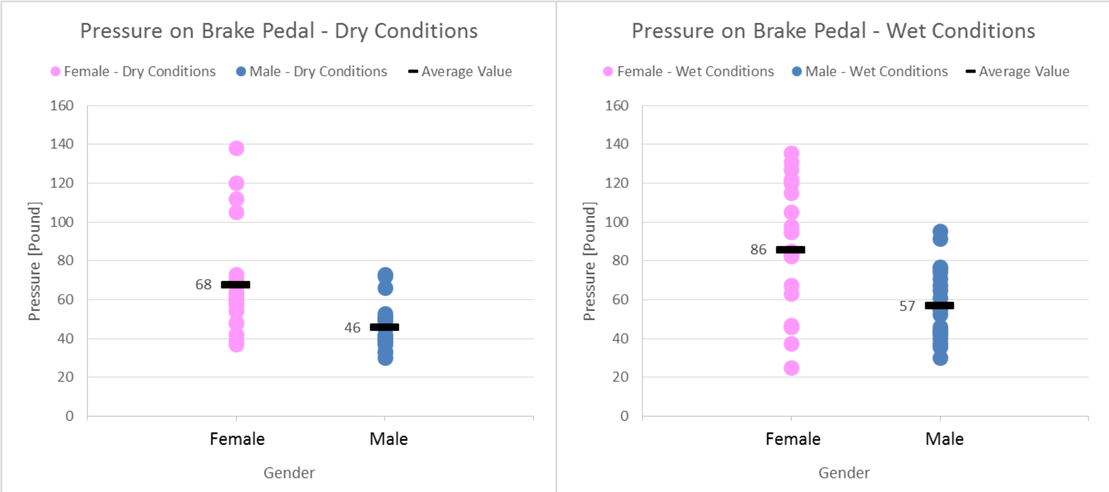

Figure 3.3: Pressure on brake pedal - PB

changing grip conditions. In fact, the increase of the value of women's pressure was approximately equal to 50% more than the average value calculated on the sample of men, both in dry and wet conditions. Evaluating the difference between the braking conditions between dry and wet conditions, regardless of the gender differences are noticed by about 25% (Figure 3.3). According to the output provided by ANOVA test, there was a statistical significance of the change in the average values of the brake pedal pressure with over 99% probability in wet or dry conditions. Analysing the significance of dry and wet conditions is approximately 92% for women and about 95% for men.

Slip Ratio (SR)

In reference to the stopping maneuver, performed by drivers after perceiving an obstacle, results of SR are studied. Values confirm those related to the indicator of the pressure on the brake pedal. In fact, women appear to have an average value of slip ratio of braking, better men. This means that women use all the grip available, sometimes even exceeding the limit value. As shown by the pressure on the brake pedal, women tend to do more heavy braking, a symptom of a fearful behaviour. The percentage values are consistent with those seen for the previous indicator, PB.

In particular, in dry conditions, women undertake approximately 30% more grip than males, but despite this, they remained below 0.6. In wet conditions, the differences are rather more pronounced with increase of values of about 50% more than the value recorded for men. Considering the condition of the pavement, women increase the adhesion value committed between wet and dry by about 40% while men only 27% (Figure 3.4). From the statistical point of view the

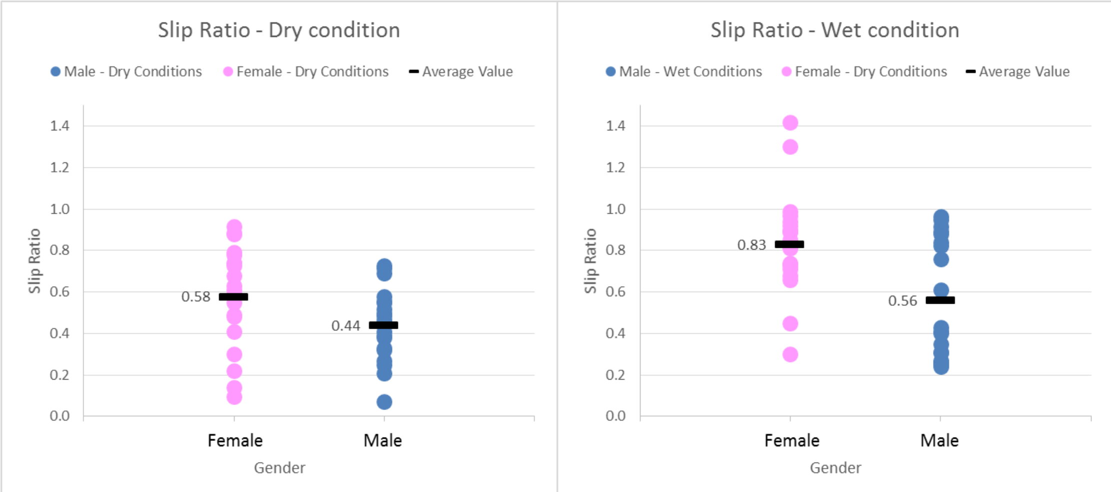

Figure 3.4: Slip ratio - SR

ANOVA gave a significance of more than 99% with regard to the gender differences in wet conditions and of about 95% in the case of dry conditions. Similarly, in regard to the changes in adhesion, considering the same kind appears a significance of over 99% for women and about 90% for men.

3.1.5 Conclusions

The analysis reveals a different behaviour between male and female gender: women appear more prudent and more careful to estimate the conditions that occur while driving. On the contrary, men demonstrate a lower risk perception and a less cautious behaviour. Nevertheless, by the interpretation of the results we can assume that women are more afraid in the performance of the maneuver: they capture and understand in advance the risk but the excessive caution, in carrying out the maneuver, could have the opposite effect, exposing themselves to greater risk.

In reference to stopping maneuver women seem to understand the potential risk (represented by a pedestrian or a crossing vehicle at the intersection) in advance, before men, but while men regularly calibrate the braking in order to stop ate the line, women slow suddenly by impressing high pressure to the brake pedal and engaging high friction values.

Differences in driving behaviour are correlated with different working conditions, lifestyles, family care loads affect differently the stress levels of men and women and consequently the risk assessment and responses. Men and women having different lifestyles and especially stress levels tend to drive differently, exposing themselves differently to an accident risk.

3.2 Effects of alcohol on driving task

3.2.1 Background

The effects of alcohol while driving are very dangerous as it compromises the psycho - motor skills.

According to [102], alcohol causes many victims and it is not only a social problem for young drivers. In fact, studies [103], [104] highlight different segment of alcohol offenders in traffic, including young drivers and middle-aged drivers that have different drinking habits.

A statistic provided by the European Commission [105] shows worrying results: in 2012 more than 10'000 people died in road accidents caused by alcohol, more than one third of the 28'000 deaths registered in European countries. In Italy, the official statistics of road accidents alcohol-related are not available due to the difficulties to establish if the alcohol could has been the cause of death. Moreover, from 2009 in Italy, the Italian National Institute of Statistic (ISTAT) stopped revealing the alcohol between the causes of road accidents.

The latest available statistics (2009) [106] highlighted that, despite the low percentage of occurrences (about 6000 occurrence – 3% of the total), alcohol-related accidents have great importance due to their mortality rate.

Nevertheless, the "Istituto Superiore di Sanità" (ISS – National Institute of Health) estimates that the fatality of alcohol-related road accidents are equal to 30-35% of the total fatal road accidents [107].

Many research show that alcohol impairs the ability of perception, attention, processing and evaluation, by acting on the reaction time.

A study conducted by researchers in psychology at the University of Amsterdam [108] deals with quantifying the delay in reaction time through the evaluation of the latent psychological processes. In a double-blind experiment, three different amounts of alcohol were provided to participants on different days: a placebo dose (0 BAC), a moderate dose (0.5 BAC) and a high dose (1 BAC). Subsequently, the participants carried out a "moving dots" perceptual discrimination task. The drift-diffusion model performed data analysis. Results show that alcohol intoxication causes an increase in the average value of reaction time and reduces the accuracy in the response. In fact, the diffusion model decomposition showed that alcohol intoxication caused a decrease in drift rate and an increase in non-decision time. It is clear that this finding could have an impact on driving activity, as the

reaction time is a significant variable in driving.
In terms of driving, alcohol acts compromising the performance, exposing users at risk [34], [109]. Furthermore, alcohol alters the estimation of distances, colors and compromises side vision and therefore it could have a significant impact on road safety.
American researchers [32] expressed the magnitude of alcohol's effects on the risk of occurrence of a fatal accident. The correlation comes from the risk curve of the alcohol concentration, which is a powerful tool to estimate the probability to die having taken a certain amount of alcohol.
Similarly, researchers from Spain [110], showed the methodology to estimate the probability to die during driving under the effect of alcohol in combination to the assumption of drugs.
It is well-known that alcohol interacts with drugs and the effects of the combination are even more worrying. Moreover, it is necessary to prevent the phenomenon by performing more frequent police checks and adopting preventive security measures to restrict the permitted amount of blood alcohol concentration (BAC). With reference to these measures, in France it has been estimated the impact on users of the various security measures against alcohol [36].

3.2.2 Objectives

This research aims to assess and quantify the risk perception on drivers under the influence of alcohol, comparing their behaviour to sober condition, through a virtual reality driving simulator, an eye tracking system and a heart rate monitor. Thanks to the simulator, it is possible to reproduce the real driving environment conditions to test the driving behaviour of a sample of drivers, with benefits on test risk and costs. The driving simulator used coupled with the eye tracking system allows to evaluate the risk perception that would not be possible to perform in real conditions.
Therefore, after a wide literature review, the present research propose an innovative contribution in the numerical evaluation of driver's behaviour under the influence of alcohol. This assessment is in term of reaction time, change of the trajectory, distance distortion and in various psycho-physiological and kinematic-dynamic indicators. Furthermore, eye measures and heart rate are recorded.
The knowledge of the driving behaviour under the effect of alcohol, for example, can improve current regulations by providing quantitative elements for operational procedures or by providing quantitative data for awareness raising cam-

paigns.

3.2.3 Method

The experiment is carried out with the virtual reality driving simulator and the eye tracking system (Figure 3.7) of Roma Tre University. According to the virtual reality driving test methodology, the creation of the simulated scenario, the sample definition, the procedure applied and the data collection are explained in detail below.

Simulated scenario

A typical Italian highway has been selected and implemented in virtual reality environment according to the Italian rule and regulation the Italian Highway Code (Ministry of Infrastructures and Transports, 1992).
The road segment was characterised by 15 length kilometers traveling in extra-urban and urban areas and a cross section of two 3.50 meters lanes. In extra-urban area the cross section provides also a right shoulder for each direction of 1.00 meter. Pedestrian crossings are not implemented and the overtaking maneuver is permitted. The speed limit is fixed to 90 km/h.
Instead, in the urban area the same road section is provided but with both-side sidewalks 4.00 m wide, the speed limit fixed to 50 km/h and several intersections and crosswalks are included, the overtaking maneuver is not allowed. The horizontal road alignment is in both the contexts typically flat.
Furthermore, a typical flow condition that occurs on the Italian highway is implemented in order to improve the realism of the test, but avoiding to affect the drivers' behaviour.
Several events are implemented in the simulated scenario in order to impose to the drivers different brakings and study the consequent behaviour. More in detail two pedestrian crossing and two intersection are located respectively in the urban and extra-urban area with the following characteristics.
The pedestrian crossing sign was designed in accordance with the Italian Code and with previous studies present in literature review ([96], [97]) with 1.50 m long strips of crosswalks, 0.50 m wide and spaced 0.50 m between each other. At each crossing the pedestrian movement (1.50 m/s) was activated when the driver reached 60 m before the zebra crossing.
The intersection events were implemented as a T-sharp intersection with another

road with the same geometric characteristics, without traffic lights and at each intersection a vehicle cross the road with a speed of 50 km/h when the driver reached 70 m before the intersection.
Finally, to measure the reaction time of the drivers during the driving task, some stimuli are included in the simulated scenario. Three red symbols that represented a right-arrow, a left-arrow and a circle appeared alternatively at the bottom side of the scenario to lead the driver to answer to the stimuli by doing something. Specifically, drivers were asked to answer to that stimuli by acting or on the turn signals (in case of arrows) or on the horn (in case of circle).
The answer to symbols are grouped in two mental workloads, low and high, in function of the complexity of the action requested to the driver that correspond to two different mental workloads. The low mental workload represents the answer to the horn that requires only an instinctive and direct response in which drivers were asked to respond while it was driving along a straight road with low traffic flow. Moreover, drivers were not involved in any maneuvers and good visibility conditions were assured. On the contrary, high mental workload, represents the action on turn signal in which drivers were asked to respond when they were traveling along a curve with limited visual conditions, or when they were involved in a maneuver with a high interference caused by high traffic flows. For example, a braking caused by a crossing pedestrian or an intersection. This condition has been associated to the urban scenario.

Sample features

A homogeneous sample of healthy and nonsmoking drivers has been recruited and selected to take part to the driving experiment.
Forty subjects (20 women and 20 men, 31 years old on average, ranging from 22 to 50 years old) were recruited via direct contact as volunteers from the Department of Engineering at the University Roma Tre. None of the subjects had previous experience with driving simulator.
As for the previous study, by means of the Chauvenet statistical criterion, the number of participants were assessed as significant from a statistical point of view, assuring a correct statistical data interpretation. In this case, according to the Chauvenet criterion the average speed of each driver has been measured in each area (urban and extra-urban) in order to fulfill the criterion in each condition. According to the Chauvenet criterion, no data were rejected in none sub sample of average speed.

Procedure

A detailed procedure has been developed on the basis of literature review [111], [112] in order to assure the same boundary condition for all drivers and guarantee reliability and effectiveness of the test.
Participants were informed about the test procedures, in terms of duration, use of the steering wheel, pedals and gear.
Each driver performed in one day the simulation scenario twice, firstly to record the baseline and afterwords in drunken condition.
Transportation to and from the laboratory was provided by a taxi service on test session day. During the practice session, subjects received no beverage but completed all other procedures to acquaint themselves with the necessary equipment, questionnaires and tasks.
At the beginning of the driving session, drivers are required to perform a training simulation scenario for at least 10 minutes of driving, in order to familiarise with the tool.
After the training scenario, a before-driving questionnaire with driver general information, and the training itself is provided.
Afterwards, drivers were asked to perform the driving test in sober status in order to record the baseline test that will be compared with the other in drunken condition. The test protocol provided the administration of alcohol in accordance to the Widmark formula. More in detail the amount of alcohol was calculated, for each driver in order to achieve the value of 1 BAC (measured in Blood Alcohol Concentration %) that is the Italian higher limit for a penalty according to the Italian regulation. The formula takes into account the gender of the driver and the weight and through some coefficients allows to estimate the amount of alcohol expressed in grams that each participants had to drink to achieve the BAC of 1. It is worthwhile considering that, in Italy, the BAC level that correspond to an administrative sanction for general drivers is 0.5 BAC and 0.0 BAC for novice drivers, while a criminal sanction is 1 BAC. Findings in literature have shown how drivers with a BAC between 0.2 BAC and 0.5 BAC have a risk of dying in a vehicle crash three times higher. This risk increases to up to six times with a BAC between 0.5 and 0.8, and above 0.8 rises exponentially [113].
Subjects were instructed to abstain from food for 4 h and from caffeine and alcohol for 36 h before each test session, and to abstain from psychoactive drugs for the duration of the study. Abstinence from recent alcohol use was verified by

measurement of BAC with the breathalyser.
The measurement of BAC started 10 min after drinking ended and than each 5 minutes. As soon as the BAC reached the value of 1 the driving test started and the BAC was measured before and after the test to assure that it remained approximately constant.
After the driving test an after-driving questionnaire was subjected and finally drivers were requested to fill a questionnaire about the eventual simulation sickness perceived.
Subjects then rested in the laboratory waiting area until the end of the session. During this rest period, subjects were allowed to consume snacks and soft drinks, and heart rate, blood pressure, and BAC were measured at 30 min intervals until the end of the session. Test sessions ended when the following requirements were met, in order: i) 5 h passed after the start of alcohol drinking; ii) BAC<0.5 BAC, and iii) satisfactory completion of the field sobriety test.
Each session lasted overall about 1:30 hour.
The applied procedure benefited from the Ethics Committee Review.

