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In-Vehicle Information Systems-related multiple task performance and driver behaviour:

Comparison between different age groups

Dissertação apresentada a defesa pública com vista à obtenção do grau de Doutor no Ramo de Motricidade Humana, Especialidade em Ergonomia

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ABSTRACT

The presence of new technologies inside vehicles is becoming more common. Due to this fact, the potential changes produced on the driving task and also on the road safety must be examined. With the intention of contributing to amplify this knowledge, the present research aimed to study the impact of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. It was investigated the interaction with more than one in-vehicle system (a guidance system and a mobile phone device) and verified its consequences on the drivers' activity. To accomplish this goal two experimental moments were planned: one conducted in a real context and another in a simulated environment. Results revealed that the interaction with two in-vehicle systems produced considerable changes on drivers' behaviour once subjects assumed more frequently unsafe actions like: inadequate indication of their actions; abrupt and unexpected adoption of determined behaviours; and also negligence of some road information from the environment. It was also verified that this situation produced more severe consequences to the driving task performance of elderly drivers. The management of all sources of information induced them to compromise their safety and be more frequently involved in dangerous situations.

Keywords: Driving behaviour; multiple-task performance; in-vehicle information systems; guidance systems; mobile phones; elderly drivers.

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NOMENCLATURE

ADAS_Advanced Driver Assistance Systems

AIDE_ Adaptive Integrated Driver-vehicle InterfacE

CONSENSUS_Project related with driving assessment ability of People with Special Needs through common methodologies and normative tools

COST_European Cooperation in the field of Scientific and Technical Research

ElectroOculoGram_Method to record the electrical activity associated with movements of the eye throughout the placement of electrodes a on the skin near the eyes

ERSO_European road safety observatory

ERTICO_Europe's intelligent transportation system organization that funds research and defines ITS industry standards

ESoP_European Statement of Principles on the Design of Human Machine Interfaces

FHA_Federal Highway Administration

HASTE_Human Machine Interface And the Safety of Traffic in Europe

HUMANIST_HUMAN centred design for Information Society Technologies

INRETS_Institut National de Recherche sur les Transports et leur Sécurité

ITS_Intelligent Transportation Systems

IVIS_In-vehicle Information Systems

MCH_Modified Cooper-Harper

NASA-TLX_National Aeronautics and Space Administration- Task Load Index

RSME_Rating Scale Mental Effort

SWAT_Subjective Workload Assessment Technique

The Wiener Fahrprobe_ method that registers the subjects’ behaviour while driving

UNECE_United Nations Economic Commission for Europe

INTRODUCTION

Industrialized countries have been watching to the development of new technologies and their introduction into the road transportation context. The advantages brought by such technology justify its presence, being this evidence each day more obvious, specially in what concerns in-vehicle technology. As these new systems are introduced on-board, it is essential to identify the exact consequences of the interaction between the driver and these novel equipments, discovering also the real costs for the road safety. For this reason, the present work aimed to study the impact of multiple visual and auditory inputs from in-vehicle information and communication systems on the driver behaviour.

This document is organized in three distinct parts. The first one is devoted to the theoretical framework where important aspects related with the driving task and the driving activity are mentioned. The most relevant theories to explain the driving behaviour are addressed in the first chapter, being focused topics like the information processing, the multiple task performance as well as aspects regarding the human variability. In the second chapter, the new technologies related to the road transportation context are mentioned, specially in what concerns the specific on-board equipments studied during this research. The first part ends with the research questions, elaborated from the theoretical review done previously and used to frame the practical work of the present research.

The second part of this document regards the methodology applied and presents the experimental framework adopted: the development of an on-road and a simulated driving experiment. These two experimental moments are explained separately, being mentioned the most important aspects of the method like the test participants, the equipments and scenarios used, the defined variables and the experiment procedure.

In the third part, the results of both experiments are presented separately in chapter one. Previously, a discussion considering the most relevant and significant aspects of the results is offered, being some of these outputs analysed and justified with the help of the information obtained in the theoretical review.

At the end of the work a final conclusion is drawn, as well as some methodological considerations that could have limited the research. Some perspectives for further investigations are also mentioned in the closing pages of this work.

1. Relevance of the Research

Researches have devoted considerable amounts of time and effort to Road Safety issues. Statistics reveal that road traffic injuries and fatalities are very high, resulting in vehicle safety being conceived as a public health concern by developed countries. Two reasons that have given cause for concern over road safety matters for some decades are the complex and dynamic nature of the road transportation context. The multiplicity and diversity of its elements, as well as their constant changing, contributes not only to the development of the system but also to the creation of challenging problems. These evolutionary characteristics are present in three vertexes composing the vehicle-driver-environment paradigm of the road transportation context. Several reasons justify this variability over time; however there is one recent product that has introduced considerable changes to the driving environment within vehicles, influencing the way drivers behave: the Intelligent Transportation Systems. The development of new technologies and their introduction into the transportation sector has been a regular occurrence in industrialized countries. The advantage brought by such technology justifies its existence; as such positive aspects of the technology becomes more visible and important daily. The presence of related systems on the road environment and inside vehicles compel drivers to interact directly with several products using similar technology and, as a result, probably changing the driving task.

It is essential to identify the exact consequences of these technological changes on road safety as the use of intelligent transportation systems become more common inside and outside vehicles. Therefore studies have been focused on investigating driver interaction with such on-board systems and the effects on driving performance. For example, investigating systems that can assist drivers' performance or equipments that are not directly related to the driving task have both been the centre of attention of numerous studies. Conclusions were already drawn and used in the elaboration of guidelines to improve the interaction with such equipments and decrease the negative impact from their utilization. However, as this technology continues to develop, new challenges arise as a result of newer, integrated functions and capabilities of such novel equipments. Moreover, with the growing diversity of on-board systems, the likelihood of having more than one product of new technology inside the car becomes greater. These ultimate systems possessing innovative features and also the higher number of equipments induce not only different forms of interaction but can also lead to different consequences which, may not always be positive, creating concern for both driving performance and road safety domains.

The present research intends to contribute to increasing the knowledge and to search for explanations of peoples' behaviour towards the multiple-task scenario. Knowing that studies have been investigating the consequences of a single in-vehicle system and that very few have analyzed the management of information provided by different and competing sources, this research aims to investigate the impact of multiple visual and auditory inputs from in-vehicle information systems on driver behaviour.

Aiming to verify the consequences of simultaneous inputs from more than one in-vehicle system, two different products were chosen to be the focus of this study: a guidance system and a mobile phone. The reason why these equipments were selected from others was mainly due to their popularity amongst road users. Mobile phone devices were introduced more than three decades ago and their frequent use is related to the advantages that they can bring to drivers. Some of the mentioned benefits are related with: the prevention of unnecessary trips; diminishment of the tendency to speed specially when a person is running late; contribution to security and peace of mind (particularly when someone is lost); improvement of mental alertness in a long and monotonous drive; augmentation of privacy in communications mainly to people that are never alone because of their job; and also the coordination of social engagements (Lissy, Cohen, Park, & Graham, 2000).

Furthermore the use of guidance systems is increasing, becoming these devices more commonly used on-board. The improvement of guidance systems, the development of nomadic devices (that can be used in different situations independently of the driving task), and the inclusion of other functionalities (like the possibility to make phone calls, access to the internet and have electronic agenda) have been transforming these products into very appealing equipments and can be the cause of the increased number of guidance devices inside vehicles.

Ultimately, this research focuses on the impact of the simultaneous interaction with a guidance system and a mobile phone. It is believed that joint interactions with more than one on-board system may significantly differ from single device operations. Additionally, the variability inherent to drivers and the distinct forms of interaction that can occur from the diversity of their characteristics will also be addressed. The increased popularity and acceptability of new technology can help to spread the utilization of these systems among distinct age groups and this study also sets to investigate the consequences of such trends evolving.

2. Aim and Objectives

The aim of the present research was to study the impact of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. It was intended to investigate the interaction with more than one in-vehicle system and verify the consequences of this simultaneous scenario on the activity of the driver.

More specifically, the objectives of this research were to determine the consequences on the driving task performance produced by the simultaneous interaction with a guidance system and a mobile phone device. The produced changes were identified by means of assessing the driver’s mental workload while receiving information from both in-vehicle systems. Furthermore, this research also intended to verify the effects that this multiple-task scenario had on the interaction with both in-vehicle equipments.

Another objective proposed by this research was to determine the age-related differences on the drivers’ performance produced by the simultaneous interaction with the already mentioned systems. This difference was analysed among average and elderly drivers.

In order to provide support for the proposed aim and objectives, this research investigated the influence of the inputs from multiple in-vehicle information systems throughout the elaboration of a literature review on the existing knowledge but also practical experiments where this multiple-task scenario was built. With this work it was also intended to contribute to the augmentation of the knowledge in what concerns the interaction with in-vehicle information systems, the driver behaviour, and the influence on road safety.

PART ONE: THEORETICAL FRAMEWORK

CHAPTER 1. DRIVING AND THE DRIVER

1. Introduction

Private automobiles have changed noticeably over the past century, although the majority of these transformations have been quite gradual. In spite of these changes the global form and function of automobiles have not been radically altered however the implementations made so far may have surreptitiously modified the driving task in several ways. For example, take the number of gears of the vehicle, which has been increasing, or the introduction of the automatic gear transmission. The speed capacity of the motor is different nowadays as well are break efficiency and the strength needed to control and manoeuvre the steering wheel. In addition to these aspects, which contribute to the modification of the way drivers interact and control their cars, are the alterations of the road environment. Roads are larger and organized in distinct ways, full of vehicles and pedestrians and surrounded by landscapes that can change from monotonous and empty to totally dynamic and crowded. However, one must not think that the ultimate stage of “evolution” has been reached; it seems that evolutionary changes will continue to be the rule. The development of new technology and its introduction into the automotive field has historically been rather slow however, as the introduction of more proven modifications continue, some consider that the infusion of information technology into the automotive world could speed up the rate of change (Nickerson, 1999).

The safety of all road system users is one of the most important aspects considered in the automotive field. Accidents are a matter of concern once they are one of the most frequent causes of deaths in most industrialized countries (Nickerson, 1999). Numbers of the road accidents can be observed in the 51th edition of the Statistics of Road Traffic Accidents in Europe and North America (UNECE, 2007). This document contains the basic statistics on this issue provided by the Governments members of the

United Nations Economic Commission for Europe (UNECE) and is usually used by governmental services for the analysis of accidents, patterns of accidents and for planning future improvements in road traffic safety.

These statistics cover the decade 1994 to 2004 providing basic data of road traffic accidents and casualties in European countries, Canada, Israel and the United States of America. The scope of the statistics comprises road traffic accidents involving personal injury only, excluding accidents with material damage. Considering the decade in question (1994-2004), this document shows that on average over 150 000 persons were killed on the roads and about 6 million persons injured in 4 million road accidents. By probing more thoroughly it can be seen that the statistics per country can be witnessed throughout the number of road traffic accidents per thousand road motor vehicles and also by the number of persons killed in road traffic accidents per million population. These figures are expressed in the following graphics and concern the year 2004 (UNECE, 2007). Due to the fact that numbers of fatality and injury are high, vehicle safety can be conceived as a public health concern by several countries (Peters & Peters, 2002).

Human error is believed to be the single most prevalent cause of motor vehicle accidents. The frequency of this cause varies, supported by some research projects over the years. Some studies revealed that the human cause of accidents accounted for about 80% of the cases (Redmill & Rajan, 1997; Wierwille et al., 2002). Moreover, a project funded by the Federal Highway Administration (Rousseau, 2006) showed the causes of accidents by factor (driver, vehicle and environment) and highlighted that human factors contribute directly to 57% of the accidents. Nevertheless human responsibility contributed indirectly to 33% of the accidents where the vehicle and the environment are the main cause. Thus, when all the human accountability is taken into account, the FHA believes that 90% of the accidents are from human error.