Data collection

In order to evaluate the effect of alcohol on drivers' risk perception, some indicators have been selected and processed from the outputs of the driving simulator as the reaction time, the trajectory, the speed and the performances in stopping and overtaking maneuvers.
The reaction time (RT) is the time elapsed from the instant of perception, attention, processing until the evaluation. Each driver takes a different reaction time as it depends on the cognitive processes that lead the drivers from the step of perception to the evaluation. In the context of this research, reaction time was chosen in order to quantify the delay in reflexes due to alcohol. It was estimated thanks to the stimuli included in the scenario, as the difference between the time in which the stimuli appeared until the time of the driver action (or on turn signals or on horn).
Concerning the driver trajectory, two indicators have been selected: the average of the driver lateral position respect to the centerline (AvT) and the number of times that drivers exceeded the standard deviation of lateral position (SDLP) centered in the lateral position average. More in detail, this number of times over the SDLP are distinguished in different classes: in terms of type of area extra-urban and urban, in terms of side, right or left and lastly in terms of geometry,

curve and straight.
The value of the drivers average speed (AvS) in the two different psycho-physiological conditions and regarding to the type of area is representative of a the level of risk perception of the drivers [12].
Furthermore, two performed maneuvers are studied: stopping maneuver by classifying the intensity of braking by means of a deceleration rate (d). Regarding the overtaking maneuver, the percentages of maneuvers in the two psycho-physiological conditions (O%) are analysed and among these the number with high risk level. A overtaking at risk occurs when it is not guaranteed double the stopping distance with the vehicle in the other direction of travel.
Most studies [81], [82] using eye tracking measures in alcohol-related disorders considered that each eye tracking index is a quite direct reflect of specific cognitive processes. Eye tracking actually allows to measure gaze location, as well as eye movements' characteristics (e.g., fixation, saccade, pursuit, and blink) or eye-related factors (e.g., pupillary diameter). In this case, in order to understand how much alcohol impact the eye movement and the ability to stay awake, the eye blinking and frequency are recorded.
Furthermore, according to [102] when BAC increases, drivers tend to fix their eyes more on the central visual field and fewer eye movements are made to the peripheral view. When under the influence of alcohol, drivers use fewer sources in the visual field to obtain information about the environment, take longer to recognize and respond to aspects that present vital information about their environment (i.e. street signs) and focus their attention on aspects occurring in the central field of vision often at the cost of peripheral information. For this reason, the position of the glance on the scenario is studied by dividing the central screen in six fixing areas (as shown in Figure 3.5).
A is the central area that corresponds to the longitudinal view, S and D are together the peripheral view, respectively left and right, C is the area of the back mirror, B the opposite side of C and lastly E is the area of speedometer and rev counter.
Finally according to [32] the heart rate in terms of BPM is recorded to monitor the psycho-physiological condition of the driver as a safety precaution and were not analysed in conjunction with other dependent measures.

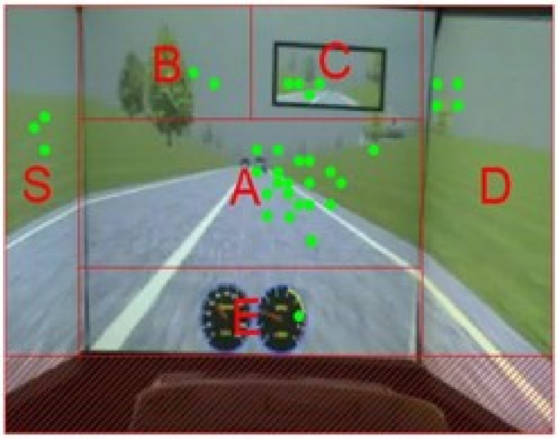

Figure 3.5: Areas layout

Figure 3.6: BAC measuring through breathalyser

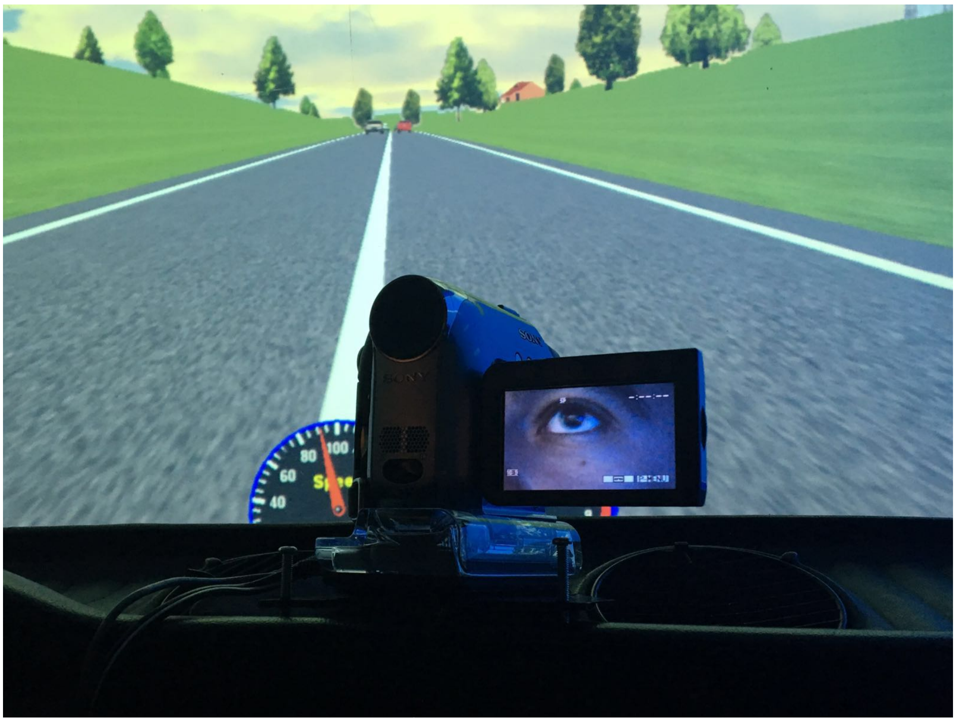

Figure 3.7: Eye-tracking camera

3.2.4 Results

ANOVA results

The results of the ANOVA have been summarised in (Tables 3.3, 3.4). The comment of the significance of those results, for each indicator, is reported in the following paragraphs.

Index	Urban	Extra-urban
Reaction Time - RT [s]	F(1,38); p<0.01	F(1,38); p=0.05
Average of Trajectory - AvT [m]	F(1,38); p=0.05	F(1,38); p=0.55
Standard Deviation of Lateral Position - SDLP [n°]	F(1,38); p=0.10	F(1,38); p=0.98
Average of Speed - AvS [m/s]	F(1,38); p=0.25	F(1,38); p=0.05

Table 3.3: ANOVA test results on alcohol factor

Reaction Time (RT)

Results about RT show an increase under the effect of alcohol.
Alcohol appears responsible for the delay of reflections that leads drivers to realise the danger in delay. Alcohol damaged the risk perception and consequently drivers are exposed to a higher risk. The result is highlighted more for high men-

Index	Sober	Drunken
Reaction Time - RT [s]	F(1,38); p=0.55	F(1,38); p=0.85
Average of Trajectory - AvT [m]	F(1,38); p<0.01	F(1,38); p<0.01
Standard Deviation of		
Lateral Position - SDLP [n°]	F(1,38); p<0.01	F(1,38); p<0.01
Average of Speed - AvS [m/s]	F(1,38); p<0.01	F(1,38); p<0.01

Table 3.4: ANOVA test results on area factor

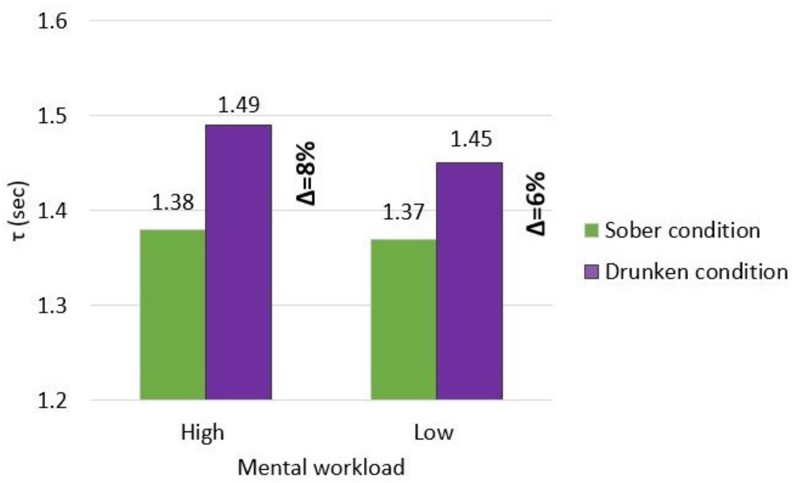

Figure 3.8: Reaction time - RT

tal workload condition, where the difference between sober and drunken condition is about 8% (Figure 3.8).
The ANOVA test show an high significance for the Alcohol factor, with value greater than 99% in Urban Area and about 95% in Extra-urban Area. Otherwise, on Area factor no significance has been recorded.

Average of Trajectory (AvT)

Results show that the AvT kept by drivers does not change significantly under the effect of alcohol. On the contrary, it is very different the position of drivers with respect to the centerline of lane, depending on the type of area, and consequently by the elements to the edge, the absence of the shoulder in urban area. In particular, between the two areas, the situation is reversed (about 30% and 60% right and left of the centerline of lane), as shown in (Tables 3.5, 3.6 and Figures 3.9, 3.10). From a numerical point of view, it is possible to state that, in terms of average trajectory any significant differences dependent on alcohol have not been found. The difference between the values AvT is less than 1%.

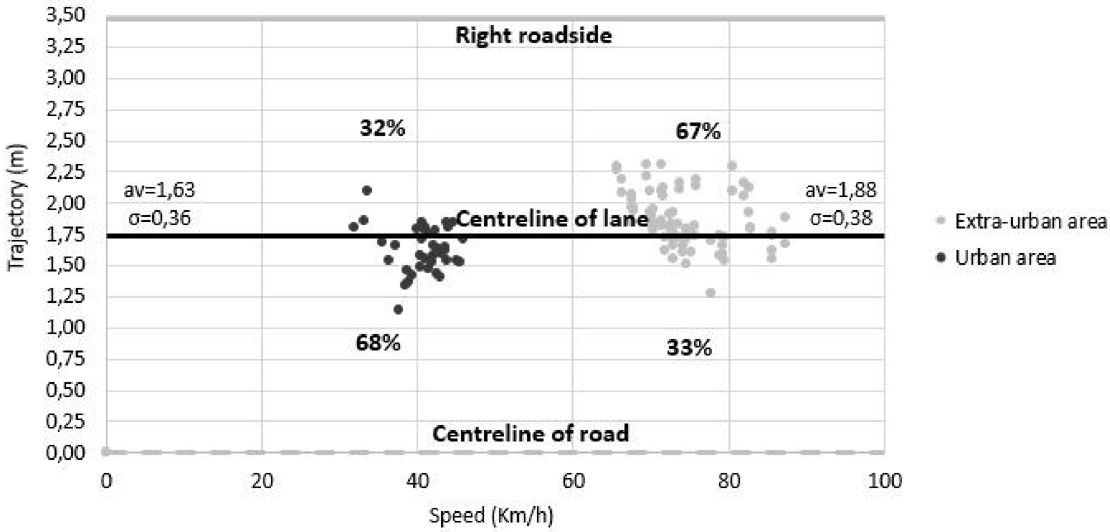

Figure 3.9: AvT on sober condition

Moreover, the above-mentioned results are confirmed by the ANOVA test. In particular, the significance of the variation of average trajectory values, in Extra-urban Area, between drunken and sober condition, is lower than 50%. On the Area factor, on the contrary, significance is higher, with values over 99% in both condition sober or drunken.

Area	Distribution	Percentage [%]
Extra-urban	Av=1.88; SDLP=0.38	67 (right); 33 (left)
Urban	Av=1.63; SDLP=0.36	32 (right); 68 (left)

Table 3.5: AvT on sober condition

Area	Distribution	Percentage [%]
Extra-urban	Av=1.86; SDLP=0.44	66 (right); 34 (left)
Urban	Av=1.69; SDLP=0.42	38 (right); 62 (left)

Table 3.6: AvT on drunken condition

Number of times over the SDLP

The number of times that the trajectory exceeds the SDLP confirms the outcomes of the average trajectory (Table 3.7). In fact, it is different with respect to the areas, but very similar in the two psycho-physiological conditions. The

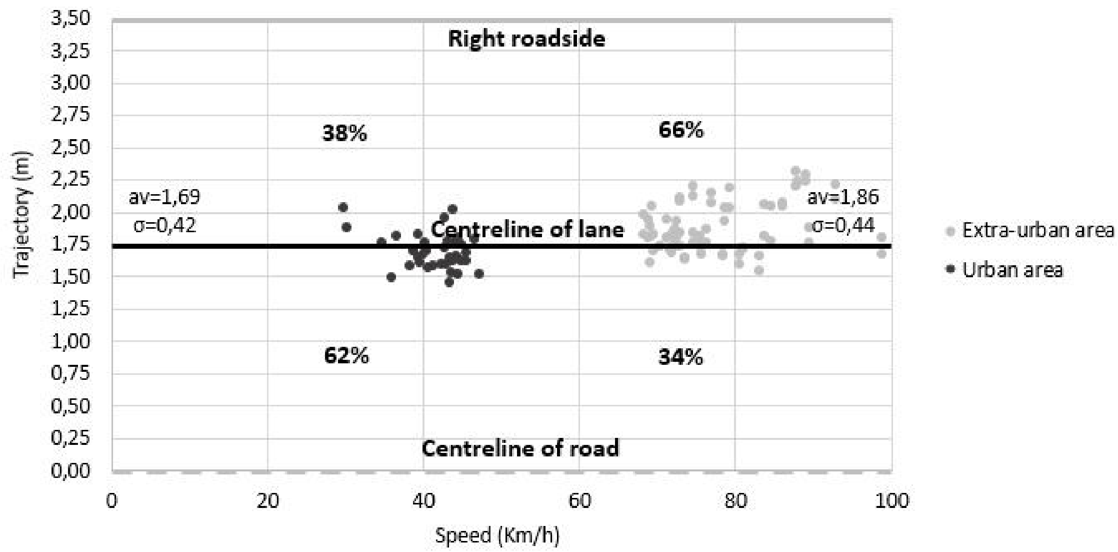

Figure 3.10: AvT on drunken condition

difference in the extra-urban is equal to zero.
Moreover, the percentage of times that the drivers exceeds the standard deviation is homogeneous between two psycho-physiological conditions both between right and left and on the geometry of the road, in curve or straight.
As recorded for the previous indicator, the ANOVA shows no statistical significance on alcohol factor, especially for the extra-urban area. On the contrary, the results on area factor is over 99% in term of statistical significance, as expected.