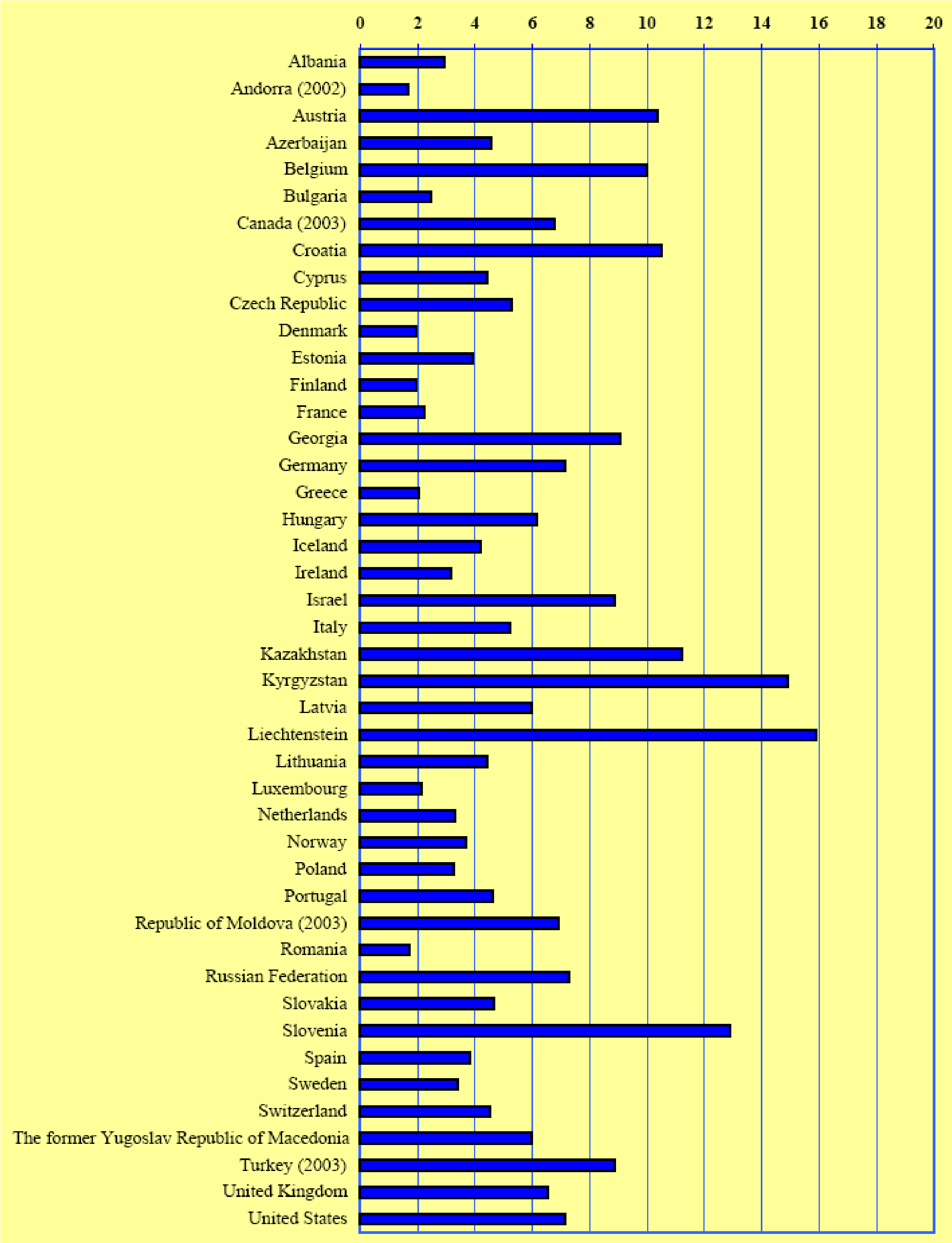

Figure 1. Number of road traffic accidents per thousand road motor vehicles in 2004 (UNECE, 2007)

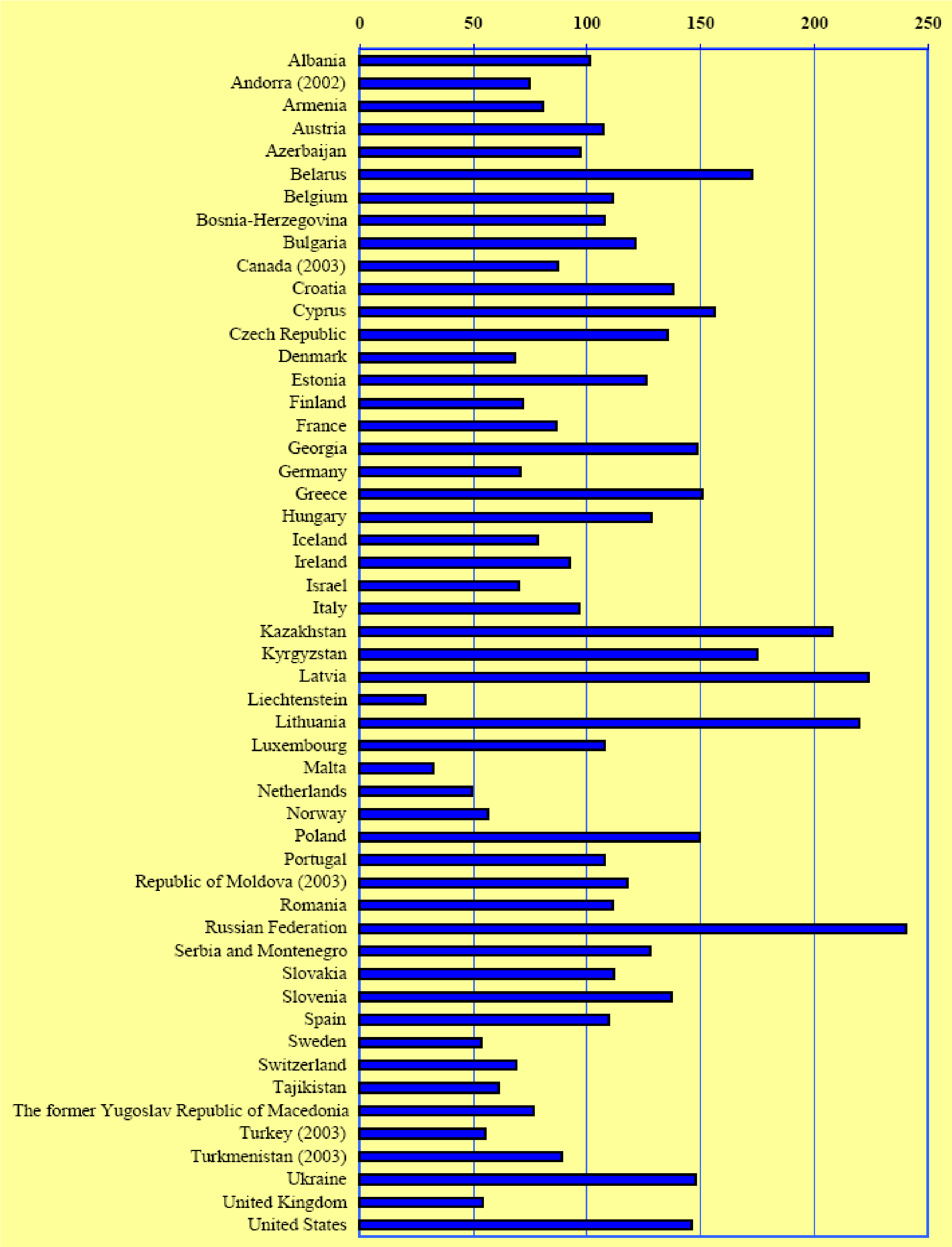

Figure 2. Number of persons killed in road traffic accidents per million population in 2004 (UNECE, 2007)

However, independently of the exact value human factors contribute to an accident, it is important to retain that human responsibility is substantial in what concerns road accidents. For that reason research on human factors must be done and the results must be considered in the design and evaluation of dashboard displays, safety restraint systems, signalling systems, vehicle lighting systems, steering and brake systems, road configuration and all concerning the automotive industry (Nickerson, 1999).

It must also be referred that these studies centred on human factors gain more importance due to the fact that some transport statistics reveal an increasing percentage of driver population. For example, the Transport Statistics of Great Britain (as cited in Groeger, 1999) indicated that from 1975 to 1991 the population of elderly drivers increased considerably; specially female drivers holding the highest percentage (males 5%, and females 29%). Statistics from the United States of America (as cited in Groeger, 1999) also support this development. In 1920 there was one motor vehicle for every ten people, while in 1990 the proportion increased leading to eight vehicles for every ten persons. These numbers take on even more importance when it is realised that the representation of some groups of drivers increase differently as described by the case of elderly females in the British statistics. Knowing that drivers can be categorised into several clusters, each cluster having specific characteristics that may determinate their involvement in a crash incident, it is of major importance to study these nuances and understand the proportion of different drivers developing over the time.

2. The Driving Task and Driving Activity

The driving task is often described as complicated and dynamic and can be considered as one of the most complex and risky tasks that the individual has to perform daily (Bellet et al., 2003). For these authors however, such attributes seem to contradict each other: on one hand the fact is that driving is a very complex task but on the other hand because it is performed by an elevated part of the population, indicating global generalization, this skill should be associated more with simplistic tasks. However this simplistic idea vanishes when one considers the annual elevated number of road accidents and also that most of the errors committed behind the wheel do not actually result in an accident.

In 1970, McKnight and Adams (as cited in Shinar, Meir, & Ben-Shoham, 1998; and also cited in Michon, 1993) suggested that the driving task comprises about 40 major tasks and 1500 related subtasks that a driver must learn in order to accomplish the everyday driving activity. Such extended list of tasks and subtasks generally performed in “normal” driving are used to make specific displacements (from one point to another) in a determined environment that is frequently changing. These displacements have specific rules, are orientated by an objective and in order to be performed, the driver must get to know the surrounding environment and the detailed criteria of each situation (Neboit, 1978).

The complexity attributed to the driving task is also seen as connected to a strong time and space constraint, once specific reactions are required within a few seconds and at exact places. Additionally, the need for the driver to divide his or her attention through different areas of the road environment also contributes to road related difficulties (Bellet et al., 2003). The driving task demands constant motor and sensory adjustment and a permanent vigilance from the driver; also demanding a high level of attention in order to be performed safely (Brown, 1994).

Another aspect to consider is the diversity that typically characterizes the road environment. The road itself can be characterized by heterogeneous types of roads in which highways, motorways, urban roads, rural roads and others are included. Each of these categories has a different status, possessing distinct rules, commanding different forms of behaviour from the driver. Even in a same category of road the driver must face diversity through changes in road configuration like, for example, straight roads, sharp curves or intersections, all requiring different manoeuvres from drivers. The enormous diversity of road users also compels the driver to use constant control, anticipating very often the dangerous situations. The variety includes other vehicles and drivers, pedestrians, cyclists, motorcyclists and also, in rare occasions, animals crossing the road. It also involves different driving styles and behaviours to which each driver has to manage and interact with (Bellet et al., 2003).

Faced with the complexity of the task, one author tried to schematize the multiplicity of driving by breaking it down into different stages. Michon in 1979 (as cited in Joly, & Brouwer, 1995; and also cited by Bellet et al., 2003) classified the driving task as having three distinct levels: a strategic level, a tactical level, and an operational level. The *strategic level* is linked with the objective of the driving task, i.e. to move from one point to another. It involves planning the trip and the selection of trip goals and routes where the driver is going to pass. This level corresponds generally to a navigation task where the route is chosen depending on some course constraints, like the amount of traffic or an accident situation for example. Time management is also taken into account at this level: the time to start the trip, its duration and the destination should be reached.

The second level (*tactical*) integrates the group of actions needed to reach the goal and to perform the driving task in a specific moment. It is sometimes referred as the manoeuvring stage and includes actions like capturing the information from the road environment, interpreting the events and making decisions for that particular moment. Some examples are actions like overtaking a car, turning left at an intersection, choosing a determined speed and a headway distance, avoiding other vehicles or even integrating a stream of moving vehicles.

The final *operational level* corresponds to the effective way drivers perform the actions or more specifically the way they manipulate the vehicle controls in order to act tactically and strategically. For example, the driver can decide tactically to reduce the speed and then carry this action out by acting in distinct ways: by simply removing the foot from the accelerator; removing the foot from the accelerator and pressing the brake; or simultaneously pressing the brake and reducing the gear levels. Thus, to fulfil a tactical goal, the driver can choose to perform either one of the previous operational actions.

These three levels are not distinct from each other; they may occur simultaneously and interfere with one another. However, the level of information needed at each level is not the same. These stages of performance can be described hierarchically when specific distinct quantities of information are featured. Considering the operational level initially before the next levels (tactical and strategic) it can be seen that each stage deals respectively with increasingly larger amounts of information. Therefore an action like braking (operational level) is less complex than overtaking (tactical level) which in turn is less complex than choosing the routes of the itinerary (strategic level) (Groeger, 1999). Another important notion concerning the hierarchy was given by Alexander and Lunenfeld in 1986 (as cited in Groeger, 1999) who stressed that the stages ascended due to the fact that while task complexity increases, the activity decreases. While driving, more time is spent controlling the vehicle (performing actions related with the operational level) than carrying out specific manoeuvres (integrated in the tactical level), but it is more difficult to make a manoeuvre correctly than to perform a single operation (like break or turn the wheel).