		Sober	Drunken
Area	Extra-urban	2.14	2.14
	Urban	3.87	4.08
Side	Right	50%	50%
	Left	50%	50%
Geometry	Curve	70%	70%
	Straight	30%	30%

Table 3.7: Number of excesses over SDLP/km

Average Speed (AvS)

The AvS indicator recorded in the two different areas, according to psycho-physiological conditions, shows a slight increase of the speed. In particular, 4% in extra-urban area, where speed limit is 90 km/h, and 2% in urban area, where speed limit is 50 km/h, as imposed by Italian rules and regulation (Table 3.8). From a statistical point of view, the results of ANOVA test show a lack of significance for the Urban Area (75%) and a significance of 95% in Extra-urban Area, on the Alcohol factor. As for the others indicator the results of ANOVA test on Area factor showed a high statistical significance (over 99%).

AvS [km/h]	Sober	Drunken
Extra-urban	74.5	77.3
Urban	40.7	41.4

Table 3.8: Average speed - AvS

Stopping maneuver analysis

From the analysis of the dynamics of the stopping maneuver, a difference between the two psycho-physiological conditions can be observed. In fact, under the influence of alcohol heavier braking (d) are recorded, above the value of 8 m/s2 (Figure 3.11). This phenomenon is explained by the delay in reflexes caused by alcohol that exposes drivers to a significant risk. An increase of 18% of sudden braking in extra-urban area and of 12% in urban area, occurs. Drivers realise too late the danger with evident consequences on the stopping distance and therefore on road safety.
The ANOVA test shows a high statistical significance on alcohol factor (over 99%) for the second and third class of braking, in both urban and extra-urban area. For the more heavy braking condition, the ANOVA test shows high statistical significance only for the results in extra-urban area. Moreover, ANOVA test on the area factor, highlighted high statistical significance for each class (from 99 to 90%).

Overtaking maneuver analysis

Regarding the overtaking maneuver, allowed only in extra-urban area, it is highlighted the influence of alcohol on risk perception, which damage the ability to estimate the risks that occur on the road. In fact, people under the influence of alcohol feel to risk more. Therefore, O% value increases by 31.8% in drunken condition compared with sober condition. In addition, regarding all overtaking maneuvers, in drunken conditions the percentage of those at risk has increased,

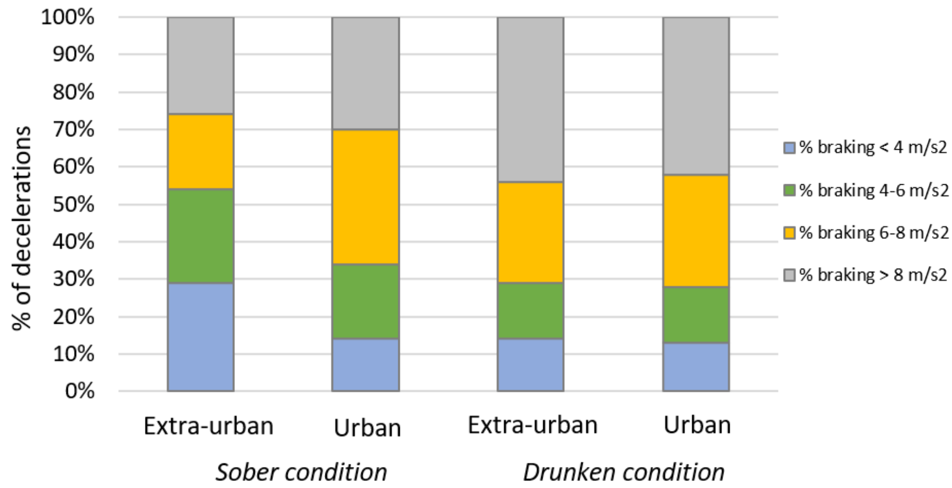

Figure 3.11: Braking classification

from 11.2% to 13.6%.
From the statistical point of view, the ANOVA confirm the high statistical significance of the result, regarding the average value of overtaking maneuver, from sober to drunken condition, with a value around the 95%.

Eye measures

The blinking trend in drunken condition respect to sober one is increasing for all drivers (Figure 3.12). More in depth, the percentage of closed-eye frames in the sober driving test was 9%, instead the percentage in drunken driving test was 13%. Five points of percentage are the difference between the blink activity in sober and drunken condition. Regarding the frequency, a smooth increasing trend was recorded with 0.74 Hz for the frequency in sober condition and 0.76 in drunken condition (Figure 3.13). This means that alcohol acts in terms of weakening of vigilance, attention and control with a number of blink slightly greater but with a closing time significantly higher.
By comparing the position of the glance in the central screen of the simulated scenario (Figure 3.14), a greater percentage of fixation points in the central area (A) in drunken condition is recorded, both in urban and extra-urban area. More in detail, 29.5% more in drunkenness than sober in urban area and 22.2% more in drunkenness than sober in extra-urban area. In all other areas, mostly in right and left areas (D-S), equal or greater values for sober condition are found. This results can means that in drunkenness the driver pay more attention to central area, losing the peripheral views. This result confirm the findings of the World Health Organisation that demonstrate that already with a low alcohol level the

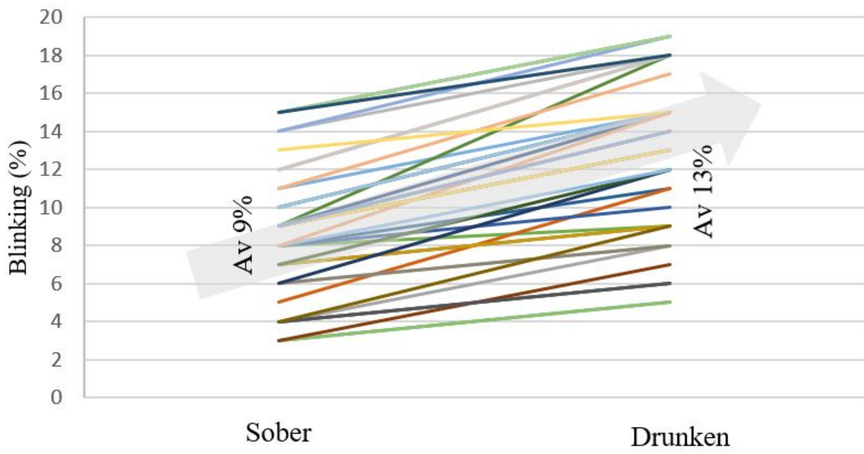

Figure 3.12: Eye blinking

lateral visual field begins to be compromised.

3.2.5 Conclusions

The research highlights how this occurrence is worrying and supervisory measures are needed.
Regarding the trajectory, AvT results showed that the drivers is not affected by the effects of alcohol. On the contrary, the effect is significant in terms of other indicators about maneuvers. Alcohol causes a delay of the reflexes that leads drivers to realise the danger with a delay, as shown by the results of the stopping maneuver.
Furthermore, alcohol is responsible for a higher number of risky overtaking (O%), exposing the drivers to higher risk. It is necessary to remember that the two analysed psycho-physiological conditions refer to the state of sobriety and drunkenness with a concentration of alcohol in blood (BAC) equal to 1. Therefore, it is not possible to generalise the results obtained for the drunkenness condition in general.
Finally, psycho-physiological measures, blinking and frequency and heart rate, shown that alcohol acts in terms of weakening vigilance, attention and control leading drivers to an attitude closer to drowsiness.
Without claiming to have fully satisfied the research gaps in this area of endeavour, the authors propose some future developments: first of all, the assessing of the risk perception with the same method, according to different blood alco-

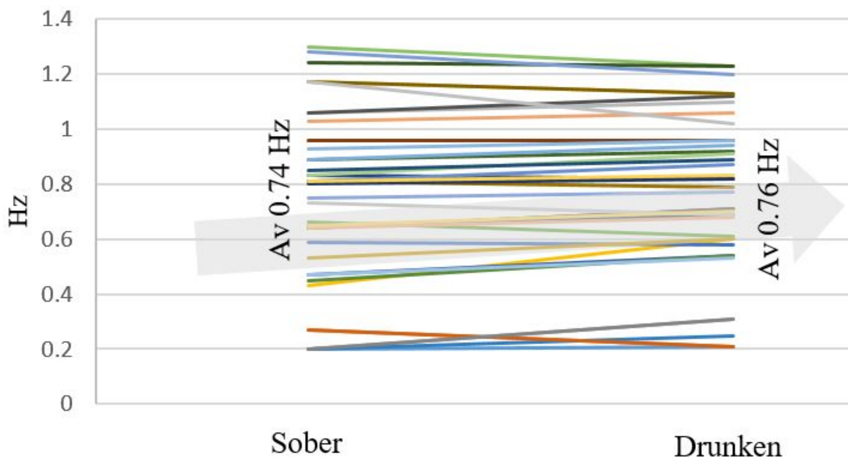

Figure 3.13: Eye frequency

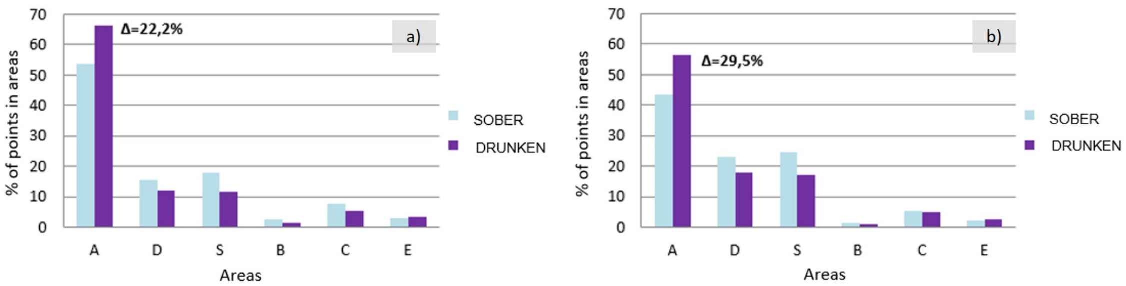

Figure 3.14: Percentage of fixation points in a) Extra-urban area; b) Urban area

hol levels in order to compare them; and then the investigation of other driving conditions, such as highways, to measure the variability of risk perception more accurately in relation to speed.

3.3 The effects of fatigue after a hospital night shift on driving performances

3.3.1 Background

Driving fatigue is one of the most frequent causes of road accidents.
According to ISTAT (Italian National Statistical Institute), fatigue is the cause or contributing factor of one in every five accidents. The Mobility and Transport Road Safety section of the European Commission has collected police reports from various countries (e.g. Netherlands, UK, North Carolina USA) showing that 1-4% of accidents are related to driving drowsiness.
Since the concept of fatigue is often misunderstood, it is worthwhile to explain the difference between fatigue and drowsiness. Although similar, these two aspects have different characteristics and causes. Fatigue can be described as a gradual and cumulative process due to sustained activity and associated with a disinclination towards effort, eventually resulting in reduced performance efficiency [114]. Fatigue manifests as a numbness in the neck, pain in the shoulders, a fixed gaze and difficulty in concentration. To overcome this physical alteration, the driver needs to stretch or take a break.
On the contrary, drowsiness indicates the difficulty to stay awake. The related symptoms can be heavy eyelids, frequent yawning, loss of attention, frequent desire to change position and, in the most extreme cases, the stroke of sleep. Since the sleepiness disappears only after sleeping, it is not enough to take a break. Fatigue can be of two types: mental fatigue and physical fatigue [115]. Mental fatigue is a gradual and cumulative phenomenon and is related to nutrition, physical health, physical activity and environmental conditions. Instead, physical fatigue is the phenomenon of reduced performance of muscle after stress. This phenomenon leads to a greater risk of accidents due to the alteration of muscle coordination and the decrease in concentration due to greater energy expenditure. This condition is a factor in increasing the risk of driving for drivers subjected to manual loading on vehicles [116].
A wide range of literature deals with the effects of driving fatigue, analysis of

personal judgment on perceived fatigue, kinematic and physiological measures. Several researchers have correlated the amount of minor accidents (when a car-wheel crossed to lateral lane marking) and major accidents (when all wheels ran out of the lane) to the subjective perception of sleepiness and the likelihood of falling asleep. More in details, in a study [117] the drivers have carried out driving sessions at the guide simulator for 2h and every 200 seconds had to give a value to the sleepiness (using the 9-point Karolinska Sleepiness Scale, 1 = extremely alert and 9 = sleepy, great effort to keep awake, fighting sleep) and to the likelihood of falling asleep (answering the question "what is the likelihood of you falling asleep during the next few minutes", from A=very likely to E=very unlikely). According to [118] the fatigue was found to be related to prolonged driving on monotonous roads and the value of subjective fatigue (the drivers expressed their level of sleepiness at the beginning and end of the SSS test, sleepiness scores) was higher at the end of the test. Moreover, during the test a constant increase in the RT value was recorded (reaction time, evaluated by the response of the driver to input on screen). The correlation coefficient for average headway and standard deviation of lateral position exceeded 0.9, this finding demonstrates that vehicular operation becomes more unstable as driving time increases [118].

Other researchers [119] have analysed physiological signals (EEG, ECG, EOG) while testing on real-road types of possible fatigue indicators: EEG spectrum analysis, blinking frequency analysis, interval histogram and speed of blinks, fractal properties of RR interval-series. The indicators relating to the EEG spectrum analysis were useful for obtaining information on the instantaneous fatigue level, while the blinking frequency and ECG indicators were relative for information on the global fatigue condition.

Many researchers have studied the occurrence of fatigue using physiological indicators [120], showing that EEG changes are associated with physical fatigue signals by verifying it through video analysis. They concluded higher the fatigue level, more the driver is led to driving errors and accidents.

In addition to the physiological aspects of fatigue, it is important to emphasise its impact on driving through the analysis of the kinematic parameters of the vehicle that represent the driver's feedback.

Driving fatigue is also reported in the return back from a night shift work. Night shift work is associated with increased reported sleepiness and several studies have shown that train drivers, truck drivers, pilots, doctors, process operators, and others, show clear intrusions of sleep-like EEG patterns when working at night [121]. Moreover, an increased risk of road accidents driving home from a night shift has been reported by [122].

In one study researches [123] have compared driving after a night shift and restful driving, analysing kinematic parameters (speed, side position, time to time crossing, steering angle) and physiological parameters (via EOG). They have shown that driving after a night shift increases the probability of an accident (increased lateral position variation, increased eye closure duration and greater subjective drowsiness) due to the combination of the circadian low and fatigue stemming from the extended surveillance period.
This research placed into such a framework in order to analyse the driving behaviour after a night shift of a sample of doctors, nurses and the hospital staff by means of the virtual reality driving simulator.

3.3.2 Objectives

The present study aims to evaluate the effects of driving fatigue on driving performances of a sample of doctor after a night shift. The experimental activity is carried out by means of the driving simulator that allows to understand the driving performance decay by recording dynamic and kinematic parameters (e.g. speed, lateral position, longitudinal and lateral acceleration, braking performance and reaction times).
In addition, a visual analysis only to verifying the driver's status was carried out by placing a GoPro 5 session inside the vehicle in front of the driver.
The experiment is carried out by means of a specific and defined protocol that assure the repeatability of the tests and consequently the validity of the achieved results. The experimental set-up allows to study a comprehensive behaviour of drivers in a complex condition that it is not possible to describe through field study.

3.3.3 Method

Driving fatigue after the night shift phenomenon is investigated through a virtual reality driving experiment that allows to reproduce the real phenomenon of fatigue while driving in a controlled environment, avoiding the correlated risks [124], [125].