Table 1. Adaptation of the levels of performance and correspondent complexity and activity levels (from Alexander and Lunenfeld in 1986, as cited in Groeger, 1999)

Complexity	Performance Levels		Activity (physical)
+ + +	Strategic	Trip planning	+
+ +	Tactical	Manoeuvring the vehicle	+ +
+	Operational	Manipulation of vehicle controls	+ + +

In 1985, the author of this hierarchy model adds a further contribution to the characterization of activities performed at each level. He suggests that the duration of the activities at different levels range from milliseconds in the operational level, to seconds at the tactical level, being the longest activities at the strategic level. He also argues that drivers handle the information differently in each stage. The activity at the operational level is generally ruled automatically by “automatic action plans”; the activity in the tactical level is governed by “control action plans”; and the activity in the strategic level are more general and broadly planned (in Groeger, 1999). In fact, this latter suggestion made by Michon to improve the driving task model matches the work done by the Danish Jens Rasmussen in 1982 (as cited in Michon, 1993; and cited also in Reason & Hobbs, 2003). Rasmussen considered that in order to accomplish the driving task, subjects must perform a driving activity that can be defined as having three different levels: the skill-based level (SB); the rule-based level (RB); and the knowledge-based level (KB). These three levels of human performance, which can be generally used to explain driver behaviour in a variety of contexts, have been utilized and recognized as very useful in the road transportation field.

The *skill-based level* is where the automatic control of routine tasks takes place. Actions like the control of the speed and the lateral control of the vehicle can be performed in this stage once they are frequently performed automatically, at least for experienced drivers. This is the level where the motor and sensory automatisms are activated and actions are performed without conscious knowledge, except for occasional checks on the progress of the driving activity. Here the activity is ruled by signals that unchain and control the automatic gestures. For the *rule-based level* of performance, activity is based on routines and relies on signs, controlled rules and procedures learned from previous experience. These procedures can also be acquired through transference of experience from others; through formal learning or even elaborated by past problem solving techniques acquired by the individual. For Reason & Hobbs (2003) most aspects relating to the social facet of driving occur at a rule-based-level. Situations like how drivers should react to other vehicles are clearly specified in highway codes and road traffic laws and control driver performance in many ways. *Knowledge-based* behaviours however are activated when no obviously familiar solution appears adequate in solving the problem in hand. When an unusual situation occurs and there is no specific rule to apply, the driver's knowledge has to be "activated" in order to solve the dilemma. At this level the subject consciously mobilizes his/her resources to face the problem to accomplish that specific objective.

Similar to Michon's work, the performance levels of Rasmussen are not mutually exclusive. There is clearly considerable interaction between them and this can be observed frequently in the driving task (Groeger, 1999; Reason & Hobbs, 2003). When the driver decides to relocate a specific destination after knowing that the usual course is blocked by works, another strategy is utilized. While the driver is thinking about an alternative way (KB) he/she encounters a junction where it has to be given right-of-way to other vehicles (RB) and to do it he/she has to reduce the speed and stop the car completely (SB).

These three levels of controlling and processing information are linked with a level of familiarization of the performed activities. The skill-based level connects with the driver's most familiar actions where the knowledge-based level is more divorced from familiar activities, i.e., more linked with unfamiliar events.

These three performance levels can also be seen as stages in a learning process where the driver is acquiring abilities and skills to perform the task. With increasing familiarization of a task the subject will gain more and more automatisms as the frequency of knowledge-based actions become reduced as experience increases. This experience is what can make driving, or at least some elements of driving, automatic because it relies on an open-loop control, i.e., sequence of actions unsupported by feedback from previous actions to accomplish subsequent activities (Groeger, 2000).

Early in 1992, Sellen and Norman have made a distinction between automatic and controlled processes that can be adopted to explain the driving task. They suggested that there are two modes of control: unconscious and conscious. The former is automatic and "modelled as a network of distributed processors acting locally and in parallel"; the latter "acts globally to oversee and override automatic control". These authors also argue that those two modes of control are complementary as the unconscious mode is "fast, parallel and context-dependent, responding to regularities in the environment in a routine way" and the other is "effortful, limited, flexible and stepping in to handle novel situations" (Sellen & Norman, 1992). Automatic processing is believed to be developed when subjects process stimuli in a consistent manner over many trails, developing a consistent practice where the driver receives the same inputs and gives the exact same answer over and over again. This is the opposite of the controlled and conscious processing that is only activated when the stimuli vary among distinct situations (Schneider, Dumais, & Shiffrin, 1984).

Hence, the three performance level of Rasmussen (1982) can be connected with the conscious and automatic control as described in the following table.

Table 2. Three performance levels of Rasmussen (1982) defined with the activity space (as cited in Michon, 1993; and also cited in Reason & Hobbs, 2003)

Situation	**Control Modes**		
	Conscious	**Mixed**	**Automatic**
Routine			Skill-base (SB)
Trained for problems		Rule-based (RB)	
Novel problems	Knowledge-base (KB)		

3. Information Processing

In order to understand the driveing activity one has to understand that this activity is based on information collected from the environment. However, support for this is not constructed from objective information of reality but based on a mental representation made of the surroundings. This idea of representation, also called mental model, was generally considered by Tolman in 1948, (as cited in Burnett, & Lee, 2005; and also in Doyle, & Ford, 2000) when he claimed that after a considerable period of environmental learning, animals (including humans) build a mental representation of the space, which analogy can be made to a real map. This representation is a circumstantial creation from the environment in which the subject acts, being this model more or less loyal to the real world (Burnett, & Lee, 2005). Moreover, this mental representation is not only built with inputs received from the road environment but also relies on previous knowledge and experience the driver collected during his/her life. Based on this mental image, the driver travels around the road environment, makes decisions, plans actions and anticipates situations. Actions taken can be readjusted in the event of erroneous representations of reality, but if proper readjustments are not performed in time, incidents or serious accidents can occur (Bellet et al., 2003).

Acknowledging the driver activity also allows for a better understanding of the subject's mental functioning and its basic structural components. Researchers have tried to achieve this goal by schematizing brain anatomy, its functions, and also some important processes. One of these important processes most relevant when studying driver reactions and behaviours is the information processing. This mechanism can explain how drivers receive information from the road environment, how is it captured through the senses, how is it analysed and then how this information is recognized as meaningful. Some simple models try to describe how this process is organized and what does the driver with all the information coming to his/her senses. Despite the complexity of these structures, the basic notion driving this processing model follows three main stages: stimulus detection, cognitive processing and response.

As mentioned by Solso (1998) Stimuli is transmitted to the brain through the various senses (vision, hearing, touch, smell, and also through the motion receptors). Any stimuli reaching the senses must be attended to before progressing onwards to the next stage, i.e., the subject must notice it and give it some attention. In case of noticing the input, a driver has to correctly interpret it, i.e., perceive it. This mechanism of perception is a complex phenomenon but essential in building the subject's reality by interpreting what he/she captures from the environment. Once the stimuli have been detected (aspect related with the attentional mechanisms) and perceived (mechanisms of perception) the driver can process them; depending on the inputs received the individual will subsequently make a decision. This decision also relies on memory and previous experience, which accounts for different reactions from subjects even when the stimuli are the same. The last stage of the information processing is the response that can be either manual or verbal, or both.

Perchonok and Pollack in 1981 (as cited and adapted in Olson, 1993) describe the process, from stimuli to response, as having four stages: detection; identification; decision and response. In spite of having equal importance within the information processing system, the defined stages will be addressed differently according to the objectives of the present work.

Detection – Occurs when the driver becomes aware that a certain input is present. For visual stimuli the detection stage starts when the stimulus enters the driver's field of vision and ends when the subject becomes consciously aware of the input. Input characteristics are one of the factors that define the easiness in which they are captured by the driver's attention. Additionally, the driver's present focus of attention, the place where the stimulus appears on the driver's field of view, and also the number of inputs competing for the subject's attention also influence the effectiveness of this detection.

This first stage is very important as its absence obviously compromises and blocks the subsequent phases. Failure of detection excludes the identification stage, however the detection of an event does not always guarantee identification in an effective way.

Identification – This second stage initiates after attention to the stimulus is achieved. This process, also referred to as perception, is the active process by which the human being transforms the sensory stimulation into meaningful information of the situation, i.e., is the interpretation process of the information detected by the senses. It is dependent on previous experience of the real world and when an individual interprets, he/she is making comparisons with previous events to create a mental model of the present situation. This mental model is based on ones recreation and construction, and therefore not a faithful "image" of the real world. For example, when any particular stimulus arouses the driver's senses and provokes attention to that object, the driver will compare it with a previous experience with similar patterns, subsequently developing a construct that fits the ones already stored in memory (Solso, 1998).

When the interaction between a driver and their environment is studied it is important to bear in mind that visual perception is a major factor as driving is thought as being primarily a visual task. Visual information and its perception are essential in controlling the car and to interact properly with other road users. Olson (1993) suggests that one characteristic of vision is the level of conscious awareness that an individual has of its use; being comparatively higher than the information provided by other senses like for example the kinaesthetic (which is also important to operate an automobile).

In recent years the importance and requirement of vision has increased with the introduction of new technological equipment that requires more attention from the visual mode of information processing. However, it is crucial to know that, as for the other senses, there are limits to how much visual information an individual can assimilate in any given moment, and the strengths and weaknesses regarding such utilization (Olson, 1993). In fact one of the major inconveniences presented to the visual system is the total amount of information that exists normally in a natural and simple road environment, even when no additional visual information is transmitted to the driver. As Hole (2007) mentions, these inconveniences are intensified by the need to process images from the surroundings at any specific moment (usually in short periods of time, readily primed, in case some response is needed at short notice). Broadly speaking, Olson refers to the eye's structure as being like a simple camera:

> "…has lens to focus the light, an aperture to control the amount of light entering, and a light-sensitive surface to record the image. In a camera the lens can be moved relative to the film plane to compensate for objects at different distances; the size of the aperture can be changed to adjust to different lighting conditions; and films of different sensitivity can be used to expand the range of lighting conditions in which photographs can be taken. The eye has all of these characteristics." (Olson, 1993, p. 164)

Due to its structure, the eye is not able to analyse the entire 'picture' in the same accurate way. The analysis of image detail is confined to a very small part of the scene, an area centrally focused on within the visual field. When a driver looks at an object in their surroundings, his/her eye movements ensure that the image of this object falls upon the region with better detailed vision. Outside of this area images are represented in a very inaccurate level of detail, being the acuity in these regions poorer. In these areas the peripheral vision can only perceive shades, gross forms and vague sensations of movement. Accurate vision is only achieved in a limited central area of the individuals' field of view; detailed knowledge of the visual world is only acquired by moving the eyes around the scene, performing brief fixations and eye movements (Sanders, 1993).

Perception is highlighted as causing some problems in driving. This can occur when situations in the environment do not match up with the subjects' expectancy, meaning that the predisposition a driver has that something will happen in a determined way is wrong. This erroneous expectancy can lead to inadequate actions or adequate action at inappropriate moments. Thus, expectancy is an important factor in driver performance as all drivers possess certain expectations based in their own practice and experience. The elaboration of expectations makes driving become easier and helps in complex situations by releasing the subject's from basic concerns so that attention can be focused to other topics. The expectancy also helps with the amount of information that the driver needs to detect or identify. The stimulus intensity required for conforming situations is minimal while, for situations that do not match with the driver's expectancy, the intensity required can be considerably higher.

Perception also has some limitations. In relation to visual perception it is important to highlight that the perceptual system is not equally effective in dealing with all stimuli in all types of situations. One example is the problems associated with perceiving the stimuli at night and optical illusions of various descriptions that can affect the ability of drivers to detect specific situations. Certain driver situations present a higher probability of error due to the limited capacity of the perceptual system to adequately interpret situations like the ones involving the assessment of relative speeds (Olson, 1993).

Decision – After obtaining the necessary information from the stimulus, the driver must decide what to do with it, and prepare an action if required.

Response – In this final stage the muscles receive the necessary instructions to carry out the adequate and planed action. This process ends when the action is effectively initiated.

The following paragraphs will give further information regarding the detection of the stimuli (attention). Only the significant aspects of the attentional mechanisms will be discussed in more detail as they are considered to explain and support theoretically the processes addressed in this research.

3.1 Attention

Subjects cannot attend to all information at once; only specific parts of the information presented in the surroundings are therefore chosen in order to provide a more effective allocation of attention. This selection is extremely important for the driving task as a correct and appropriate collection of information from the road environment is crucial for effective driving performance. Attention is the first stage in which discrimination of information is done and everything in the scene has a chance to be caught by attention and get through to perception. However it is not possible to capture everything and attention primarily acts like a filter, selecting only some parts of the available information. The amount of information that can be passed on to the perceptual process is known as the channel capacity.

For Egeth and Yantis (1997), there are two main determinants of where attention is directed to: exogenous and endogenous factors. Attention can be driven to exogenous factors, i.e. to a stimulus that is presented in the surroundings and captures the driver's attention. These exogenous factors attract the driver's attention automatically and involuntarily (e.g. a sudden movement of a pedestrian or a rapid appearance of a car). On the other hand, attention can be controlled by endogenous factors, being goal-driven. In these cases it is directed to something in a voluntary and conscious manner in order to obtain specific information to fulfil an objective. It is important to understand that these two processes are not exclusive and, in an everyday driving situation, attentional allocation is a complex correlation between exogenous and endogenous factors.

James Reason and Alan Hobbs (2003) describe a number of characteristics of attention:

- Has limited capacity; a subject can only attend to a small portion of the sense data available.
- Has limited commodity when focused on one particular thing due to attention being withdrawn from other competing material.
- Can be captured by unrelated matters; concerns, thoughts and worries can all be sources of distraction and deviate attention from the primary task.
- Is hard to sustain for a long period of time.
- Sustaining it depends highly on the subject's interests of the current object of attention.
- Its demand decreases for highly skilled or habitual actions.
- A correct balance is needed to perform adequately in specific situations, too much attention to routine actions can disrupt them and a low level of attention in demanding and unusual situations can lead to incorrect behaviours.

(Reason, & Hobbs, 2003)

A number of competing factors can control the direction to which the driver's attentional resources can be focused. The individual's intention [the endogenous aspect that Egeth and Yantis (1997) mentioned earlier] and an enormous number of other different stimuli (exogenous) can claim driver's attention, being grabbed and switched from one to another. Directing attention to important exterior inputs depends on their physical characteristics but also on the understanding of surroundings. For that reason experience is an essential aspect that influence the way drivers direct their attentional resources and capture information (Durso, & Gronlund, 1999).

Attention is capable of guiding the subject's perception along the environment; however this concept is relevant to broader scopes of human performance. Attention is not only crucial for unchaining the perceptual process but also for distributing the resources between varied tasks (Wickens, 1992). Authors have studied these attentional mechanisms and tried to explain how individuals directed, maintained and managed their resources while performing one or several tasks. Along decades a range of models were developed, expressing structures that explained the processes in which subjects selected and allocated their attentional resources through more than one task. A central idea for most models suggested that subjects have limited resources to allocate to a specific task or set of tasks. When the task demands exceed the individual's limited capacity, performance may visibly deteriorate. Thus, knowing that *resources* can be envisaged in terms of neural processing capacity, this deterioration means that resources needed to perform such task are greater than the ones made available by the subject (Hole, 2007).

3.1.1 Selective Attention

In what concerns the selective attention mechanisms, a common factor in earlier experiences was the limited capacity of subjects to attend to all available cues. An inadequate channel capacity which determined a certain incapability to process simultaneously all the information was the reason for this limitation. This idea suggests the existence of a bottleneck in the information processing mechanisms, being the specific position of this access restriction the focus of other studies.

One of the most notorious experiments regarding the selective attention mechanisms was the one performed by Broadbent (as cited in Fortin, & Rousseau, 1992). Results from this experiment (where participants were asked to listen simultaneously to two distinct lists of numbers) induced to a set of conclusions that were used to support his model. Broadbent's *filter model* of selective attention defended that the sensory information (speech) was received in channels. Afterwards, this information was kept for a short period of time into a buffer (temporary store) before reaching into a filter. The filter selected which information passed on to perception, being this choice based on its physical characteristics. This selected data was defined as the focus of attention. Another aspect that this model suggested was that unattended information could be recalled from the temporary storage however, this recall couldn't take long because unattended information decayed rapidly. In sum, this model showed that subjects could only attend to one channel at a time and that switching attention between channels required considerable effort (Fortin, & Rousseau, 1992).

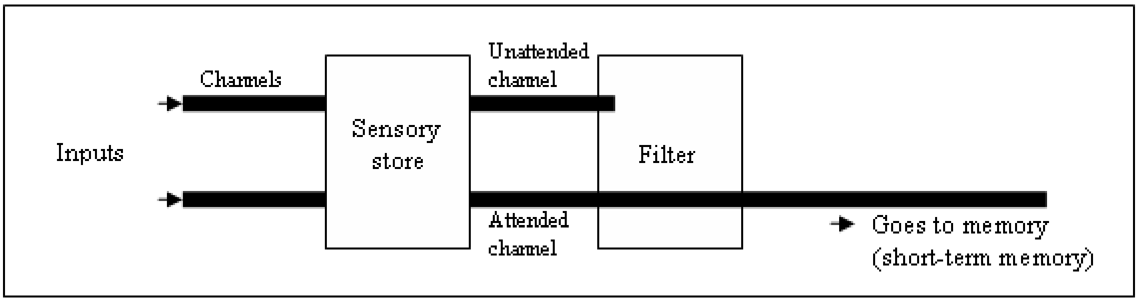

Figure 3. Filter model from Broadbent (1958)

Nevertheless, Broadbent's model didn't explain everything, leaving some situations without representation in his theory. Some examples were the moments where a subject could actually attend to two distinct inputs at the same time even if with limited quantities of information and for short moments. After the development of the *filter model* the problem of detection of sensitive information through an unattended channel was identified. Moray, in 1959 (as cited in Solso, 1998; and also cited in Fortin, & Rousseau, 1992) conducted an experiment and discovered that while involved in a conversation, subjects noticed their own names from unattended channels about thirty three percent of the times.

To explain this fact Moray suggested that some kind of analysis must occur before the filter. Soon afterwards, another investigator tried to find an explanation for that event suggesting that in the subject's stored words some have different threshold of activation. For that reason Treisman (as cited in Solso, 1998; and cited in Lucas,1992) drew up a new model. Instead of the unattended channel of information being turned "off" like Broadbent defended, the channel was turned "down". Thus, information in unattended channels was partially processed, just enough to allow a breakthrough if the subjects' attentional mechanism considered it to be sufficiently important or interesting. This model, called *attenuation theory*, considered that the "turned down" unattended channel was attenuated by a filter, allowing that non-attended meaning information could pass on but in a weaker form. Due to this weaker signal subjects could ignore it however biological or emotionally important stimuli may get through.

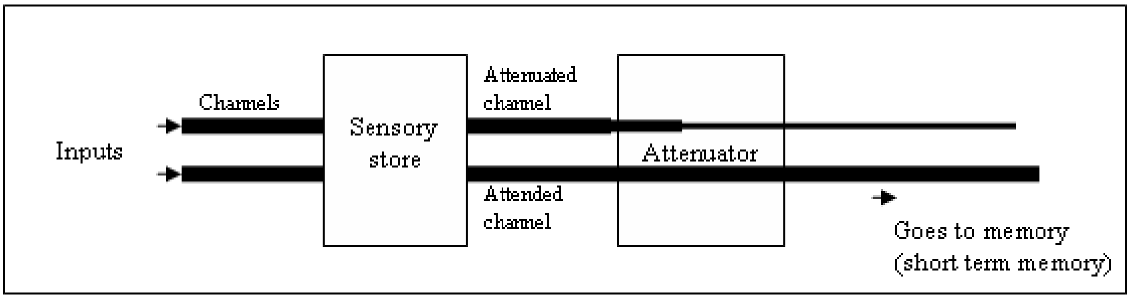

Figure 4. Attenuation theory from Treisman, adapted from Treisman and Geffen (1967) as cited in Solso, 1998.

Both models of Broadbent and Treisman suggested that the extraction of meaning from the information (channels) was made after the filtering/attenuation. However an experiment made by Mackay (as cited in Driver, 2001) indicated that the unattended channels were processed for meaning before being filtered, revealing that the filter happened at a late stage. For this reason the theory of Deutsch and Deutsch (as cited in Solso, 1998) gained strength. They hypothesised that all stimuli were analysed for meaning, including the unattended message; however the unattended message could stay at a non conscious level being the subject not aware of it. Such messages could be recognized but not passed into awareness, being only noticed if their relevance exceeded the relevance of the attended channels. After the meaning analysis of all stimuli, only some could be selected for response. These thoughts were also defended by Norman (as cited in Fortin, & Rousseau, 1992). He elaborated on Deutsch and Deutsch's model by suggesting that selection was determined not only by the pertinence of the sensory inputs but also by the strength to which inputs reached and stimulated the sensory systems.

Nevertheless, with the development of investigation further researches raised also some questions regarding the fidelity of this *late selection model*. Some considerations were made to this theoretical framework as it could be showed that subjects were much better than expected to detect messages and analyse the meaning of information. In fact, simultaneously to the development of these models of selective attention, other authors tried to unmask the mechanisms of attention. The elaboration of experiments to validate or to oppose previous theories also allowed discovering other aspects related with the studied processes. Some examples are the mechanisms related with the divided attention, i.e. the processes occurred when an individual tries to attend to two or more sources of information at the same time.

3.1.2 Divided Attention

While performing a single task, subjects try to allocate specific amounts of attention to capture the surrounding information and perform the activity. This idea is related with the quantitative properties of attention and was very much considered by Moray in 1967 (as cited in Wickens, 1992). This researcher proposed that attention is a limited capacity that could be allocated in diverse amounts and to several activities. This supplied quantity could depend on the difficulty of the task but also on the demand for that capacity. This means that more attentional resources can be needed for more difficult tasks or if a higher level of performance is required.

In fact, if a subject wants to perform better in a task he/she must try harder and invest more mental effort into its execution. Thus, resources concept can be seen as the mental effort invested to perform and improve a determined task (Wickens, 1991).

The relation between the task difficulty and the attentional resources needed was also mentioned by Kahneman (as cited in Fortin, & Rousseau, 1992; and cited in Wickens, 1992) however this author also defended that, apart from difficulty, task demands also increases when additional tasks are imposed. He suggested that when performance of two tasks happens at the same time an increase in the attentional resources supply occurs. If this increase is not enough to compensate the demands that both tasks require, a performance decrement can be verified. This lower level of performance increase as the discrepancy between the requirements and the supplies augment. In fact, this is the nuclear idea for the *single resource theory*.

Along the years one set of theories proposed that individuals have a unique resource of attention (single resource). This resource concept was based on the assumption that subjects possessed limited capacities of available cognitive processes for performing a task. If, in principle, two tasks demand more attention than a single one, simultaneous task execution could lead to a situation where one ore both tasks are supplied with fewer resources than required. Then, a management between stimuli/tasks must be done in order to accomplish dual-task performance. If tasks have smaller amounts of resources than needed or, at least few resources than they would have if performed alone, it is expected to see a decrement in the performance of one or both tasks (Wickens, 1991).

To better explain these mechanisms in 1975 Norman and Bobrow (as cited in Wickens, 1992) introduced an important concept: the *performance resource function*. This concept expressed the function relating the quantity of resources invested in a task and the performance level obtained. These authors suggested that tasks performed simultaneously and interfering with each other due to the same resource sharing evidenced a relation between the quality of performance and the attentional investment made. Diverting some resources from the main task into another additional task could have consequences on primary-task performance, being those consequences in accordance to the allocation of resources made to the additional task. Furthermore, other investigations presented an improvement of this idea considering that the performance on the main task was not the only one being affected with the introduction of an additional task. If resources were divided performance could drop in one or in both tasks. The division of resources was also considered by this single resource idea once it was argued that subjects could allocate their resources in a flexible way. This means that individuals might allocate the desired proportion of resources to accomplish the tasks, not needing inevitably to adopt a 50/50 split to each task. As an example, if a driver conducts a mobile phone conversation while driving, he/she can choose to devote 15% of the attentional resources to complete the additional task or, in case of a highly difficult or more interesting conversation, allocate a higher percentage of attentional resources, penalizing more the main task – driving (Wickens, 1992).

Recent theoretical approaches define and justify the problem of dual-task performance in a different manner. The opposition to the single-task resources theory and the drawing results from a large number of dual-task studies, led to the emergency of a new construct: the *multiple-resource theory*. This theory was developed based on experiments suggesting that, rather than a single resource subjects possess a number of resources, each one dedicated to a particular type of processing job. Some authors like Allport in 1972 (as cited in Fortin, & Rousseau, 1992; and cited in Wickens, 1992) have supported this idea. He demonstrated that pianists were able to read music while shadowing speech, maintaining an adequate performance in both tasks. Moreover, in 1976 Spelke and colleagues (as cited in Wickens, 1992) trained students to perform two simultaneous tasks: reading a short story while writing down dictating words. Six weeks after students ability to recall the short stories was very good, being this performance equal to the performance without the dictation.