Simulated scenario

A simulated scenario is designed to reproduce four different road environments: extra-urban, sub-urban, urban and industrial.
The extra-urban area is 4 kilometers with a speed limit of 90 km/h as the rules and regulations, the Italian Highway Code (Ministry of Infrastructures and Transports, 1992) of an extra-urban context impose. The cross section is two 3.50 meters lanes and both-side shoulders 1.00 m wide. The horizontal road alignment is typically flat. Trees and country houses are implemented in the simulated road environment to reproduce a real extra-urban context.
In order to link the extra-urban area and the urban area, a gradual transition of 1 kilometer of sub-urban area is designed. This latter has the same cross section of the extra-urban area and is characterised by an increasing density of houses more typical of an urban environment. Also in this case, the horizontal road alignment is not so significant.
The urban area is 5 kilometer long with a speed limit of 50 km/h. The dimension of the cross-section is the same but in place of the shoulders, both-side sidewalks 4.00 m wide have been designed. The horizontal road alignment is typically flat. The urbanisation is characterised by a high number of skyscrapers, bus stops and benches. Moreover, some pedestrians walking on sidewalks in all directions and some pedestrian crossing are designed in accordance with the Italian Code with 1.50 m long strips of crosswalks, 0.50 m wide and spaced 0.50 m between each other.
Finally, 4 kilometers of industrial area are designed with the same characteristics in terms of geometry and speed limit to the extra-urban part, but with impressive industrial buildings such as warehouses and generic commercial buildings.
The overall scenario length is 14 kilometers for a duration of around 15 minutes. According to Crundall et al. classification [126], two different hazard groups are selected and designed in order to test specific drivers' behaviour respect to selected events.
More specifically, environmental prediction (EP) hazards and dividing and focusing hazards (DF) are selected. EP events referred to initially hidden hazards for which participants must then predict the hazard profile of the situation based on the environment (e.g., school sign); whereas, DF events included more than one potential hazard.
The first type of environmental prediction hazard in the tight curve that is selected in the scenario in order to allow the drivers' trajectory analysis. The tight curves are located in the extra-urban area with a radius of 200 meters and a

length of 100 meters. This event is reproduced four times only in extra-urban area where the approaching speed is equal to 90 km/h. 150 meters before each curve, a specific sign of the tight curve is located.
The second type of EP hazard is the traffic light event. Traffic light leads the driver to brake since the red light turns on when the driver reached 60 m before the traffic light. Traffic lights is locate only in urban environment and 150 meters before the traffic light, the correspondent traffic sign is located.
Finally, a type of dividing and focusing hazard is selected in order to lead the driver to a sudden braking maneuver. It is a pedestrian that cross the road from right to left on the proper pedestrian crossing sign but starting hidden between other pedestrian that are walking on the right sidewalk. The pedestrian movement (1.50 m/s) is activated when the driver reached 40 m before the zebra crossing. Also in this case, 150 meters before the event a pedestrian sign is located. The pedestrian crossing event is reproduced twice only in the urban environment.
The types of events implemented in the tested scenario according to this classification are summarised in Table 3.9 and Figure 3.17.

Sample features

The sample of users was recruited among the hospital staff of a Hospital in Rome after a night shift. To avoid biasing of results induced by driver attitude, experience in driving, age, additional stress phenomena, emotional state or neuro - cognitive status or by other subjective factors, the same driving conditions were generated for each driver.
Ten males and three females with the average age of 36 years, ranging from 23 to 53 years, were asked to take part to the driving experiment twice: one time immediately after a night shift and another time after having a regular night sleep to record respectively a fatigue driving test and the baseline.
Two participants were excluded from the analysis due to simulation sickness during the training test. Therefore, the sample of 11 participants was assessed from a statistical point of view by means of Chauvenet criterion on the average speed recorded both in each road environment (extra-urban, sub-urban, urban and industrial) and in the overall scenario pattern.
Although the sample size was rather low, due to difficulty to recruit participant after the night shift and invite to reach independently the laboratory at Department of Engineering at the University Roma Tre, results confirm that the size is

sufficient to assure a correct statistical data interpretation.
In fact, among the 11 drivers, according to the Chauvenet criterion, no data were rejected.

Procedure

As mentioned before, each participant performed the test twice the first time immediately after a night shift and the second time to record the baseline. The test were performed with a time interval of one week to avoid any learning effect among the participants. Both tests were conducted between 7.30 AM and 10.00 AM of the morning.
The test procedure provided a before-test questionnaire with subject general information (age, contacts and educational qualifications), personal driving experience (license years, annual traveled kilometers, vehicles characteristics usually driven) and visual skills.
Afterwards, two scientific scales were subject to the drivers to collect information about the self-reporting level of fatigue based on the actual feeling sleepy.
The first one is the Epworth Sleepiness Scale (ESS) ([127], [128]) that measure the level of tiredness with a scale from 0 to 3 (0 = I never fall asleep, 1 = I have some probability of falling asleep, 2 = I have a fair probability of falling asleep, 3 = I have a high probability of falling asleep) and indicate the probability of falling asleep in certain situations.
The second one is the Stanford Sleepiness Scale (SSS) ([129]) that describe the degree of sleepiness using a scale of 1 to 7 (1 = You feel active, vital, alert, 2 = High level of attention, but not at most; You feel able to concentrate, 3 = You feel awake, but relaxed; Relative but not fully attentive, 4 = Almost clouded, tired, 5 = Clouded, slowed down, 6 = Sleepy, difficulty in stay awake, you'd rather lie down, 7 = You can't stay awake much longer, you'll fall asleep soon).
Drivers were considered tired when the following requirements were both fulfill: i) ESS results 2 or 3 values; ii) SSS scale results from 4 to 7. Drivers who has not achieved both the requirements, has not perform the driving test and came again after the next night shift.
Once completed the before-test questionnaire, the subjects were requested to drive for 10 minutes the training scenario in order to become familiar with the tool and mitigate the novel effect which could affect the reliability of the test.
Therefore, drivers drove through the 14 km scenario containing the events described above. Once the test was completed, they were asked to complete the

last two sections of the after-test questionnaire containing information about the perceived discomfort and subjective fidelity of the experiment. The perceived discomfort was qualified as perceived illnesses with respect to nausea, dizziness, fatigue and level of drowsiness (choosing on a scale from "null" to "high") or general driving difficulties (asking to specify the difficulty if the answer is the affirmative). Finally, drivers were asked to give a feedback of the fidelity of the driving experiment in terms of realism of the simulation.
Each session consisted in the driving test and lasted for about 1 hour.
The applied procedure benefited from the Ethics Committee Review.

Data collection

Regarding the data collection and processing, three different analysis were carried out: a speed macro-analysis, a stopping maneuver analysis and finally a vehicle trajectory analysis. For each category of indexes, the further analysis was carried out by comparing the results obtained in the "tired" condition and the "rested" condition.
A macro-analysis of average speed (AvS) was carried out in terms of the four areas: extra-urban, sub-urban, urban and industrial. The analysis of speed is very useful to study the tired drivers behaviour and they speed perception ([39]). The average value and the standard deviation of speed were calculated for each homogeneous zone to point out its distribution.
Stopping maneuvers were studied by analysing the drivers' behaviour approaching to pedestrian crossings and traffic lights. Three indicators were investigated: initial and final speed (Si, Sf), reaction time (RT) and deceleration (d). Initial speed is the speed value at the moment when the driver start the braking, instead the final is at the end of braking when the driver release the brake pedal. Reaction times were calculated between the time when the driver identifies the event that will lead to the stopping maneuver, therefore from the moment when the pedestrian starts to cross the road or the yellow light at the traffic lights is turned on, to the moment when the driver starts to brake. Furthermore, deceleration in terms of average and standard deviation was estimated.
The trajectory analysis (AvT) was carried out by comparing the average value (Av) and standard deviation (SDLP) of the vehicle lateral position in specific section: tangent section and curves, in urban and extra-urban areas.
The analysis was carried out with respect to the approaching speed in curves and tangent section; for the urban area the limit of 50 km/h was considered and for

Figure 3.15: A driving test

the extra-urban area 90 km/h.

Hazard	Description	Precursor
EP	Four tight curves (R=200, L=100) Extra-urban area Approaching speed 90 km/h	A tight curve sign 150 m before the event
EP	Two traffic light events Urban area	A traffic light sign 150 m before the event
DF	Two pedestrians cross the road on pedestrian crossing, hidden between other pedestrians walking on the the curb	A pedestrian sign 150 m before the event

Table 3.9: Hazards classification by [126]

3.3.4 Results

ANOVA results

ANOVA results show the statistical significance in terms of the considered variables.

The following tables report the F-statistics and the probability for each variables,

Figure 3.16: Another participant in the driving test

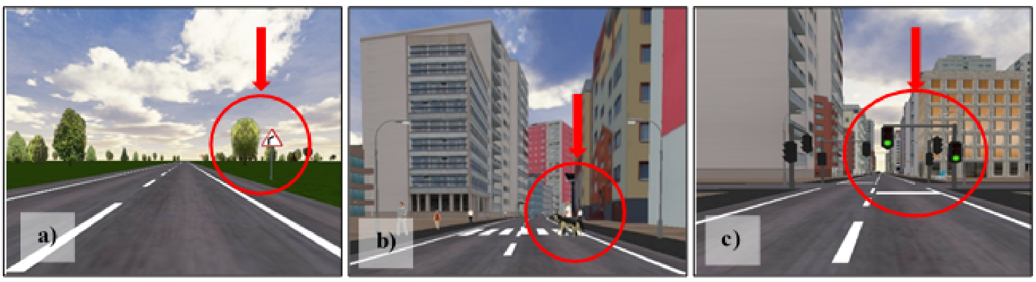

Figure 3.17: a) Tight curves; b) Pedestrian crossings; c) Traffic lights

speed, stopping maneuver and lateral position. Average value and standard deviation of indexes will be discuss in the following paragraphs.

Area	F	p
Extra-urban	1.78	0.20
Sub-urban	1.82	0.20
Urban	2.04	0.18
Industrial	1.76	0.20

Table 3.10: ANOVA test results of AvS

Indexes	F	p
Reaction Time - RT	3.34	0.07
Speed difference - Si-Sf	3.00	0.09
Deceleration - d	1.04	0.30

Table 3.11: ANOVA test results of stopping maneuver

Section	F	p
Curves 200m (EU)	0.01	0.97
Curves 600m (EU)	3.25	0.09
Tangent (EU)	0.07	0.78
Curves 300m (U)	0.01	0.92
Tangent (U)	0.11	0.74

Table 3.12: ANOVA test results of AvT

Average Speed (AvS)

AvS values were studied in four different areas, extra-urban, sub-urban, urban and industrial. Results from ANOVA test show a good significance of the variables.

Results of the drivers' performances show that the AvS values of tired drivers are 6%, 11%, 8% and 7% more in all areas respect to rested drivers. On average, tired drivers have a speed 8% more than rested drivers. Also the values of SD are greater in tired condition for all the areas except for the urban context, where although the average speed is 8% more in tired condition respect to rested condition, the standard deviation in approximately the same.

This result shows a less prudent attitude of tired drivers compared to those rested,

as the tired drivers' behaviour demonstrate that drivers fight against drowsiness keeping a higher speed. In fact, higher speed increases the level of task demand on the driver which can be a way for the driver to stay more alert and fight against drowsiness.
Although some studies report that sleepiness lead the driver to drive slowly [130] also due to physical fatigue is accompanied by reduced muscle force manifesting itself in less force on the accelerator pedal [131], the achieved results is supported by [132]. This latter in a driving simulator study has demonstrated that driver fatigue increases aggressive behaviours (according to [133]), vehicle speed and decreases driver awareness of pedestrians.
Further, progressive fatigue adversely affects driver control of steering and speed regulation; this finding is supported by the arousal theory that performance is poor when arousal is very weak or very strong [134].
In such a framework results show that the effect of the night work affect the speed regulation and seem to lead drivers to drive faster to complete in the shortest possible time the driving task (Table 3.13 and Figure 3.18).

Condition	Extra-urban	Sub-urban
Rested	Av=76.1; SD=3.8	Av=66.4; SD=4.0
Tired	Av=81.1; SD=5.4	Av=73.8; SD=6.4
Condition	**Urban**	**Industrial**
Rested	Av=43.1; SD=1.7	Av=79.7; SD=3.7
Tired	Av=46.5; SD=2.8	Av=85.1; SD=6.1

Table 3.13: Average Speed - AvS

Stopping maneuver analysis

The stopping maneuver was analysed in terms of reaction time (RT), difference between initial and final speed (Si-Sf), average and standard deviation of deceleration (d) regarding two specific events: traffic light (EP hazard event) and pedestrian crossing (DP hazard event). ANOVA test results demonstrate a statistical significance of the measures and the relevant results are shown in Tables 3.14 and 3.15.
The Table 3.14 summarises the stopping maneuver values for traffic light events. RTs of tired drivers are 7% more than rested drivers. The same results is showed for the difference of speed (Si-Sf) that is 2% more in tired condition. Regarding

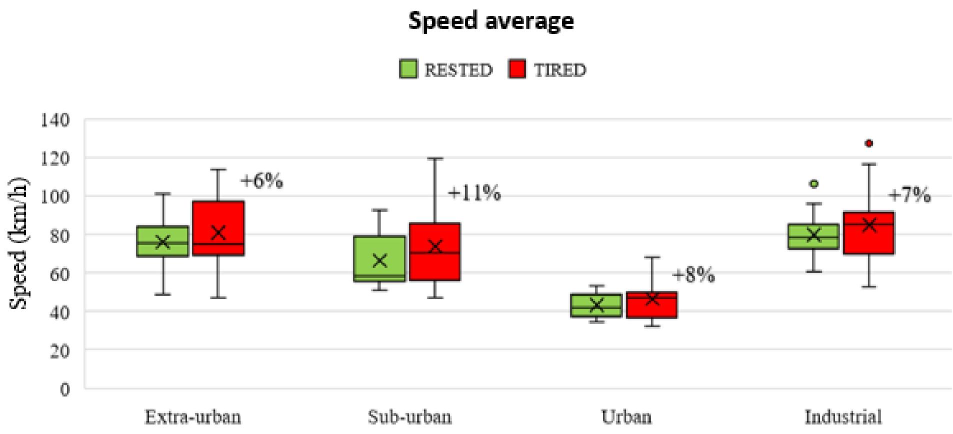

Figure 3.18: Average Speed - AvS

d values, average and standard deviation, the average is 3% more in terms of amount for tired drivers respect to rested condition (in addition the rested values are more scattered, as the standard deviation shows).
Concerning the values recorded during the pedestrian crossing (Table 3.15) RT values are 30% higher for the tired condition than the rested. This difference in RTs between the two types of events (traffic light and pedestrian crossing) demonstrates that the tired driver has a slower response to dangers that are not clearly visible on the road (DF hazard as had [126]classified): in fact, pedestrians remain hidden by other pedestrians until they cross, while the traffic light is easily identifiable from a significant distance.
Driving fatigue after a night shift acts directly on reaction time, as several studied have demonstrated [135], [136]. Reaction time is a significant fatigue factor and a potential cause of fatigue-related accidents.
Finally, by comparing the speed values for the two conditions any considerable variations have not been reported, while during this stopping maneuver a higher value (19% more) of the average deceleration can be noticed for the tired drivers. This latter result shows that tired drivers perform a more heavy braking, since they perceive in delay the hazard event.

Condition	RT [s]	Si-Sf [km/h]	d [m/s^2]
Rested	0.96	-30.98	Av=3.18; SD=1.38
Tired	1.04	-31.72	Av=3.30; SD=1.53

Table 3.14: Stopping maneuver at traffic light events

Condition	RT [s]	Si-Sf [km/h]	d [m/s^2]
Rested	0.69	-31.12	Av=4.20; SD=2.04
Tired	0.90	-31.12	Av=4.99; SD=2.43

Table 3.15: Stopping maneuver at pedestrian crossing events

Average of Trajectory (AvT)

The AvT was analysed by comparing the behaviour of the participants in five different situations: urban tangent section, urban curves with R = 300m (approaching speed 50 km/h), extra-urban tangent section and the two types of extra-urban curves (R = 600m and tight curve with R=200m) with approaching speed equal to 90 km/h.
Driving performances results are shown in Tables 3.16, 3.17 and Figure 3.19.
The analysis shows that in general, performing the curves the trajectory seems to be more to the centerline respect to the tangent section where the drivers keep a value around 1.75 meters that is the ideal trajectory. It is emphasized in the tight curves where the lateral position value is around 2 meters.
Tired drivers values are more scattered respect to rested drivers. It means that tired drivers have more variable behaviours. This difference is greater in tangent section (both in urban and extra-urban) respect to curves.
Although, we can assume that the variability of the driver position into the lane can be due to the tired condition it must be notice that results of ANOVA test demonstrate a low statistical significance between variables.
Desmond [137] found that effect of fatigue on steering performance and on lateral position was greater on straight road sections than in road curves. The study concludes that tired drivers have more difficulty regulating attention and performance in situations with low task demand (straight road sections) than in situations with high task demands (curves).
Vehicle trajectory is affected by the driving fatigue especially in terms of the different driving behaviour of the drivers in approaching the tangent or the curve sections.
Other studies [138], [131] have analysed the steering performances in place of the lateral position. Theyhave found that tired drivers have indicated that steering performance gradually deteriorates and that performance decreases are correlated with subjective ratings of fatigue. According to [139] the increase of fatigue and sleepiness was accompanied by an increased aversion to continue driving and a deterioration of steering performance.

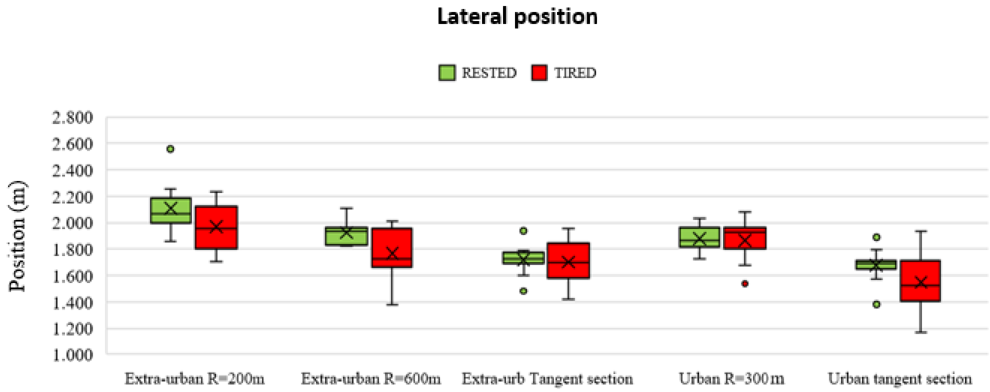

Figure 3.19: Average of Trajectory - AvT

Condition	Curve 200m [m]	Curve 600m [m]
Rested	Av=2.03; SDLP=0.52	Av=1.93; SDLP=0.32
Tired	Av=1.97; SDLP=0.43	Av=1.75; SDLP=0.35

Condition	Tangent section [m]
Rested	Av=1.73; SDLP=0.36
Tired	Av=1.74; SDLP=0.31

Table 3.16: AvT in extra-urban area

3.3.5 Conclusions

The issue related to the hospital staff that after the night shift have to drive to come back to home, was studied by taking into account three driving parameters: speed macro-analysis, in terms of AvS in each road environment context; stopping maneuver analysis by studying the RT values, the Si ans Sf values and the d values); lastly the vehicle trajectory analysis in order to understand the driving behaviour in performing tangent sections and curves.

Regarding AvS, tired drivers recorded an average speed higher, in each environment areas compared, to rested drivers. On average of the overall scenario, tired driver have a speed 8% more than rested drivers. Also concerning the standard deviation of speed, values are more scattered for tired drivers compared to rested drivers, except in urban area.

The fatigue increases the drivers' intention to fight against drowsiness keeping a higher speed and thus having a more complex driving task to perform due to the greater mental work load. It can be a way for the driver to stay more alert and fight against drowsiness.

Condition	Curve 300m [m]	Tangent section [m]
Rested	Av=1.88; SDLP=0.33	Av=1.67; SDLP=0.20
Tired	Av=1.86; SDLP=0.34	Av=1.55; SDLP=0.26

Table 3.17: AvT in urban area

Concerning the stopping maneuver, the main results is the tired drivers' RTs. Values of RT are very greater respect to rested drivers especially for road events that are not clearly visible as a pedestrian that remains hidden until he crosses down the road (DF hazards). These slower reaction times results have direct consequence on a greater speed variation during the maneuver and higher deceleration values (much more for DF events respect to EP).
According to literature review driving fatigue acts directly on RT that is a significant fatigue factor and a potential cause of fatigue-related accidents.
Finally, regarding the AvT, tired drivers have a more scattered values and consequently different behaviours in approaching to tangent sections and curves have been observed. SDLP is found that an effective index to study the drivers' trajectory.
Literature review has examined also the steering performances that is direct correlated with the vehicle position.
The obtained results are promising, but they can be surely improved in future studies by expanding the sample of participants and exploring the behaviour of tired drivers by adding independent variables, such as age or gender, keeping the same boundary conditions.

Chapter 4

External Factors

4.1 Effects of social network activities on driving task

4.1.1 Background

Actually, although the term "mobile phone" is still commonly used, the devices perform other several activities than the simple calling and texting. Nowadays, the smartphone is in fact an agglomeration of technological devices, containing not only the phone, but also camera, navigator, radio, videogame console, allowing either Internet access that carries out all the operations performed by a PC. Moreover, a smartphone is typically a device of entertainment with the largest number of applications available for downloading, most of which are social networking apps. However, the smartphone is one of the main sources of distraction for driving users, as also documented in Italy by the ACI - Istat data for 2017: it is known that, in the extra-urban context, 40.8% of the accidents occurred (about 175,000) originate from incorrect driving behaviour, incorrect use of the rules, and distraction to driving [49]. In 2015, the American company AT&T (American Telephones and Telegraph) with Braun Research, had diffused a survey to understand how the Americans lived the relationship with their smartphone while driving. The sample was 2067 drivers ranging from 16 and 65 years that had a smartphone and drive at least once a day [140]. The main objectives of the research was to establish how much drivers kept their devices at hand. It was found that more than half of sample keep it at a distance that is considered easy-achieving (place for drinks 36%, passenger seat 12%, dashboard 7%) while 30% leave it in places not easy to reach (18% in the pocket, 14% in the bag). A small percentage of people, about 7%, keeps it on legs or in hand. Although the use of the smartphone while driving increases the chances of accidents, in many countries the distracted driving due of smartphones remains a growing issue that call on the legislators to ban its use with the penalty of withdrawal of the driving license. Nowadays, most of the scientific studies on the effects caused by the use of the smartphone while driving focus on two device's functions: talking and texting. In fact, according to the European Commission, the main forms of distraction that involve the use of the smartphone are tactile and visual distraction. From the tactile point of view, many researches are focused on the use of smartphone in regards of the activities of dialing telephone numbers, writing messages, e-mail, addresses for browsing with an on-hand phone ([141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [52], [53], [54], [55], [56], [57], [58], [155]). It was found that visual distraction has a significant impact on the driving performances more than the auditive distraction. In fact, by measuring the time that a driver spent in the lane, it results equal to 96.8% in calling activities and 85.1% in texting activities. Furthermore, also the average speed has reduction in driving while texting [156]. Moreover, the start braking time is calculated in order to highlight the drivers reflexes delay where they are involved in dual task test, driving and texting [157]; It is about 0.2 seconds. Instead, the auditory distraction while driving is investigated in order to analyse the effects of audio files or songs on the driver mood to understand how it can influence and affect the driving performance. Israel researchers [158] have studied changes in drivers behaviour due to the listening of music random and chosen by the driver. Out of 510 tests carried out and evaluated by the driving instructors that supported the drivers, only 61 of these (12%) were carried out without committing traffic violations. On average the 85 participants committed 3 driving errors in at least one of the six planned routes. Among these, 90% of drivers have committed an error listening random music and 98% listening their favorite music. Instead, [159] has tested the auditive distraction but due to audio message (classified as interesting and boring) and not to music. It was found that the reaction time while listening an interesting audio message is 0.04 seconds more than the baseline, while listening a boring audio message it is 0.02 seconds. Furthermore, the headway distance was 1 meter more than the baseline while listening an interesting audio message and 0.3 meters more while listening a boring one. Moreover, many researches aim to study the visual distraction ([141], [142], [144], [146], [156], [157], [147], [149], [150], [151], [152], [154]). The main source of distraction is actually the smartphone, more in detail the reading and texting activities as demonstrate by several researchers ([52], [53], [54], [55], [56], [57], [58]). The presence of a secondary task, as the use of smartphone while driving, changes the attention on the driving task, compromises the road safety of the drivers and leads to increasing the number of accidents (according to accidents statistical data). Smartphones can be a cause of accidents for vulnerable users as pedestrian [160], cyclists [161] and also for drivers [162], [60]. Today, the smartphone is also used for other activities, especially for social media, which engage different cognitive needs than a call phone or texting. Although the effect of the use of the smartphone while driving is quite explored, typically in terms of reading and texting, much effort must be oriented to the distractions due to social networks with the smartphone while driving. In fact, only one published research [163] focuses on the use of social applications while driving (e.g Facebook, Instagram, SnapChat) and shows Brake reaction times (BRTs) and Time Headway (TH) significantly greater in the social-condition compared to the baseline. Therefore, a questionnaire realised by Basch et al. in 2018 [61] has been subjected to a sample of university students on the custom to use the social network while driving. The first data of this questionnaire shows that about 43% of the 324 interviewed students admitted to scroll the home page of the social network, read posts and articles, and also post thoughts and photos on social media while driving. Studies on distraction are developed principally in virtual reality driving environment due to dangers that occur in distracted driving conditions in real driving. However, these experiments have been conducted or in the presence of driving instructors as supervisors [145], or selecting as a test sample only professional drivers [153] or by choosing a closed traffic circuit as a scenario [54].

4.1.2 Objectives

The lack in knowledge on quantifying the effect social activities on driving, highlights the need to investigate more in depth the phenomenon. Therefore, it becomes necessary to investigate the influence by means of a tool that allows to measure the driving performance decay in terms of kinematic and dynamic driving parameter. In this regards, the present paper aims to investigate how much the driving performances are compromised by the secondary task (social activities) and to explore the difference between the effects of the tasks required by the two most common social network: Facebook and Instagram.

4.1.3 Method

The experimental tests are carried out by means of the driving simulator in order to study the behaviour of a sample of drivers in performing the driving task simultaneously with the secondary "social-network" task that will be explained in the following paragraph.

Simulated scenario

Five simulated scenarios of 10 km are designed combined different road environment tracks, in urban, extra-urban and industrial contest to randomised the order and avoid the memorisation process. A simulated two-lane rural road, with one lane of 3.50 meters for each direction are designed according to the Italian rule and regulation the Italian Highway Code (Ministry of Infrastructure and Transports, 1992).

In extra-urban and industrial context, the cross section provides also a right shoulder for each direction of 1.00 meter, while in urban context the same section provides also a 4.00 meters wide both-side sidewalks. The horizontal road alignment is typically flat.

Furthermore a typical flow condition that occurs on the Italian highway is implemented in order to improve the realism of the test, but avoiding to affect the drivers' behaviour.

By means of the 3D objects of the Stisim Drive library a series of realistic elements have been included in the scenario in order to improve the level of realism of the simulation, such as markings and vertical sign, vegetation, buildings and other vehicles.

Several events have been included in scenarios in order to test the driver's attention to the hazard of the road environment. These event are located in the five scenarios at different point to avoid the memorisation of the event sequence and the consequently affection of the results, but they are designed with the same characteristics assuring a reproducible situation. Three events are identified: a car-following maneuver, a legal pedestrian crossing on the proper pedestrian crossing sign, an illegal pedestrian crossing out of the proper sign.

The car-following event is a typical maneuver that is implemented in the scenario in order to study the driving behaviour and performance when the driver perform these maneuvers [164].

In particular, it is implemented to understand the effect on this of "social-network" task.

The car-following maneuver is designed as follows: the driver meets a slow vehicle ahead, called leader that has a speed of 50 km/h and it is positioned on the driver lane. The leader vehicle drive in this position for a distance of 1000 meters. Under such car-following condition, the leader vehicle suddenly brake with a deceleration value of 5m/s2 and it stop in the center of lane, imposing to the driver a sudden braking. Then, it accelerates when the driver reach a speed value after the braking lower than 5 km/h.
The legal pedestrian crossing event is designed according to [163], [96]. The pedestrian start to cross at the right edge of the road on the proper sign with a speed of 1.4 m/s when the driver is at 50 meters far away to have a TTZ (Time to Zebra) of 4 seconds (considering a driver approaching speed of 45 km/h).
The illegal pedestrian crossing event is designed based on the same studies with the same initial characteristics.
Finally, a baseline scenario is recorded to compare results.

Secondary task

Based on the wide knowledge of literature review about distractions due to smartphone while driving, the design of the secondary task is defined. Two social networks referred to two levels of task complexity are set out: low task complexity involves the activities on Facebook and high task complexity involves the activities on Instagram.
More in detail, two social network profile one on Facebook and one on Instagram (Figures 4.1, 4.2) have been created ad hoc. The required activities on Facebook were scrolling on the home page, liking and sharing posts, among these available classified into five classes, sport, music, cinema, funny and cooking. Instead, the activities on Instagram were to take a selfie and share it as story.

Sample features

A sample of drivers is recruited and subjected to the driving test. The selection criteria were: an age ranging from 22 and 30 years, B driving license, smartphone and social networks familiarity. 51 drivers have participated to the driving experiment, 57% males and 43% females with an average age of 26 years ranging from 21 and 32 years. Finally, the time spent every week on social networks are reported, 38 minutes on Facebook and 47 minutes on Instagram. These results are lower than the national average but assure a good knowledge of the

apps by the drivers.
During the experiment, 9.8% of the sample has finished the test before the end due to simulation sickness. The other part of the sample has be statistically validated through two statistical criteria: the Chauvenet criterion and the Box-Plot technique that allow to identify the outliers. Therefore, a final sample of 44 drivers has been analysed.

Procedure

For each driver, the same test procedure is applied. As mentioned before each participant was requested to drive five simulated scenarios with the contemporaneity of the primary task, e.g. driving, and the above-mentioned secondary task. Moreover, they were requested to drive a baseline to record the standard driving parameters to compare to those of the distracted driving. Two test session days with a difference of one week were define: the first with two scenarios and the second with three. The order of the scenarios among the participants was randomised and the two session days were with the difference of one week to avoid the memorisation by the drivers.
Before the session each driver has to drive a training scenario of ten minutes to familiarise with the tool.
Moreover, a before-test questionnaire and an after-test questionnaire are subjected to sample by means of Google Form application, to collect general information about the drivers and his or her impressions and feelings of the driving test and secondary task.