In 1984, based on the results of dual-task studies, Wickens (1984) drew a model expressing that resources could be defined by three dichotomous dimensions: the stage of resources; the modality and also its processing codes. In a more specific manner these dimensions were defined as following:

- **Stage**: resources can be present in the three stages of the information processing mechanism. The first one is associated with the *encoding*/perception of information, being followed by the *central processing* phase and by the moment a *response* is given. The resources used for the encoding and the central processing activities are referred as being the same, however responses have to be executed with different resources. This separation is justified by the results of some experiments: different levels of difficulty to respond to a task were imposed and this manipulation had no interfere with the performance on a concurrent task whose demands were more perceptual.

Table 3. Stages in which resources are presented, multiple-resources theory

Processing stages		
Encoding	Central processing	Responding

- **Modalities**: two modalities can define the way inputs reach the subject. It can be done in a visual or in an auditory manner. Experience showed that subjects can sometimes divide attention between what is seen and what is heard. This is done in a better way than dividing attention between two auditory messages or between two visual inputs.

Table 4. Modalities in which information can be presented, multiple-resource theory

Modalities	Visual
	Auditory

- **Codes**: after the visual or auditory messages enter the processing information mechanism, they are transformed in different codes. Messages are encoded and processed centrally in a spatial or in a verbal way, being afterwards transformed into manual or vocal to produce an effective response. It is believed that the separation of spatial and verbal resources apparently accounts for the high degree of efficiency, while manual and vocal outputs can be time-shared. It is also assumed that vocal responses are based in verbal encoding and processing of information, being the manual outputs concerned to spatial codes.

Table 5. Codification modes inside the information processing stages, multiple-resources theory

Processing stages			
	Encoding	Central processing	Responding
Codes	Spatial		Manual
	Verbal		Vocal

In other terms, to explain the multiple-resource theory model it can be said that a certain task can be divided into three different stages (encoding, central processing, and response). Information can reach the subject’s sense through visual or auditory modalities and once it enters the processing stages it is stored (coded) in a spatial or visual manner. If a response is needed, that codification change into manual or vocal modes and a response is given.

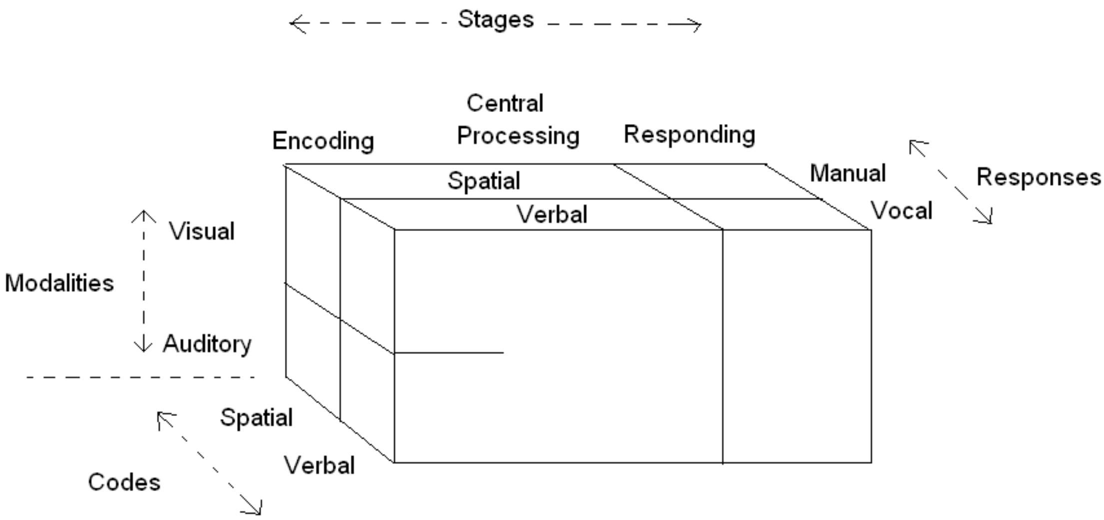

Figure 5. Structure of the Multiple-Resource Model of attention (Wickens, 1984)

The model perception (encoding) and central processing use similar sets of resources. However a slight distinction must be considered between the first and the second stages. In the left face of the cube four areas can be visualized: the two in the top when stimuli are visual and the two in the bottom when stimuli are auditory. When entering in the perception stage (encoding) those two modalities can either pass to the spatial or to the verbal coding. This means that visual information can be coded spatially or verbally, and the same happens for the auditory information. Reading a text can be given as an example: text is read, visually, but is coded verbally once subjects remember the verbal meaning of the message and not the way characters where placed spatially in the text. Additionally, if reading aloud is needed, the response will be vocal. This process can be schematically observed in the following figure.

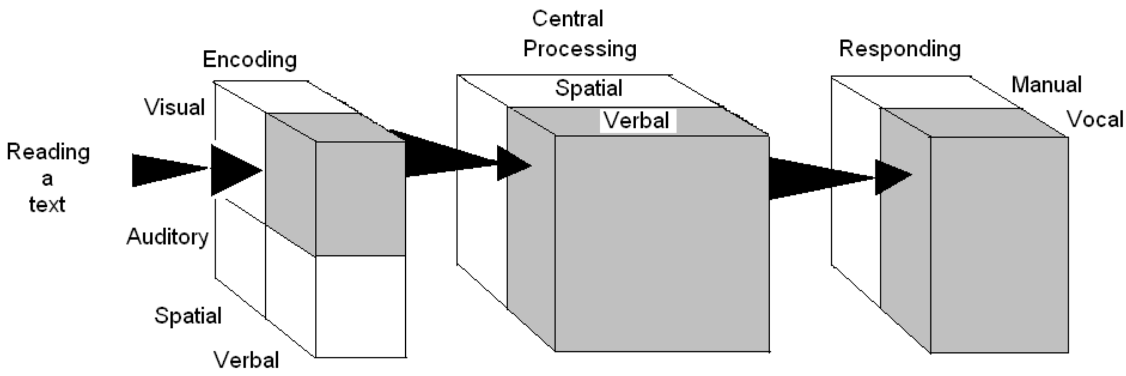

Figure 6. Scheme of reading aloud process, explained throughout the multiple-resource model (Wickens, 1984)

When two tasks are similar in terms of their sensory or motor requirements, it is likely to occur interference between them and it is foreseen that performance will degrade. Thus, two auditory signals are probable to interfere with each other, as well as two verbal processing tasks or two manual responses. Contrarily, this model suggests that tasks involving visual inputs, verbal coding and a vocal response should get little interference from an auditory task that is coded spatially and requires a manual response. In this sense it seems like, in order to predict if the accomplishment of a multiple-task situation will be done without interference and with high level performance in both tasks, the only thing that needs to be done is the categorization of the task in what concerns the three stages of the model. However, while some tasks are easy to forecast if they will be coded spatially or verbally, others are more difficult to categorize. Taken the example of a driver conducting a mobile phone conversation it could be argued that there are questions a driver might be asked that require more the use of visual imagery and others that require verbal resources. Furthermore, when the driving task is taken as an example as being part of a multiple-task situation, much more careful is needed. As mentioned by some authors, the driving task is not a unitary activity once it can be separated into several sub-tasks (McKnight, & Adams as cited in Michon, 1993; and Groeger, 1999) or even divided by different task levels (Michon, as cited in Joly, & Brouwer, 1995; and in Bellet et al., 2003). As a result each sub-task or level must be considered separately so that an adequate representation into the multiple-resource model can be performed (Hole, 2007).

4. Multiple Task Performance

The act of performing simultaneously two or more tasks gains relevance in some specific contexts due to the type and severity of the consequences that this situation can produce. Specifically in the road context, multiple-task scenarios are of much concern once the outcome of this synchronized performance can be highly severe. For this particular context, performing several tasks at the same time means that, while driving the subject performs other tasks and gives attention to other situations. These other tasks can be related to driving as their execution can assistance the fulfilment of the driving goals (like when looking to a paper map to find the best route to reach a destination or gaze to a device that sends graphical information to help parking). However, some other tasks can be unrelated to the driving itself, not being their accomplishment a benefit or an assistance to driving (like eating, brushing the hair or having a trivial mobile phone conversation with a friend).

As it was previously explained, the major concern related with the multiple task performance in road context is associated with the allocation of attentional resources. This preoccupation is based on the assumption that, while driving and performing an additional task, the attentional resources that should be entirely directed to driving are divided with the supplementary task. Thus, less attention is devoted to the vehicle and to the road environment, leading to an accident risk augmentation. For this reason investigators have been studying the causes and consequences linked to this challenging issue, using theories and models that try to explain the human behaviour in those particular scenarios. Example are the previously presented theories of attention, which attempted to describe the way drivers select the information and manage their attentional resources to perform simultaneously more than one task. Along with those theories and studies, other works have been conducted to unmask the mechanisms related with the multiple task performance.

Trying to contribute with an explanation for these complex processes, in 1971 Broadbent (as cited in Hole, 2007) introduced the concept of *level of control,* referring that human information processing occurs at a number of different levels, some conscious and others unconscious. He suggested existing a lower level to treat familiar processes and a higher level to monitor and alter the operations in the lower stage. When something impairs the process of information at the lower stage, the activity at the higher level increases as a way to compensate that limitation. However, when the processing capacity of this higher level reaches its limits (like the emergence of fatigue), the overall task performance can be deteriorated. Considering the driving activity as an example, whenever the completion of an additional is asked to a driver, the higher level for processing information is activated and the cost and effort devoted to that situation may decline its performance.

Consistent with this theoretical perspective was the idea of Schneider and Shiffrin (as cited in Fortin, & Rousseau, 1992), that expressed a distinction between controlled and automated processing. Controlled processing was characterized as being conscious, dependent of voluntary control, flexible but slow. Comparatively, the automatic processing was seen as requiring less processing capacity from subjects, faster but rigid and with limited voluntary correction. Thus, for experienced drivers the task performance may be relatively automatic, allowing this automatic processing of vehicle control some spare capacity for executing other tasks.

Some years latter Norman and Shallice (1980) postulated the existence of two qualitative control systems: a lower level *contention scheduling* and a higher one named *supervisory attention system.* Similarly to the previous theories, the first level was described as automatic and present in most of individuals' activities, being routine selections under its responsibility. The second was mentioned as accountable for the conscious activity, being activated when the contention scheduling was not adequate, like for novel situations or actions that did not happened according to what was expected. This model suggested also that the performance of two tasks could not interfere with each other as long as they were both undemanding. For moments where the driving task was easy, the contention scheduling system could take over leaving space to the execution of an additional task. However, if driving became difficult the supervisory attention system needed to take control of both driving and additional tasks. Only in that condition performance could deteriorate.

A recent work developed by Hockey (1997) represented the multiple task performance in a model named as *compensatory control model*. He believes that if subjects are faced with a variety of complex tasks they try to preserve their performance on the primary task by utilizing some strategies. According to this model performance derive from two types of informational processes: 1) automatic and unconscious control process and 2) another process that allows conscious control. Well-learned skills and routine behaviour are controlled by the automatic process (represented in the following figure as *loop A*). However, if something unexpected occurs and the actual performance doesn't match with the desired one, the conscious control is activated (represented in the following figure as *loop B*). This activation aims to change the situation, either in the form of changing the task goals or modify the amount of effort expended.

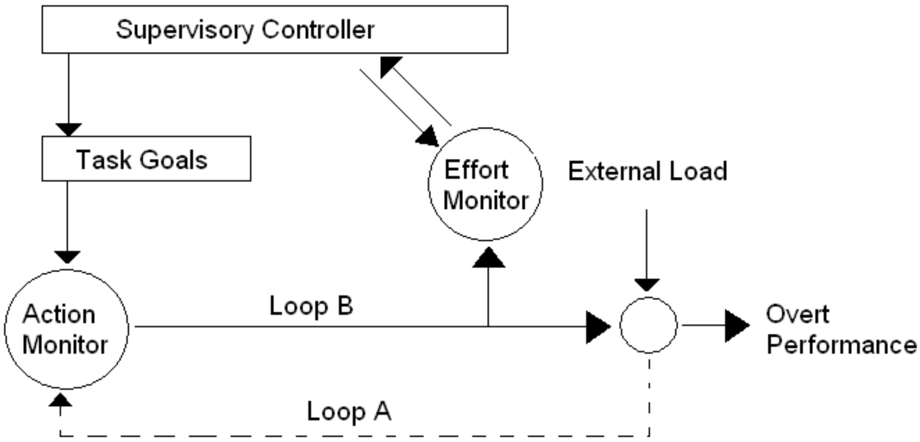

Figure 7. Hockey's compensatory control model of performance, 1997

All this process must work out adequately when the driver hierarchies its tasks in a way that driving is placed in a priority position. However when priorities are the other way around it can lead to an augmentation of the accident risk. In fact, this scenario does happen probably more often that what investigators desire. Evidences that drivers underestimate the extent to which some additional tasks interfere with their driving task are seen in some reports, where a great amount of subjects claimed that their driving is not affected by the secondary task (e.g. Strayer, & Drews, 2003).

4.1 Distraction

Performing one or more tasks while driving is an issue that researchers have been focusing on. As it was briefly explained earlier, driving and conducting a simultaneous task can impair driving performance once individuals are not devoting the necessary attention to the primary task (driving). Attention, or part of its resources, are driven away to the additional task(s), leading to a situation were drivers can be distracted from their main mission. Besides the recognised importance of distraction, its analysis is not done easily nor do results show a unique characterization of its consequences.

Early in 1980, Treat (as cited in Transport Canada, 2003) mentioned that the leading human factor causes for collision included driver distraction, inattention and improper lookout. Latter in 1996, other authors considered that driver distraction estimated to be a contributing factor of about 20% to 50% of all accidents (Ranney, Mazzae, Garrott, & Goodman, 2000). More recently the U.S National Highway Traffic Safety Administration (as cited in Manser, & Even, 2002) estimated that driver inattention was the cause of a minimum of 25% crashes, being half of these crashes due to a form of inattention called distraction. Besides the possible evolution regarding the contribution of distraction to road accidents statistics, these data can show some confusion when it is intended to know specifically the extension of this problem.

As mentioned on the inquiry to driver distraction made by the Road Safety Committee (2006), data from statistics can be somehow imprecise due to several factors. Once the cause of accidents can be varied and attributed to a combination of factors, authorities that characterize accidents can miss to qualify the cause to distraction because it can be less obvious and more difficulty to identify. In those situations, accident causes can fall into other more obvious categories, like for example speeding.

Hole (2007) also devoted some time to this aspect and suggested that another problem can mask the reality. He mentions that statistics are frequently based on what drivers claimed to be doing at the moment of the accident (as opposed to what they were actually doing). This occurs because drivers can refuse to admit having been distracted due to the legal implications of the situation. However, another concern rises when the quantified consequences of driver distraction are taken into account: the fact that a single internationally accepted definition of distraction does not exist. Thus, to determine the role of driver distraction it is important to clarify its definition and distinguish it from other related driving behaviours. This lack of common, valid and reliable definition is pointed out by Pettitt, Burnett, and Stevens (2005). They consider that an agreed definition could help to clarify the future research once it would facilitate the categorization of cases and allow easier cross-study comparisons.

Generally, definitions of distraction have been made by relating it with inattention or, in the other hand by separating them into two distinct behaviours. An early definition was given by Treat in 1980 (as cited in Transport Canada, 2003) stating that driver distraction happened when a driver was delayed in the recognition of information needed to accomplish the driving task safely. This delayed recognition was due to an event, activity, object or person inside or outside the car that compelled or induced the driver to transfer attention away from the driving task. This definition, also supported by other researchers (e.g Pettitt, Burnett, & Stevens, 2005; Manser, & Even, 2002; Stutts, Reinfurt, Staplin, & Rodgman, 2001) is in fact in agreement with the Traffic Injury Research Foundation of Ontario (as cited in Road Safety Committee, 2006) when it considers that distraction is different from inattention and what distinguishes these two definitions is the presence of a triggering event or activity. This means that whenever something or someone captures the attention of a driver from the driving task, distraction should be considered. Young, Regan, and Hammer (2003), which also shares the same idea of differentiation between distraction and inattention, starts a chapter named “What is driver distraction” by saying that “driver distraction forms part of the broader category of driver inattention” (pp.2).

The Road Safety Committee (2006) exhibits in its inquiry about driver distraction a definition presented by the Monash University Accident Research Centre which considers that distraction occurs when the driver is involved in a secondary activity that interferes in the performance of the driving task. This involvement can happen freely or in an unwillingly manner. This report made by the Victorian Committee also elucidates about another definition defended by VicRoads, a corporation under the command of the Victorian Government. Similarly to the previous description VicRoads also considers distraction as triggered by a secondary event or action. This attentional deviation can be made voluntary or involuntary, happening in two possible distinct situations: while performing one or more additional task(s), or when focusing an object, event, person that is not related with the driving itself. This distraction can reduce the drivers' awareness, the decision making and also the performance on the primary task, and can lead to serious consequences like collisions or ultimate corrective actions to recover from inadequate situations. Considering that the definition from VicRoads could be more explicit, the Road safety Committee (2006) adopts an explanation made in the 2005 International Conference on Distracted Driving:

> "Distraction involves a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver awareness, decision-making, and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes." (in Road safety Committee, 2006, pp. 9)

Additionally is referred in this report that driver distraction and driver inattention should be classified as two distinct behaviours.

Driver distraction is a concern that has been debated since the beginning of the twentieth century. It appeared around 1905 due to the introduction of the car windshield wipers. Some were very worried about their consequences because these "equipments" were believed to have a "hypnotic effect" on the driver. Later in the thirties, this issue reappeared with the emergence of car radios. Some experts predicted that with the introduction of radios in vehicles, drivers would be very involved in the program content, being that distraction the cause of many accidents. Nowadays none of these issues are a persistent problem and debates about their negative effects almost disappeared (Curry, 2002). Nevertheless, in present days distraction is once again a concern as a consequence of changes in road environment, and specially due to the presence of new technology systems inside and outside vehicles.

According to the New Zealand Ministry of Transport (as cited in Victorian Road safety Committee, 2006), based on the analysis of police crash reports of 2002 and 2003, distractions can be classified into three types: inside the vehicle; outside the vehicle; and other distraction resources. Some examples expressed in the report, related with internal and external distractions, can be mentioned:

- Internal sources: passengers, telecommunications, entertainments systems, food/drinking or smoking;
- External sources: other road users, pedestrians, emergency vehicles, crash scenes or animals outside the vehicle.

Other two institutes tried to categorize distractions. For the Monash University Accident Research Centre (as cited in Road Safety Committee, 2006) distraction can be divided in: “technology based distracters” like mobile phones route navigation systems or CD players; and in “non-technology based distracters” as the case of talking to passengers, drinking or smoking. Additionally VicRoads (as cited in Victorian Road Safety Committee, 2006) consider distraction in terms of the role of the driver, considering that they can be: purposeful (when they are conscious like watching a DVD or dial a phone number), incidental (when it concerns an activity that diverts the attention from driving but is incidental like eating, drinking or answering a hands-free mobile phone), and uncontrolled (that doesn’t have conscious control like distractions from children or the sudden movement of someone in the peripheral field of view). However, besides these particular categorizations of distraction “there is no widely accepted taxonomy of distraction in either crash reports, observations of real world, or naturalistic driving” (Road Safety Committee, 2006, pp. 11).

Within the context of distraction, like it could be observed in some previous examples, new generation of in-vehicle technologies is viewed with much concern due to the possible adverse consequences. The use of in-vehicle equipments is mentioned as a reason for problems since drivers need to devote considerable amounts of time looking to the device displays, dedicating less time observing the road and detecting hazardous situations. In some situations drivers initiate and carry on in-vehicle tasks even when they experience some form of workload (Green, 2004). For Ranney and his colleagues (Ranney, Harbluk, Smith, Huener, Parmer, & Barickman, 2003), in-vehicle technologies will have even greater impact in the future once the availability of in-vehicle systems will rise.

However, if distraction was already a main issue in the beginning of the twentieth century and investigations have proven that windshield wipers, or other types of car controls, if used adequately have no serious consequences on driver performance, couldn't this be expected also for the in-vehicle investigations? If not, why are new in-vehicle technology systems different from other in-vehicle tasks?

Green (2004) answers to these questions in his paper called "Driver distraction, telematics, and workload managers: safety issues and solutions". He considers that the problem of using an in-vehicle device is associated with duration and frequency of its interaction, i.e. to the exposure. The time needed to complete a task with vehicle controls (like headlights, windshield wipers or even turning indicators) is very short when compared with tasks of in-vehicle devices (Green, 2004). Moreover, the increased number of functions that these devices possess lead to a more complex interaction, requiring drivers to navigate through a menu hierarchy instead of pressing just one button (Green, 2001).

4.2 Workload

As it could be observed in the last topic, when multiple-task performance is an issue distraction can be the focus of discussion. However other researches prefer to put emphasis on the driver overload as the consequence of performing more than one task at the same time. For this reason many talk about workload or, more specifically, driver mental workload. As for the driver distraction concept, driver mental workload does not have a common and consensual definition. Its description is based on constructs made by some authors and also by the relation created with other concepts as it will be verified some paragraphs ahead. Consequently, no single and commonly accepted designation has yet been established within the scientific community in what concerns its source(s), mechanism(s) and consequence(s) (Huey, & Wickens, 1993).

It is considered that the difficulty in gathering a common definition is due to its relatively young existence. This concept of workload was almost unknown until the 1970s and only since then efforts were made for its elucidation. As the automobile became an even more complex system with the introduction of new functions and new sources of information, the mental workload topic gain importance and an increasingly number of researches investigated its causes, mechanisms, and also the most efficient ways to measure its levels and consequences. The importance of its study is justified by the already demonstrated assumption that workload is one important factor in the occurrence of human error. A level of workload that is not adequate to the capabilities of the driver (very high level or even very low) can contribute to a higher percentage of driver error and, depending on the situation, may be critical for safety inducing to an accident (Kantowitz, & Sorkin as cited in Schlegel, 1993).

Another reason for the disagreement around this concept derives from the existence of at least two strongly based theoretical approaches and definitions. First, workload can be seen as a task property with which individuals have to cope, in a more or less efficient way. In this framework workload possesses a simplistic definition once it is built on the demands placed upon the humans, attributing workload exclusively to an external cause. Secondly, workload can be an expression of the interaction between task requirements and the subject's capabilities and resources, an approach much more supported by ergonomists and occupational psychologists (Hart, & Staveland, 1988). This theoretical approach is defined also in terms of experienced load felt by subjects, being this concept not only based on the characteristics of the task but also on the individuals' capacities (de Waard, 1996).

In agreement with this last idea, Eggemeier and O'Donnel in 1982 (as cited in Schlegel, 1993) considered that mental workload could be defined as a multidimensional interaction between: task and system demands, operator capabilities and effort, subjective performance criteria and also subject's training and experience. Thus, for these authors, mental workload is a compromise between the task demands imposed to a subject and the capacity of this individual to meet these demands and produce an adequate level of performance.

The introduction of the operator capabilities to face the task demands reflects the idea that the same level of demands does not produce the same reaction in different subjects. This means that the effort applied to reach the goals can be completely different from person to person due not only to the individual capabilities but also to motivation, strategies applied in the task performance and also mood. Thus, the level of mental workload defines the amount and strategic allocation of resources to achieve a determined level of performance (Schlegel, 1993).

To better understand this conceptual framework of workload, Schlegel shows in his book section named “Driver mental workload” the following schema:

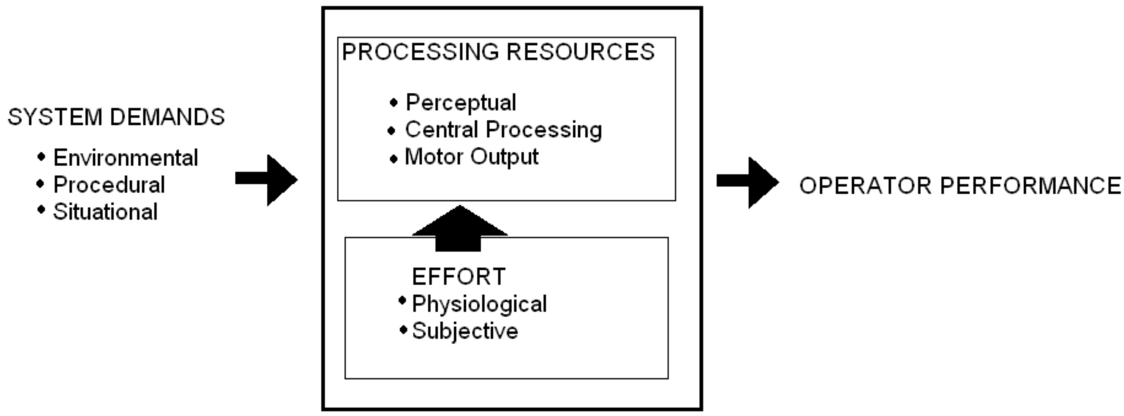

Figure 8. Simplified model of mental workload (Schlegel, 1993)

Driver mental workload does not depend exclusively on one unique factor. Several are the factors that may increase or decrease mental workload. As an example it can be stated that automatic processes can help drivers by lowering their workload in conditions where environmental demands are high; but can increase it if driving is turned into a monotonous task (Wierwille, & Eggemeier, 1993).