Data collection

Several driving performance and surrogate safety measures were collected, analysed and compared between the two conditions (distracted driving and baseline) in order to investigate the differences between drivers behaviour respect to several indicators that describe the driving performances in the three situations: car-following, legal pedestrian crossing and illegal pedestrian crossing.
Regarding the car-following maneuver four different indexes have been studied: the reaction time (RT) as the time between the previous vehicle (leader) braking and the driver's accelerator pedal release, the minimum distance between vehicles (Dmin), the average distance between vehicles (Dav) and the average of trajectory/lateral position (AvT).

Figure 4.1: Experimental Facebook profile

Moreover, four measures have been examined about the legal pedestrian crossing, the initial speed (Si) as the approaching speed before the deceleration, the initial distance between vehicles (Di) at the same point of Si, the maximum value of acceleration (dmax) and the time to zebra (TTZ) respect to the position of the pedestrian.
Finally, for the illegal pedestrian crossing the initial distance between vehicles (Di), the minimum distance between vehicles (Dmin), the value of the maximum acceleration (dmax) and the TTZ have been studied.

4.1.4 Results

Statistical validation

Each variable for each maneuver (car-following, legal pedestrian crossing and illegal pedestrian crossing) is validated from a statistical point of view.
Table 4.1 summarises the results of the statistical analysis.

Descriptive analysis

From a preliminary descriptive analysis, a higher number of accidents in case of distracted driving is recorded respect to the baseline. More in detail, during the car-following manouver, drivers without any distractions never perform an accident, while drivers in Facebook scenario are involved in 16% of accidents and

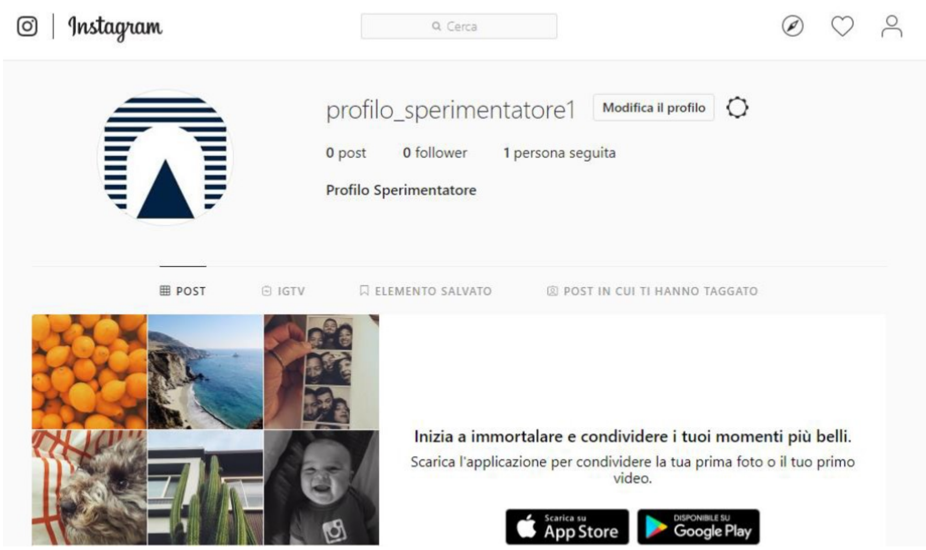

Figure 4.2: Experimental Instagram profile

in Instagram scenario 9%. The same result is while a legal pedestrian crossing, on the proper crossing sign, with a percentage of accidents of 7% both for Facebook and Instagram scenario.

Instead, in the illegal pedestrian crossing the percentage of accidents increases: 5% in baseline condition and 55% and 34% respectively in Facebook and Instagram scenario. Among these, some drivers that crash without any reaction before the collision with consequent high impact speed and acceleration (up to 58 km/h) have been noticed. In particular 50% in Facebook scenario and 67% in Instagram scenario where the workload was higher.

Furthermore the trajectories at the moment of crash seem to be more convergent to the centerline.

Car-following

Results of the car-following manouver are shown in Figure 4.3. RTs are greater in social condition, especially in Instagram scenario, up to a value of 3.92 seconds, respect to the baseline condition of 1.32 seconds. Dmin results in the three conditions are different, lower for Facebook scenario (13.21 meters), and higher for Instagram scenario (22.55 meters), compared with the baseline of 15.95 meters.

Furthermore, Dav along the car-following distance is higher in social condition, seeming affected by the distracted driving. Values are 76.05 meters for Instagram scenario and 45.74 for Facebook scenario. AvT are significantly more on the right respect to the ideal trajectory that is fixed at 1.75 meters for a 3.50 meters two-

Car-following	Test
Reaction Times (RT)	Median Sig. 0.000
Minimum Distance between Vehicles (Dmin)	Median Sig. 0.000
Average Distance between Vehicles (Dav)	Median Sig. 0.000
Average Lateral Position (AvT)	ANOVA Sig. 0.000
Legal Pedestrian Crossing	**Test**
Initial Speed (Si)	ANOVA Sig. 0.000
Initial Distance between Vehicles (Di)	Median Sig. 0.005
Maximum Acceleration (dmax)	Kruskal-Wallis Sig. 0.000
Time To Zebra (TTZ)	Median Sig. 0.000
Illegal Pedestrian Crossing	**Test**
Initial Distance between Vehicles (Di)	Kruskal-Wallis Sig. 0.000
Minimum Distance between Vehicles (Dmin)	ANOVA Sig. 0.044
Maximum Acceleration (dmax)	Median Sig. 0.015
Time To Zebra (TTZ)	Browne Forsythe Sig. 0.002

Table 4.1: Statistical analysis results

lane road.

Legal pedestrian crossing

Legal pedestrian crossing results are reported in Figure 4.4. Results of Si, that is a reliable index of road safety [12], recorded at the moment when the driver start to decelerate seem to be lower for Instagram scenario and higher for Facebook scenario always respect to the baseline. Values are 49.16 km/h for Facebook scenario and 38.04 for Instagram scenario, compared to 46.51 km/h for the baseline.

Di show a greater value for Instagram scenario and a lower value for both Facebook scenario and baseline. dmax results show the highest value of deceleration for Facebook scenario up to -7.62 m/s^2 and finally regarding the TTZ, values seem to be different each other, with the highest value always for Instagram scenario and lower value for Facebook scenario (0.73 seconds) and baseline (0.87 seconds).

Illegal pedestrian crossing

The results of illegal pedestrian crossing maneuvers are reported in Figure 4.5. In addition, values in the three conditions are recorded. In particular, the Di

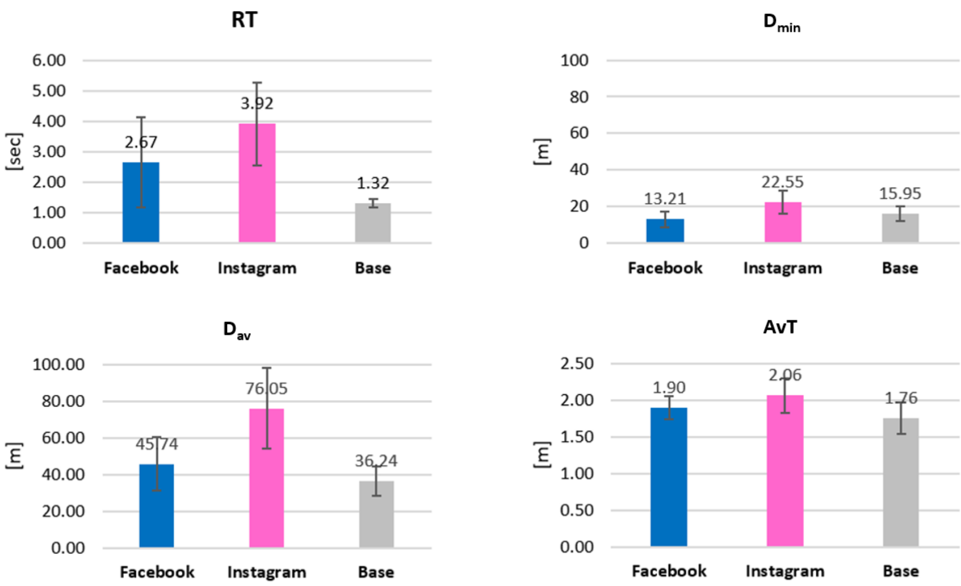

Figure 4.3: Car-following

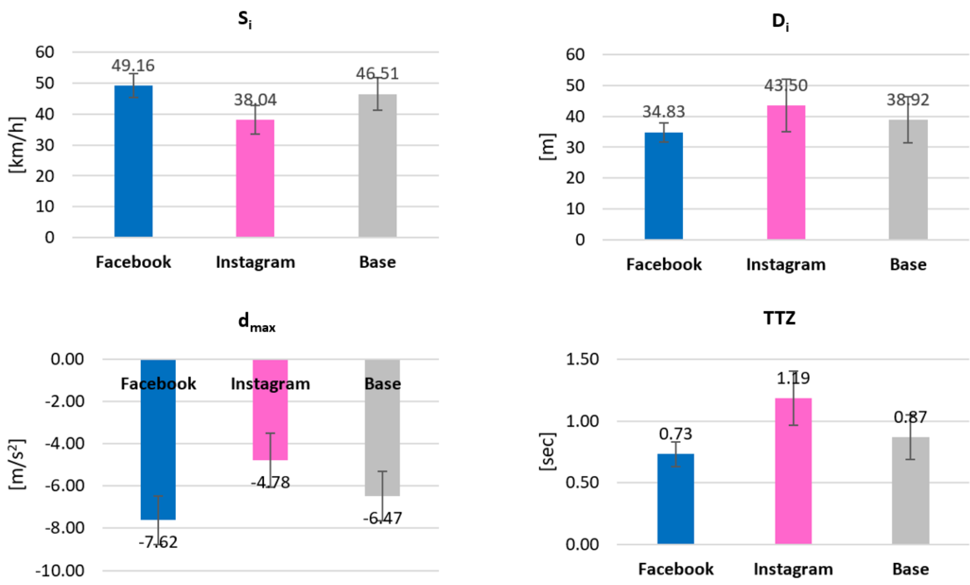

Figure 4.4: Legal pedestrian crossing

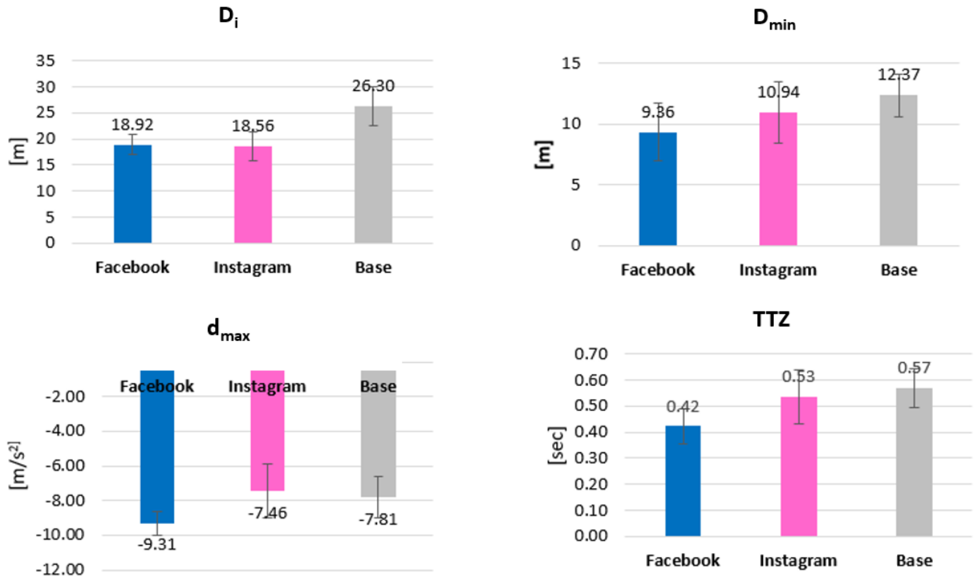

Figure 4.5: Illegal pedestrian crossing

at the moment when the driver start the deceleration are greater in the baseline (26.30 meters) respect to the distracted driving where the drivers are closer to the previous vehicle (18.92 meters for Facebook scenario and 18.56 for Instagram scenario).
Also the Dmin values are higher for the baseline condition and lower in distracted driving, while the results of dmax show a greater value for Facebook scenario of 9.31 m/s^2 of deceleration in approaching to the pedestrian crossing out of the proper sign.
TTZ results are lower respect to the baseline, more for Facebook scenario 0.42 seconds.

4.1.5 Conclusions

The phenomenon of the use of smartphone for the social-network activity was studied from a general point of view where results show an high number of accidents in condition of distracted driving with high speed impact and consequently high acceleration values at the moment of the crash.
Furthermore, three events that request to the driver to performance specific maneuvers are investigated: car-following, legal pedestrian crossing on the proper crossing sign and illegal pedestrian crossing out of the sign.
Results about car-following show a significant impact of the use of the smartphone on driving in terms of longer RTs and Dmin during the manouver. Furthermore

values more on the right are recorded for AvT.
In terms of legal and illegal pedestrian crossing, Si, dmax and TTZ show the impressive decay of driving performances in case of distracted driving.
The finding of this application are promising as it gave a insight of how the phenomenon of distracted driving due to social-network activities are serious and worrying for the drivers and road safety.

4.2 Effects of smartphone texting activities on driving task

4.2.1 Background

As for the previous case of study, a wide literature review about the use of the smartphone while driving has been addressed. In fact, nowadays smartphones are personal assistants that take a fundamental part in the human life, both for working and social life.
For these reasons, the smartphone manufacturers prefer to focus on the optimisation of the use of the smartphone while driving, rather than the exclusion that in any case would lead to non-standard behaviour. Therefore, the future objective is to integrate the smartphone in the vehicle system in order to allow the driver to access in hand-free mode to the main smartphone functionalities, calling and texting, but also camera, navigator and music. This could be applied with specific app as AndroidAuto for Android devices or CarPlay for Apple devices that could decrease the mental workload while driving, leaving the driver to focus on the primary task.
However, nowadays from a road safety point of view, the distracted driving due to the use of the smartphone is one of the major cause of accidents. According to Italian statistical data (ACI-istat data for 2017), in the extra-urban area, 40.8% of the accidents occurred (about 175,000) caused by incorrect driving behaviour, incorrect use of the rules, and distraction to driving [49]. Smartphones can be also cause of accidents for vulnerable users as pedestrian [160], cyclists [161] and also for drivers [162], [60].
Moreover, many researches aim to study the visual distraction correlated to smartphone activities while driving [141], [142], [144], [146], [147], [149], [150],[151], [152], [154], [157], [158].
More in details, some studies are focused on reading and texting activities [52],

[53], [54], [55], [56], [57], [58]. The presence of a secondary task as reading or texting, changes the attention on the driving task, compromises the drivers risk perception and leads to increasing the number of accidents. According to [156] by measuring the time that a driver spent in the lane, it results equal to 96.8% in calling activities and 85.1% in texting activities.
In fact, texting activity respect to calling involve a higher mental workload that lead drivers to a visual distraction and consequently a lower attention to the road pattern. Furthermore, also the average speed has reduction in driving while texting. Moreover, start braking times are calculated in order to highlight the drivers reflexes delay when they are involved in a secondary task test, as driving and texting [157]. The reduction of start brake times is about 0.2 seconds.
In such a framework, it is well known how the phenomenon of the use of smartphone for the texting activity while driving are worrying and for this reason much effort must be made to improve the research in this field.