In 1996, de Waard showed a table that listed the factors affecting the workload divided into three main categories: driver state affecting factors (like the monotony, fatigue, sedative drugs and the alcohol), driver trait factors (experience, age and strategy), and environmental factors (as the road environment demands, the traffic demands, the ergonomic criteria of the vehicle instruments, the automation and also the feedback).

In order to have a better understanding of this mental workload concept some other constructs must be well known and understood. The first one is the notion of *demand*, which can be determined as the goal that has to be achieved by means of task performance, being this goal external and independent from the individual. Inherent to this task is a certain *complexity*, which augments with the increases of the number of cognitive processing stages required to perform the task. The *demand* and *complexity* are mainly external but depend upon the objectives defined by the individual for that task performance. Leaving the external field and entering in the subject's main area, it can be found the concept of *difficulty* of the task. This difficulty is directly related with the processing effort required for accomplish the task, i.e. the amount of resources made available and used by the individual. This differentiation between task complexity and task difficulty was proposed by Kantowitz in 1987 (as cited in de Waard, 1996) once the former is a reflection of the task in isolation and the last is developed upon the interaction between the task and the individual.

As mentioned earlier, the task difficulty can vary from one subject to another once it is dependent of the context but also on the state, capacity and strategies for the allocation of resources. Thus linked with the mobilisation of the attentional resources is the term *effort* once it reflects the operator reaction to the demand. It is a voluntary process and is one of the most important components of mental workload. This importance is justified by the fact that the effort allocated by the driver is not unequivocally related in the same proportions to the task demand. The subject's reaction to this demand depends upon the developed internal task goals and also on the strategies adopted to accomplish them. Due to this reason, it can be stated that there is no simple relation between the amount of effort and the performance of a subject once the amount of effort depend on the structure of the task but also on the practice, experience and state of the driver (de Waard, 1996).

Knowing that mental workload can be determined by the task difficulty, being also a reflection of the amount of resources allocated to that specific task, it is important to establish a correlation between the task demand and the driver's performance. In 1976 Meister (as cited in de Waard, 1993) considered three regions to define this link between demand and performance:

- region A, described by the low demand, high performance and consequently a low level of mental workload;
- region B, registering an increase of demand and a decrement in performance as consequence of an augment in workload;
- region C, where the demand is high and due to the elevated levels of workload the performance remains at a minimum level.

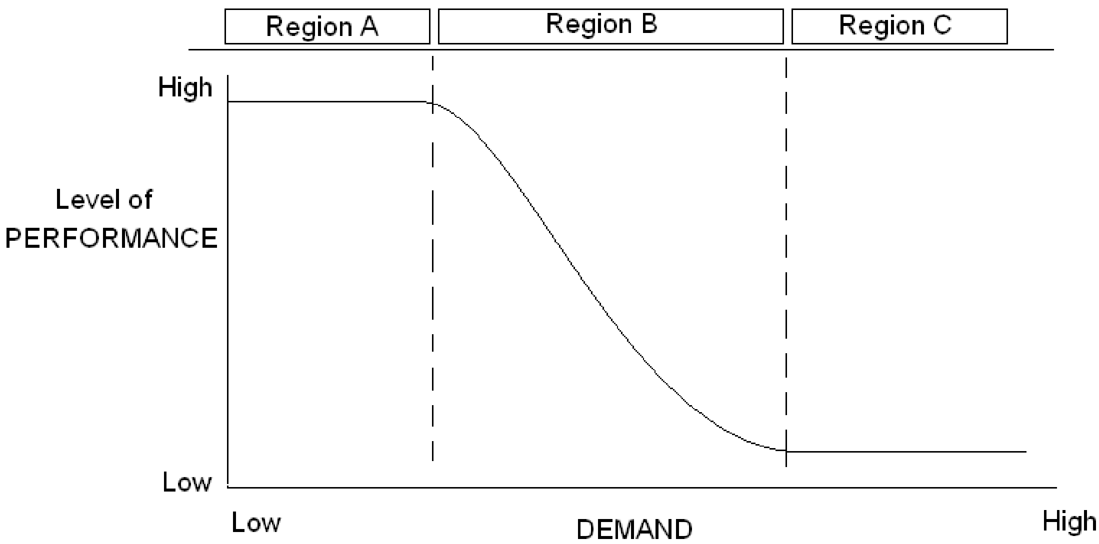

Figure 9. Relationship between demand and performance based on Meister, in de Waard, 1996

Observing this model it can be seen that in region A performance remains the same independent of the variance in demand, however from a certain point of demand this variation begins to have visible consequences on performance. Consequently, region C represents high demand tasks where the performance stays at a minimum level, independent of some variances in the demand. This region model was completed some years latter by the addition of one region: D. This area, placed at the far left end, represents tasks where very low demands are present inducing to increased task difficulty and workload. This is the case of very monotonous tasks where a reduced demand requires that a larger proportion of capacities are used to performance, resulting in an increased mental workload. By adding the D region, an inverted-U characterizes the region model, and four areas are now visible.

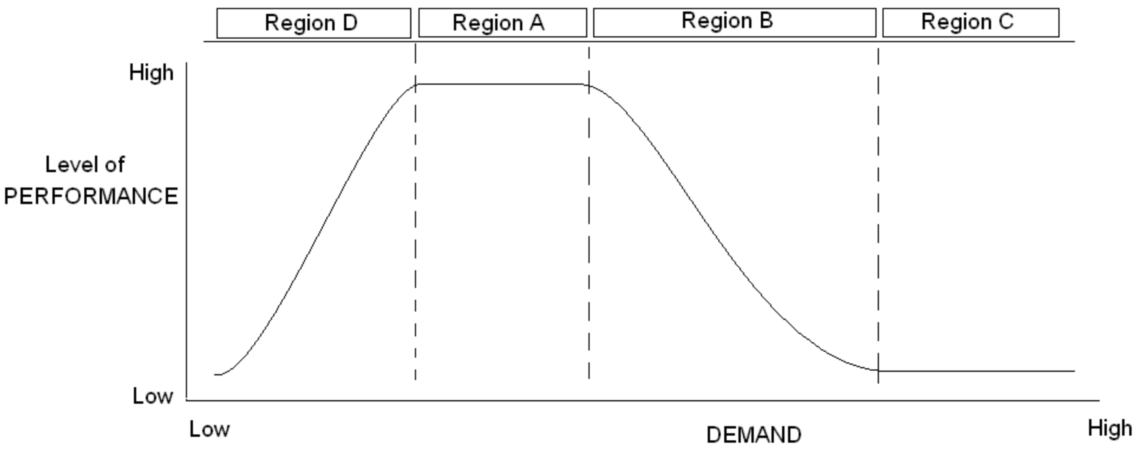

Figure 10. Upgrade of region model with inclusion of a fourth region (D), in de Waard, 1996

In spite of this last upgraded version of the model, this was not its final appearance. While trying to define "how much workload is too much" and using the theoretical support of other authors, de Waard (1996) presented in his work an improved vision of this figure. Setting up a redline determining the point from which the workload is too much, can suggest a first proposal indicating that this point could be in the transition from region A to B. However, this first suggestion only defines the detectable performance decrement while the searched point can be a bit before, inside A region. For this reason, the area A was divided into three smaller regions: A1, A2 and A3.

In the middle part, A2, are represented the tasks where subjects can cope easily with the task demands at a stable level, without increasing effort. The following region, A3, represents the state where the level of demand induces to an increasing effort but the performance still does not show any decline. This higher demand is temporarily compensated by an exertion of the effort; however it can not be maintained for a long period of time. This very demanding situation can induce to high levels of stress and major negative consequences for the individual well-being. Thus, as de Waard (1996) suggested, the workload redline should be placed in the transition from region A2 to A3 in order to maintain this redline point related to the workload itself and not only with the visible decline of performance.

Furthermore, a similar situation exists between the A2 and A1 regions. At the A1 area a monotonous task can be represented but performance is not yet affected due to the invested effort. This higher effort to maintain a high performance level denotes also an elevate workload.

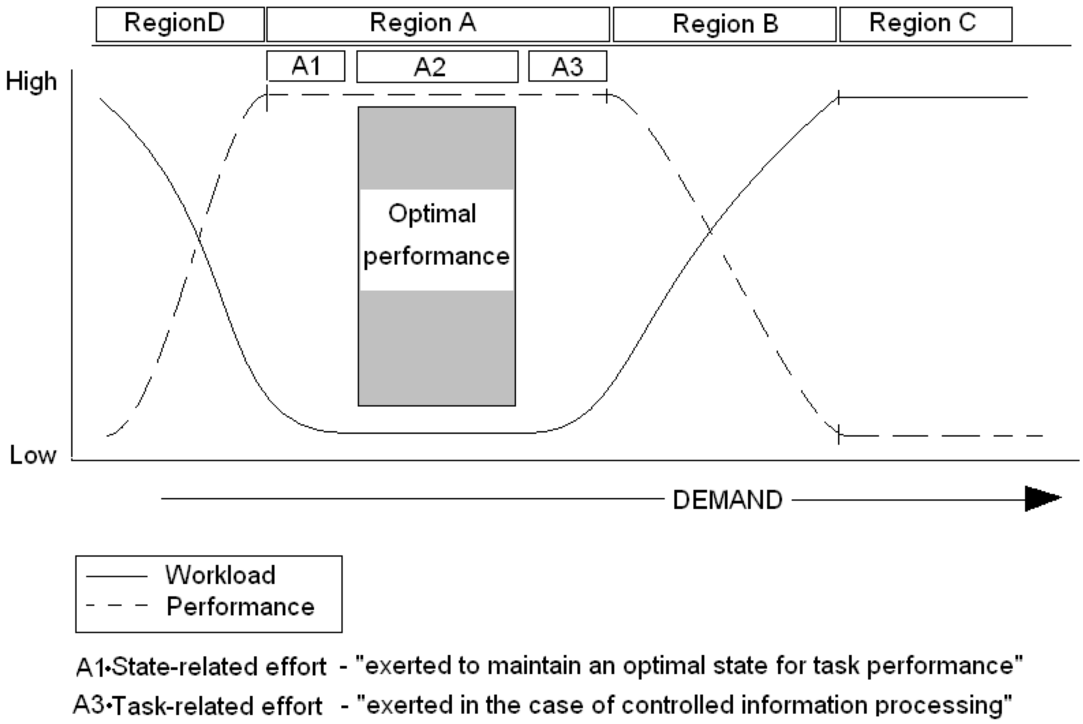

Figure 11. Representation of workload and performance in six regions (de Waard, 1996)

As it can be seen in the last figure, besides the performance representation the workload levels are also shown for the six regions. Additionally, it is also important to refer that only one dimension of workload is displayed and that this model represents the overall relation between the demand, the workload and the performance.

4.2.1 Assessing Mental Workload

In order to assess and quantify the mental workload three distinct workload-measurement groups were defined: *performance* measures, *subjective* measures and also *physiological* measures (O'Donnell & Eggemeier, 1986; Meshkati, Hancock & Rahimi, 1992). These categories are frequently used to assess the mental workload of subjects in specific driving situations.

Performance measures can be split into two groups: primary and secondary task performance. The former group involves the measurement of the driver's ability to perform the driving task and according to Wierwille and Eggmeier (1993) they should be included in any assessment of the subject mental workload. This primary task performance can also be considered as the overall effectiveness of the man-machine interaction and as mental workload increases it is expected that the driver performance suffers a decrement.

The main advantages of using these measurements are their sensitivity to workload variations and their ease to apply. Their most important disadvantage is related with some subject's experience and ability to perform an efficient drive even with high levels of workload. Moreover, primary task performance measurements can also suffer from low workload levels once these moments can also induce to performance decrements due to lack of motivation or inattention (Stanton, Salmon, Walker, Baber, & Jenkins, 2005).

In what concerns the secondary-task performance measures, they evaluate the ability of a driver to perform an additional task and two distinct paradigms can be addressed: the first one is related with the maintenance of the secondary-task performance even if some decrements in the primary task occur; and the second one regards the instruction given to maintain the primary task performance, expecting as a consequence to observe variations in the secondary task performance.

These variations observed in the second paradigm are a consequence of the variation in difficulty, indicating also the spare capacity[1] of drivers to perform the additional task (O'Donnell & Eggemeier, 1986). These second paradigm was the one used in the present experiment once the driving activity was the most important task and high levels of performance and safety should be maintained. Thus, the measurements of the secondary task performance are based on the assumption that the performance on a low priority task reflects the workload induced by a concurrent high-priority task. The ability to perform the additional task will diminish as the operator workload increases, as a consequence of the reduction in the spare capacity.

Secondary task performance measures have been reported as good methods for assessing visual and mental workload peaks. The major disadvantages are reported as: lack of sensitivity to minor workload variations, intrusion on the primary task (Stanton et al, 2005; Zhang & Luximon, 2005), requirement for additional instrumentation and, specially in on-road experiments, safety compromise of the primary task performance (Eggemeier & Wilson, 1991).