4.2.2 Objectives

Based on the wide analysed literature review, the aim of this research is to understand the effect of the texting activity by means of WhatsApp app on the driving task. As for the previous study a decay in driving performances is expected, respect to the specific event implemented in the simulation scenarios.
Furthermore, the effectiveness of AndroidAuto app that allow to interact in hand-free mode based on a voice recognition assistant, is evaluated by the comparison of results in WhatsApp scenario and AndroidAuto scenario.

4.2.3 Method

The experimental tests are carried out by means of the driving simulator is a very useful tool in the field of road and infrastructure engineering capable to investigate how different factors, as the use of the smartphone while driving.
In order to perform the secondary task with AndroidAuto app, the smartphone is applied on the dashboard to allow the driver to interact with the smartphone in hand-free mode (Figure 4.6).

Simulated scenario

Three scenarios of 10 km are designed combined different road environment tracks, in urban, extra-urban and industrial area. A simulated two-lane rural road, with one lane of 3.50 meters for each direction are designed according to the Italian rules and regulation, the Italian Highway Code (ministry of Infrastructure and transports, 1992).
As for the previous road simulated scenarios, in extra-urban and industrial context the cross section provides also a right shoulder for each direction of 1.00 meter, while in urban context the same section provides also 4.00 meters wide both-side sidewalks. The horizontal road alignment is typically flat.
Furthermore, a typical flow condition that occurs on the Italian highway is implemented in order to improve the realism of the test, but avoiding to affect the drivers' behaviour.
With the objects of the Stisim Drive library a series of elements have been included in the scenario in order to improve the level of realism of the simulation, such as markings and vertical sign, vegetation, buildings and other vehicles.
Several events have been included in scenarios in order to test the driver's attention to the hazard of the road environment. These event are located in the five scenarios at different point to avoid the memorisation of the event sequence and the consequently affection of the results, but they are designed with the same characteristics assuring a reproducible situation.
Three events are identified: a car-following maneuver, a legal pedestrian crossing on the proper pedestrian crossing sign, an illegal pedestrian crossing out of the proper sign. These events are designed with the same features of the previous study: for the car-following the driver meets a slow vehicle ahead, called leader that has a speed of 50 km/h and it is positioned on the driver lane. The leader vehicle drive in this position for a distance of 1000 meters. Under such car-following condition, the leader vehicle suddenly brake with a deceleration value of 5m/s2 and it stop in the center of lane, imposing to the driver a sudden braking. Then, it accelerates when the driver reach a speed value after the braking lower than 5 km/h.
The legal and illegal pedestrian crossing events are designed with the same features according to [163] and [96] with a pedestrian speed of 1.4 m/s and a TTZ (Time to Zebra) of 4 seconds (considering a driver approaching speed of 45 km/h).
These elements are combined into the three scenarios: the first one is the baseline with events but with any distraction is recorded to compare results with the distracted driving (presence of a secondary task); the second one is with WhatsApp

app and finally, the third one is with AndroidAuto app.

Secondary task

Based on the analysed literature review a secondary task is designed according to a specific protocol defined ad hoc in order to standardise the activities. Both for WhatsApp and AndroidAuto app the drivers were requested to answer (or texting or aloud respectively) to some question by replying to messages in 5 seconds elapsed from the reception. If the driver does not reply to the message after 10 seconds from the reception, the message will be resend.
The rate of sending messages follows time intervals that are calibrated according to the driver position in the scenario.
In truck without critical events, the rate is 10 seconds, while in trucks with critical events the rate decreases. The messages mental workload is the same, with replies of one univocal word, with few letters.
A set of five answers macro-groups are defined about presentation (name, surname, age, gender, etc.), colors game (what is the color of the strawberry?), numbers game (3+2=?) and letters game (A is a vocal or a consonant?).

Sample features

A sample of 51 drivers is recruited as volunteers via direct contact in the Department and subjected to the driving test. The selection criteria were: an age ranging from 22 and 30 years, B driving license, smarthphone and social networks familiarity. From a statistical point of view the sample features are 57% males and 43% females with an average age of 26 years ranging from 21 and 32 years. Around 45% of the sample ranging from 21 and 25 years, while 47% is ranging from 26 and 30 years, only 8% is younger than 20 years and older than 30 years. Concerning the driving experience, 72% of the sample had B driving license from 4 and 10 years, 9% for more than 10 and 19% had it for less than 4 years.
Furthermore, 59% of drivers has a smartphone with Android working systems and 41 with iOS. Any other working systems have been not found and more than 50% use the same working system since at least 5 years. Moreover, 86% do not know and do not use the AndroidAuto app while driving. During the experiment, 11.3% of the sample has finished the test before the end due to simulation sickness. The other part of the sample has be statistically validated through two statistical criteria: the Chauvenet criterion and the Box-Plot technique that allow

to identify the outliers. Therefore, a final sample of 46 drivers has been analysed.

Procedure

For each driver the same test procedure is applied. As mentioned before each participant was requested to drive three simulated scenarios with the primary and above-described secondary task.
Moreover, they were requested to drive a baseline to record the standard driving parameters to compare to those of the distracted driving. Two test session days with a difference of one week were define: the first with two scenarios and the second with three. The order of the scenarios among the participants was randomised and the two session days were with the difference of one week to avoid the memorisation by the drivers.
Drivers before the driving session are requested to drive a 10 minutes training scenario to familiarise with the tools. Moreover, a before-test questionnaire and an after-test questionnaire are subjected to sample by means of Google Form application, to collect general information about the drivers and his or her impressions and feelings of the driving test and secondary task.

Data collection

As for the study of the use of social network while driving, several driving performance (speeds, distances, etc.) and surrogate safety measures (BRT, TH) were collected, analysed and compared between the two conditions (distracted driving and baseline) in order to investigate the differences between drivers behaviour respect to several indicators that describe the driving performances in the three situations: car-following, legal pedestrian crossing and illegal pedestrian crossing.
Regarding the car-following maneuver four different indexes have been studied: the average speed (AvS), the average acceleration (dav), the average trajectory/lateral position (AvT) and the reaction time (RT).
Moreover, four measures have been examined about the legal pedestrian crossing, the average speed (AvS), the minimum value of speed (Smin), the average of trajectory/lateral position (AvT) and the speed reduction time (SRT).
Finally, for the illegal pedestrian crossing the initial distance between vehicles (Di), the time to zebra (TTZ), the average speed (AvS) and the minimum value of speed (Smin).

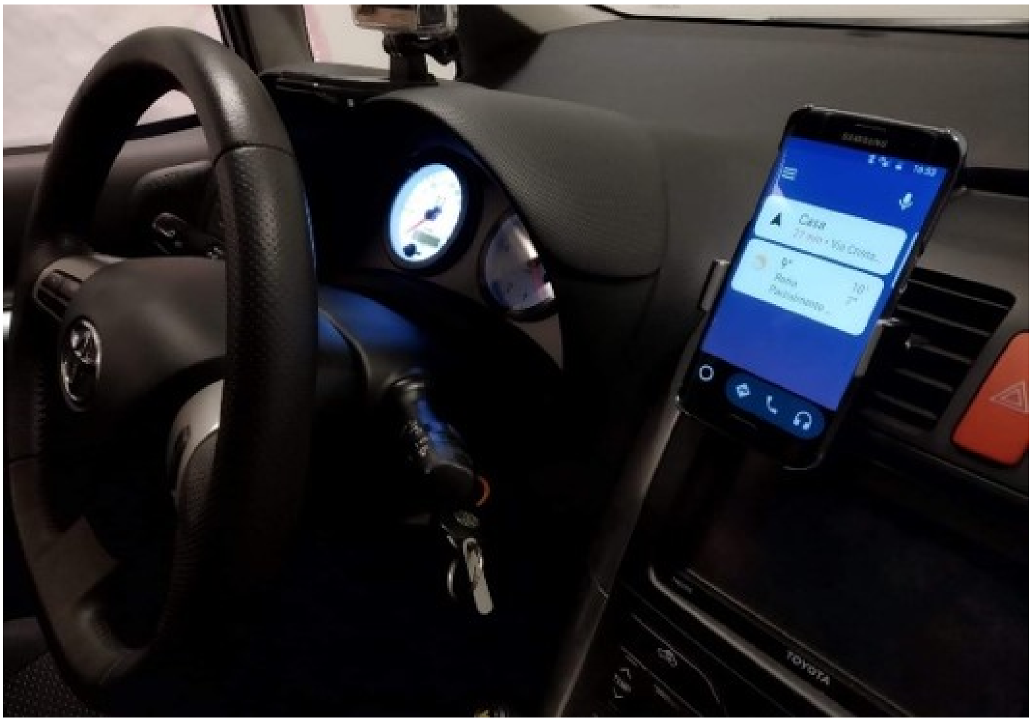

Figure 4.6: Smartphone support on the dashboard

4.2.4 Results

Statistical validation

Each variable for each maneuver (car-following, legal pedestrian crossing and illegal pedestrian crossing) is validated from a statistical point of view.
Table 4.2 summarises the results of the statistical analysis.

Descriptive analysis

As for the previous study, from a general descriptive analysis the number of accidents during the manouvers are higher in distracted driving respect to the baseline. More in depth during a car following maneuver, 9% of accidents are recorded in WhatsApp texting scenario and 0% for AndroidAuto scenario and baseline. While for the illegal pedestrian crossing compared to 5% of the baseline, up to 34% of accidents are recorded in AndroidAuto scenario, 23% in WhatsApp scenario with the audio messages and 14% of accidents in WhatsApp scenario with text messages.
Moreover, a greater number of excursion out of the centerline and the edge line are highlighted in distracted driving (WhatsApp and AndroidAuto) compared with the baseline and also very high impact speed values at the moment of crash.

Car-following	Test
Average Speed (AvS)	Kruskal-Wallis Sig. 0.463
Average Acceleration (dav)	Median Sig. 0.002
Average Lateral Position (AvT)	Kruskal-Wallis Sig. 0.069
Reaction Time (RT)	Median Sig. 0.000
Legal Pedestrian Crossing	**Test**
Average Speed (AvS)	Browne Forsythe Sig. 0.014
Minimum Speed (Smin)	Browne Forsythe Sig. 0.037
Average Lateral Position (AvT)	ANOVA Sig. 0.532
Speed Reduction Time (SRB)	Median Sig. 0.040
Illegal Pedestrian Crossing	**Test**
Initial Distance between Vehicles (Di)	Kruskal-Wallis Sig. 0.329
Time To Zebra (TTZ)	Kruskal-Wallis Sig. 0.203
Average Speed (AvS)	ANOVA Sig. 0.637
Minimum Speed (Smin)	Kruskal-Wallis Sig. 0.123

Table 4.2: Statistical analysis results

Car-following

Concerning the values of car-following maneuver, a lower value of AvS in case of WhatsApp scenario is recorded, in particular 41.90 km/h respect to 43.57 km/h of the baseline. AndroidAuto app seems to allow to keep the same value of speed. Regarding dav, it seems significantly greater for WhatsApp scenario with positive value of 0.08 m/s^2 instead of -0.03 m/s^2 for both AndroidAuto scenario and baseline.

Finally RTs are very higher in WhatsApp scenario where the mental workload to reply to a message by texting is high, respect to AndroidAuto that has a slight increase of 0.30 seconds respect to the baseline value of 1.32 seconds. Also in this case AndroidAuto app seems useful to reduce the mental workload of drivers involved in a primary task.

Legal pedestrian crossing

The AvS and also the minimum value of speed seems lower in WhatsApp scenario respect to the use of AndroidAuto app and the baseline. In fact, AvS is 45.82 km/h respect to 52.27 km/h of the baseline and the minimum value is 8.06 km/h respect to 13.37 km/h of the baseline. The reduction can be due to the

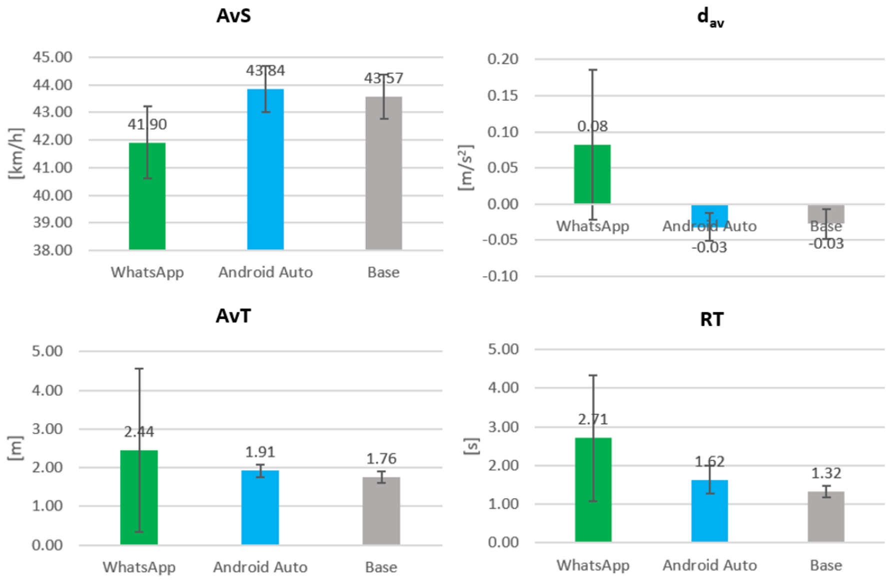

Figure 4.7: Car-following

distraction imposed by the secondary task that lead the drivers to keep a lower speed. Instead, AndroidAuto scenario has almost the same value of the baseline. Regarding AvT, although it is validated from statistical point of view, it seems not so affected by the distraction, in fact, values very close to each other are recorded.

Finally, SRT are 9.08 seconds for WhatsApp scenario, slightly higher respect to the baseline of 8.56 seconds, while in AndroidAuto scenario they are 10.39 seconds.

Illegal pedestrian crossing

In case of illegal pedestrian crossing out of the proper crossing sign down the road, different paramentes for all the indexes are recorded.

More in detail, Di at the moment of the crossing are lower for all the distracted scenarios, WhatsApp text message, audio message and AndroidAuto, all around 20 - 22 meters, instead of 26 meters for the baseline. Furthermore, TTZ values confirm the same trend, lower values, but not so significant for distracted driving respect to the baseline.

AvS values are very close to each other and any trends between these have not been found. Concerning the minimum speed value, a very lower value is recorded in Android Auto scenario, 6.05 km/h respect to the baseline of 12.12 km/h. The other values of WhatsApp scenario (text messages and audio messages) are be-

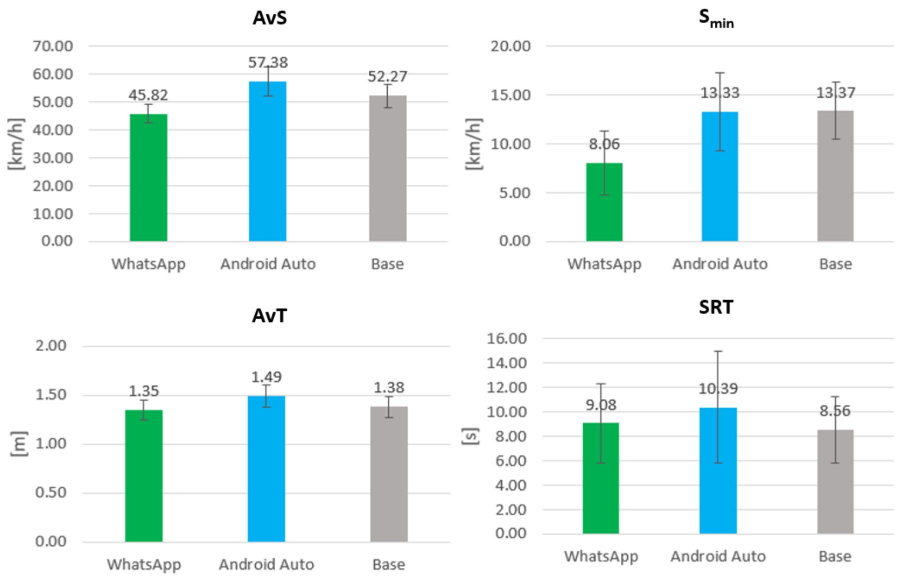

Figure 4.8: Legal pedestrian crossing

tween 10 and 12 km/h.

4.2.5 Conclusions

This application investigates the effect of the texting activity by means of a smartphone while driving. As for the previous study, the impact of distracted driving of the number of accidents during the investigated maneuvers is impressive, especially concerning the pedestrian crossing event. Moreover, results for the descriptive indexes of the three events are analysed: car-following maneuver, legal pedestrian crossing and illegal pedestrian crossing.
During the car-following maneuver, a delay in drivers reflexes is emerged, typically shown in average speed and reaction times.
In performing the braking maneuvers due to pedestrian crossing, legal and illegal, the results of WhatsApp scenario highlight a worrying lack in concentration to the road due to the distractions of the secondary task, but the AndroidAuto app seems to be useful to reduce the mental workload of the replying to the messages and improve the drivers performances.

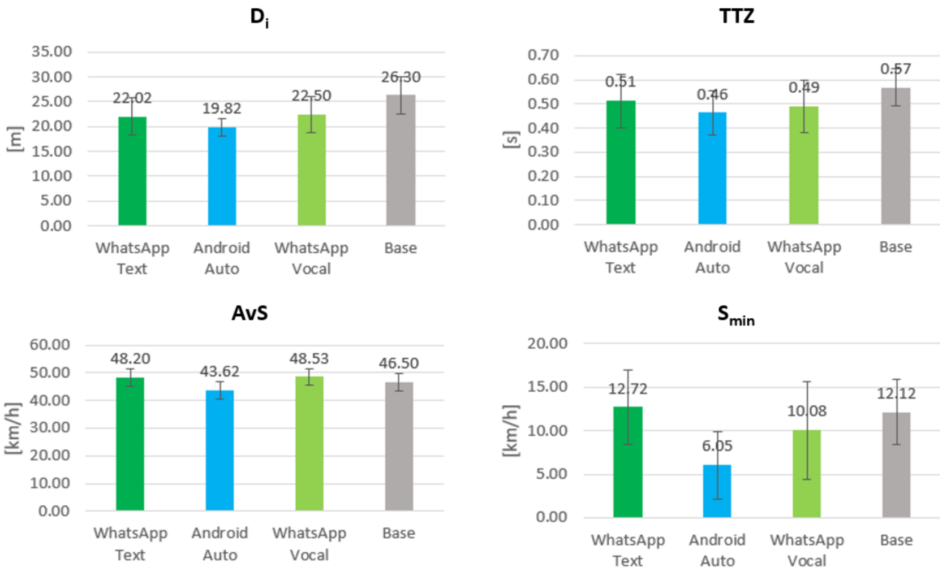

Figure 4.9: Illegal pedestrian crossing

Chapter 5

General Discussion and Conclusion

Previous studies have highlighted the importance to investigate the effect of human factors on driving. An extensive literature review on the effect of several human factor on driving has been addressed to understand the driving performances decay due to the specific human factor. However, much effort must be oriented about the standardisation of human factors impact on driving risk perception to compare the results.
The present PhD thesis project has tackled a variety of case studies in order to investigate the impact of human factor by means of a standardised methodology with kinematic-dynamic and psycho-physiological measures obtained from driving simulator experiments.
This final chapter of the manuscript includes first of all a summary of the empirical results achieved with the five case studies; then a review of the objectives and an evaluation of the research limitations has been addressed. Afterwards, practical and theoretical implications of the research have been presented and finally, the direction for future research.

5.1 Summary of Empirical Result

This research attempts to provide insights into the impact of the human factor on the driver's behaviour and more in general on the road safety. Five applications have been undertaken towards achieving the specific objectives of the analysis.
Each study has been developed with a driving simulator experiment, following a specific protocol defined *ad hoc* for each application. A sample of participants are recruited and validated from a statistical point of view, a precise set of road scenarios are built and a series of tests are recorded for each participants. Finally

a defined data set of indexes are processed in order to point out the outcomes.

More specifically, in the chapter 3, the impact of internal factors are investigated. Internal factors act internal to the driver, as age, gender or impaired psycho-physiological conditions. In this PhD thesis, three case studies are carried out, specifically, the effect of gender, alcohol and fatigue after a night shift work, on risk perception assessment.
Results of case studies of chapter 3 show a significant impact of internal factors on driving. In fact, all the measures describing the driving behaviour according to the risk perception assessment demonstrate a significant decay of driving performances.
The differences by gender show higher values of time to collision for female drivers respect to male drivers, in both pavement conditions (wet and dry), also higher pressure on brake pedal for female drivers and consequently higher values of slip ratio that means higher probability to performance a braking in slip risk condition.
Concerning alcohol factor, greater reaction times and slightly increase of average speed values are recorded. Furthermore, regarding the overtaking maneuvers a behaviour more incline to risk are underline with an higher number of overtaking and brakings over the safety threshold that can lead to slip risk condition. The eye-tracking results show a sleepy attitude of the drivers as blinking and frequency values demonstrate.
The same trend just mentioned is recorded in case of fatigue for higher reaction times and heavier brakings that highlight a low risk perception of tired drivers.
Lateral position values unifying the last two case studies of the investigation of the internal factors, in fact, it not respond to any factors and seems to be more dependent to the area, the context of the road environment and the pattern, that the specific factors. In fact, in case of alcohol experiment, results are influenced by the area, urban or extra-urban and not significant differences are recorded between the two psycho-physiological conditions, while in case of fatigue it seems to be influenced by the pattern, presence of slight curves or tangent sections.

The chapter 4 contains two case studies developed with the same defined methodology in virtual reality driving experiments, with the purpose to investigate the effects of external factors. In this research project, the distraction effect of smartphone are studied in two different secondary tasks, social-network consulting and messages texting.
In both analysis a very high number of accidents are recorded in condition of

distracted driving in all the three analysed maneuvers, car-following, legal or illegal pedestrian crossing up to a value of 67% of accidents against 0% recorded in baseline driving. In addition very high impact speeds and accelerations at the moment of crash are presented.
Furthermore, in performing a car-following maneuver higher value of reaction times are pointed out. In legal and illegal pedestrian crossing lower values of average and minimum speed and initial distance between vehicles are measured. Also for these two studies of external factors, lateral position values seems to be not affected by the distracted driving in relation to the maneuvers.

5.2 Achieved Objectives

An effective research project must fulfill the set objectives.
The present PhD thesis, based on a interdisciplinary approach, aimed to understand how much do the internal and external factors affect the risk perception assessment while driving. The objective is achieved by means of the analysis of kinematic-dynamic and psycho-physiological measures of five case studies conducted by the driving simulator and an eye-tracking systems used coupled with the simulator. More in depth the three key objectives have been achieved as explained below.

- Search for traditional indexes, methodologies and tools to estimate the risk perception.

Several traditional indexes and methodologies are addressed in the literature review section in order to define the best indexes that could describe the variation of driving behaviour respect to human factors.
More specifically, performance-based measures obtained from the outcomes of a driving tests by the driving simulator are selected. Among these the speed average, the deceleration rate, the pressure on the brake pedal, the average trajectory, reaction times respect to specific events and time to collision are the most used indexed for driving risk perception assessment.

- Search for psycho-physiological indexes, methodologies and tools used to estimated the risk perception.

Psycho-physiological measures and methodologies achieved by traffic psychology studies and behavioural investigations are selected with the aim to monitor stress levels and concentration levels while the driving task.
Among all the psycho-physiological tools, an eye-tracking system is selected to monitor the drivers' behaviour in case of alcohol assumption while driving.

- Risk assessment and calculation through kinematic-dynamic, geometric and psycho-physiological measures by means of experimental activities in virtual reality driving environment.

Finally to fulfill the last key objective, five case studies are designed and developed in virtual reality driving simulator experiments to assess the risk perception of drivers by means of the above mentioned indexes and methodologies.

5.3 General Research Limitation

Some limitations of this PhD thesis should be acknowledged in order to provide ground for further research in the future.
The first limitation of this research has been found in the complexity of data collections and raw data processing. The computing of driving simulator outcomes became very time-consuming as many analysis and skills were required. Therefore, the management of the data collection and processing turned into the biggest logical challenge of this study.
Furthermore an important consideration should be given to the big driving simulator data set in relation with the accuracy and high quality of data. In fact, the simulation system allows to record up to ten data per second for each parameter that is chosen and defined by the experimenter. The maximum number of parameters that the driving simulator can record are more than 50, it means that with a frequency of ten data per seconds, in a typical scenario of ten minutes, about 6000 data are recorded for each driving test and for each driver. The overall data set for a study is very wide.
An additional comment should be made on the samples that are recruited for each study. In fact, among the case studies the number of participants is different due to some difficulties in the recruitment of the participant especially in experiment tests that required a particular physical condition, as the alcohol study or the driving fatigue of the users after their night shift.

However, it is important to emphasise that each sample for each study has been validated from a statistical point of view in order to check if the number of the recruited participants was enough to study and generalise the results of the specific investigated phenomenon. Each sample result befitting for the study.

5.4 Practical and Theoretical Implications

The implications of the key findings of this PhD project with respect to theoretical and practical implications are discussed below.

The main theoretical implication of this work is to define a mathematical model of the risk assessment by means of the correlation of kinematic-dynamic and psycho-physiological measures. In fact, starting from the case studies outcomes it could be possible to identify a mathematical correlation between the measures in order to calibrate a function and applied a model to estimate a general index of risk perception.

Furthermore, several practical implications of this work can be defined.

First of all, impressive insights are oriented to promote road safety awareness campaigns to sensibilise people to social problems driving-related, e.g. drink and drive, driving fatigue or campaigns against the use of the smartphone while driving.

Furthermore, this work can give to the competent authorities some indications into the regulation of specific recommendations, rules, legislation and laws pertaining to this area. For example the study on alcohol could give important insight on the definition of the penalty limit, or the study of fatigue of the hospital staff could encourage to define a new regulation for people that have to drive back home after a night shift.

Lastly, the importance to develop driving simulator studies lies into the deep insight regarding the mechanism of operating of drivers' behaviour in order to understand the lack in terms of specific measures and promote the development of driver support systems.

The continuous technological progress has promoted in recent years vehicles manufactures to focus on the development of Advanced Driver Assistance Systems (ADAS), devices that equipped the vehicle and increase and improve the road safety, supporting the driver in the driving task.

5.5 Direction for Future Research

The overall direction for future research in terms of driving studies is always to improve the global road safety. In the specific field-related research of human factors while driving, several new systems and approaches are proposed.

The vehicle manufactures are developing increasingly ADAS systems to support the driver in the primary driving task by restricting the effect of the human factor on driving performances. Some of these are already implemented in vehicles, as the adaptive cruise control (ACC), a system that provide a control of speed by fixing the speed previously defined by the drivers. In most recent cases, it allows also to accelerate and decelerate without any input by the driver but only in accordance to the traffic flow. Furthermore, the emergency braking sensor is already equipped in vehicles and allow to detect a objects in front of the car and provide, in case, an emergency brakings.
The most diffused ADAS systems are the parking sensors that help the driver to park the car by a recognition of the space of the parking thanks to sensors at the back of the vehicle. Another system that support the driver in the driving task is the lane keeping systems that alert the driver of the centerline crossing and automatically returns the vehicle to the lane in the correct direction.
Moreover, a recent application of ADAS system in the vehicle is the integrated breathalyzer that through a sensor detects the concentration of air to estimate if the value of BAC is over the allowed threshold imposed by country regulation.

In addition to these, other solutions to improve the drivers' risk perception are open matters of research. More specifically, two studies conducted with the driving simulator have been developed in this direction by the author and her research group. These are not subject to this thesis as they are still ongoing projects that have achieved only satisfactory preliminary results.
The first one deals with the application of the augmented reality in the virtual reality road environment. In fact, one modality to implement the concept of connected vehicles in order to assure the exchanging of information between vehicles and between vehicle to infrastructure and consequently road environment, is the augmented reality.
Augmented reality is the new technological approach that allow to overlap digital information on other kind of information such as those coming from the road environment. In case of real driving information of the road environment are the real world things (e.g. pedestrian, sign, vehicles), instead, considering the virtual

reality driving environment, the digital information of the augmented reality can be overlap to the virtual road information.
Information of augmented reality can be related to the distance from the previous vehicle, the time to collision, the speed difference or for objects that highlight potential road environment risks.
In this regard, the ongoing-project aims to understand and verify the effectiveness of dynamic objects designed as augmented reality on the drivers' behaviour. The objects could be lighting rectangles or arrows to highlight the presence of pedestrian that is crossing down the road, or the previous vehicle that is suddenly brakings or even virtual signal light that allows to choose the gap between a vehicles flow in which to pass.
More in detail, an experimental set up based on a driving simulator protocol is applying in order to test a sample of 46 drivers in four simulated scenarios. They are built in order to reproduce a typical two-lane road environment in urban, extra-urban and industrial areas with the presence of pedestrian crossing and cyclist events in three configurations without any augmented reality system, with a visual augmented reality system and lastly with also an audio system.
Furthermore, two maneuvers are tested, the car-following and turn left maneuver with a rectangle for the car-following maneuver that lighting when the previous vehicle is braking and a virtual signal light in case of left turn maneuver. Each of these two maneuver are studied in the above mentioned three configurations of augmented reality system.
The sample test is carried out and the first promising results are analysed but much efforts have to be done in results deeper analysis.

Moreover, a study on the effect of automated driving has been developed by means of the driving simulator with the aim to understand the effect on the drivers' behaviour of automated driving, more specifically when the driver is requested to take over the vehicle commands after a period of automation.
A simulated scenario of a freeway with two lanes for each direction is implemented with a part of automation that involve the wheel and the pedal of the car and allows to keep the same speed during the simulation. Specific TORs are implemented in order to test the most effectiveness system to inform drivers to release and take over the vehicle commands. After the period of automation the driver is requested to drive in a scenario with some events with respect to which several driving parameters are measured. Results are compared with a scenario drive in all manual driving.
A sample of 43 participants have been take part to the experiment following a

specific and detailed procedure. During the automated driving mode, drivers were requested to perform a secondary task that distracted drivers from the primary task, i.e. driving. After a literature review, a secondary task that distracts the drivers from the primary task but does not require excessive effort and concentration and without an overload of mental workload was chosen. Drivers were requested to watch two short videos of maximum 5 or 6 minutes on a created YouTube channel. Five categories of videos are created on the channel in order to effectively direct choice of drivers among comic, musical, sport, funny and "how it is made" videos.
As the study of augmented reality, this research are an ongoing project. The first results appear promising and prompt to continue the survey.

The above proposed future directions provide important insights and information in terms of facilities for the driver to estimate exactly the potential road environment risks thanks to new technological supports or new concept of driving mode to achieved the global objectives of road safety.

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