Physiological measures of the driver's mental workload consider the physiological aspects that can be affected by a variance in the levels of workload. Several measures have been found to be differentially sensitive to global activation levels or to specific stages in information processing. The main advantages of these types of measures are related with the absence of intrusion on the primary task once they do not require a specific response from the subject and also with the fact that they can be measured continuously (de Waard, 1996). Concerning the equipment used, this measurement can, or can't, be obtrusive dependently of the measure and related material. While some equipment can interfere physically and influence the driver's performance, others are unnoticed due to the evolution of technology and its miniaturization. Nevertheless, generally this material can be expensive and need technical expertise (Stanton et al., 2005; Zhang & Luximon, 2005).

[1] Spare Capacity – This concept, defined by Brown & Poulton (as cited in de Waard, 1996) is frequently used in dual task performance evaluations and is the available capacity to perform all tasks. This capacity is undifferentiated and when a task is performed in isolation, it is the unused capacity that is spared and available for additional tasks.

The third category of mental workload assessment techniques is the *subjective* measure. Also named as self-report measures (de Waard, 1996), they need the involvement of participants once they require their rating regarding the perceived mental workload during the task performance. Depending on the number of workload dimensions that they assess, they can be categorized as uni-dimensional or multidimensional.

The advantages of these techniques are related with their easiness of application, low cost, un-intrusiveness to primary task performance if conducted after its completion and can be used in simulator and in on-road experiments (Stanton et al, 2005). Some critics are concerned with the fact that subjects' ratings of their supposed mental workload can be confounded with their performance on the task under analysis. Due to the difficulty in diagnose the source of the demands, physical and mental workload can also be hard to distinguish for participants (de Waard, 1996). It is also registered that some participants are prone in forgetting some parts of the task, even if there were perceived variations in the mental workload (Stanton et al., 2005).

There are subjective measure techniques already validated, and some of the most frequently used are NASA-TLX (National Aeronautics and Space Administration- Task Load Index; Hart & Staveland, 1988), and SWAT (Subjective Workload Assessment Technique; Reid et al., 1981) for the multidimensional group of techniques and the MCH (Modified Cooper-Harper; Wierwille & Casali, 1983) and the RSME (Rating Scale Mental Effort; Zijlstra, & Van Doorn, as cited in de Waard, 1996) for the uni-dimensional cluster (see also Zhang, & Luximon, 2005; Rubio et al, 2004; Verwey, & Veltman, 1996; Park, & Cha, 1998).

The existence of such variety of assessment techniques was supported by the importance of having a battery of mental workload assessment methods, which has been proven as more appropriate than one single approach (Stanton et al, 2005; Zhang, & Luximon, 2005; de Waard, 1996).

5. Human Variability in Driving

While studying a specific human-machine interaction with the aim of conceiving or improving an environment or a product, one of the things that should always be considered is the human variability. The magnitude of its importance is even greater when the concerned system is used by a large number of people, with different ages, in different contexts and with distinct purposes. When considering the human variability one should take into account that human beings characteristics are distinct in several ways. These differences can be highlighted when distinct individuals are compared, but can also be visible for the same subject over time. The first category of human variability is called *inter-individual differences* and it differentiates the characteristics of two or more distinct individuals. Those characteristics can be related to the subject's physical features, cognitive capabilities, age, gender, experience, training, and other biographic aspects. They enable to distinguish the individuals among themselves in a determined context and time. The second category is defined as *intra-individual characteristics* and is expressed when features of the same individual are compared over time. The development and evolution of an individual along a period of time allow him/her, for example, to change experience or capacity to perform a specific task, and can be completely different if measured in two distinct moments.

Like in other contexts, the human variability is of much importance. The diversity of road users and, in particular, of vehicle drivers should be taken into account when conducting a research, once different subjects' characteristics may influence the way they interact with a system and behave in a certain moment. Along time and in parallel with research development in road transportation area, several road user groups have been studied. Some of these groups were elaborated depending on their driving experience (e.g. novice and experienced drivers), on the purpose of their interaction with the vehicle (e.g. professional or non-professional drivers), on the type of vehicle they frequently drive (e.g. truck drivers; bus drivers; motorcyclists), on their age (e.g. young and elderly drivers), and other characteristics.

Age is probably one of the most frequently studied driver characteristic. The comparison of drivers with distinct ages and the evaluation of their behaviour while driving have been object of analysis along the years. The importance of age is justified by the gradual alteration of the driver's performance over time, as a result of increased experience and knowledge as well as different functional capabilities. In fact, numerous studies have reported that ageing can bring some cognitive and physical declines, being the modification of driver's performance a probable consequence (Groeger, 2000). Together, past experience, knowledge and present capabilities can determine drivers' ability to perform the driving task.

5.1 Age and Driving

The driving task performance of subjects belonging to different age groups has been the main focus of attention of several researches along the years. As a consequence, an extensive bibliography can be found and some conclusions regarding behaviours and attitudes of these road users can already be evidenced (some examples: Monárrez-Espino, Hasselberg, & LaXamme, 2006; Sagberg, & Bjornskau, 2006; Clarke, Ward, & Truman, 2005; Department for Transport, 2000, 2005; Slick, Cady, & Tran, 2005; Smith, Carrington, & Trinder, 2005; Hakamies-Blomqvist, Siren, & Davidse, 2004; Mayhew, Simpson, & Pak, 2003; McCartt, Shabanova, & Leaf, 2003; McKnight, & McKnight, 2003; Meyer, 2003; Molnar, Eby, & Miller, 2003; Williams, 2003; Green, 2001; Holland, 2001; Lerner, 2001; Mourant, Tsai, Al-Shihabi, & Jaeger, 2001; Tijerina, Parmer, & Goodman, 1998; Eby, & Kostyniuk, 1998).

When driver's age is concerned, two major clusters are frequently focused: young and elderly. A foremost reason for its study is the number of fatalities that have been registered along the years, indicating higher values for younger and elderly groups. Some latest studies displayed a graphic (similar to the following one), showing a curve that indicates a higher number of fatalities for the younger drivers aged until 24 years-old; a decline in fatalities between the 25 and the 65 years-old, and again an augment in the number of killed drivers for those who had 65 years or more.

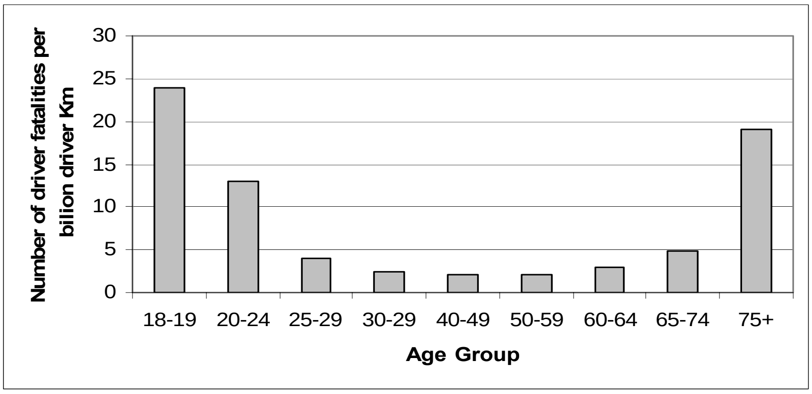

Figure 12. Traffic fatalities per billion kilometres travelled by age (SWOV, 2005)

Similar graphics are shown in other documents like the Report for the Special Committee on Ageing of the United States Government (GAO, 2007) and the study conducted by the Accident Research Centre of the Monash University in Australia (Oxley et al., 2005). Both documents refer that young and elderly drivers are the two age groups with higher number of serious injuries and fatalities. However, besides their higher representation in fatalities, it has been observed that they present distinct characteristics that typify their behaviour and make them unique clusters.

Both groups have equivalent importance, however elderly drivers will be considered with further detail in this research. This higher attention given to older drivers will be the support for framing the experimental work presented in the second part of this work and accomplish the objectives proposed in the beginning of this research.

5.2 Elderly Drivers

One of the main reasons why road safety research has devoted considerable attention to elderly drivers is their growing representation in the population in most industrialized countries. In fact, the proportion of elderly drivers is increasing in society and is expected to enlarge even more (Jun et al., 2007; Simões, 2003; Dissanayake & Lu, 2002; Parker, McDonald, Sutcliffe, & Rabbitt, 2001; Holland, 2001; OECD, 2001).

Driving is nowadays a fundamentally important part of society and is essential to determine the quality of life of older individuals. Driving enables easy access to activities, services, to fulfil social needs and because of that is a good indicator of mobility, independence, good health, quality of life and well-being. The car represents to elderly the possibility to maintain their autonomy and self-esteem being also a symbol and a way of freedom, independence and self-reliance (Charlton et al., 2006; Oxley et al., 2005; Burkhardt, 1999).

In contrast, the fact of not being able to drive is considered a limitation in life control, mobility and independence. Stopping driving seems to have consequences not only on elderly “practical” life but also a negative effect at a psychological level once it is reported to increase the feeling of isolation and loneliness (Johnson, 1998) as well as augment the depressive symptoms (Harper, & Schatz as cited in Oxley et al., 2005; Marottoli et al. as cited in Oxley et al., 2005). For besides the social and health disadvantages, elderly drivers report strong feelings about the importance of driving and extremely negative opinions about the loss of driving (Harris, 2000). Ceasing driving means that they have to rely on others for transportation or have to incur in potential inconvenience of public transportation. It is not surprising that many older drivers rely on their cars for most of their transportation needs, being strongly interested in keeping their own cars and licences for as long as possible (OECD, 2001). Additionally, they are sometimes reluctant to use public transportation because it doesn’t fulfil their travel needs; it is often considered as unreliable and perceived as providing inadequate personal security (Oxley et al., 2005).

5.2.1 Safety of Elderly Drivers

Driving is a complex task that depends on visual, cognitive and physical functions that allows the subject to observe the road environment; recognize the observed surroundings, process the information, decide how to react, and also act physically to control the vehicle (GAO, 2007). With the ageing process and the natural functional declines, the driving ability can be modified and impairments can be observed at sensory-motor or cognitive levels (Eby, Trombley, Molnar, & Shope, 1998). Some laboratory and simulator studies have shown that sensory, cognitive and physical performance of older drivers may be sometimes compared unfavourably with that of their younger counterparts (Owens, & Tyrell, 1999; Stutts, Stewart, & Martell, 1998). Some complex situations in driving that demand a rapid series of decisions can be particularly problematic for some elderly once it was already reported that cognitive deficits can be linked to safety (McKnight, & McKnight, 1999).

The major concern about elderly drivers' safety is not so much the potentially hazardous situations that they can cause but the risk that they are exposed to. In absolute numbers, the older drivers' crashes have been reported has inferior when compared to other age groups, specially the young drivers (GAO, 2007) (see Figure 12). However, the overall number of older driver crashes may under-estimate the magnitude of the older driver problem once their total distance travelled tend to be less when compared to other younger drivers. This may have an influence on their crash rate because drivers that travel few kilometres have increased crash rates per kilometre compared to those driving more (Charlton et al., 2006; Oxley et al., 2005). In fact, when the distance travelled is taken into account, the fatality rate for the 75 years and older is more than five time higher when compared with the other drivers' group (ERSO, 2006; Baldock, & McLean, 2005). This adjustment of the crash rates for distance driven was reported by other studies, and evidence that rates for the elderly drivers are not inferiors to the ones observed for the younger group, giving rise to the concern of older driver population (Brayne et al., 2000).

Dellinger and colleagues (2002) conducted a study to investigate the crash involvement rate of US older drivers aged 55 years or older. The selected subjects were implicated in fatal crashes in 1990 and 1995 and the factors that influenced their fatal crash involvement were explored. Authors believed that *crash involvement rate* could be thought as the product of the *crash fatality rate*, the *crash incidence density*, and the *exposure prevalence*. More specifically, the risk of dying in a car crash equals the risk of dying when a crash occurs (*crash fatality rate*), multiplied by the risk of a crash (*crash incidence density*), multiplied by the amount of driving done by the age group (*exposure prevalence*):

Crash Involvement Rate = (*crash fatality rate)* **x** (*crash incidence density)* **x** (*exposure prevalence).*

By dividing subjects into three main age categories (55 to 64; 65 to 74; 75 to 84 years old), the analysis of the crash reports revealed interesting aspects. When age groups were compared it could be seen that the oldest group of drivers was the one that drove less in both years - 1990 and 1995 (exposure prevalence). This supports the assumption that with increasing age, drivers have the tendency to drive less.

On the other hand, the risk of having a crash (crash incidence density) was higher for the older group of drivers. When all the components of the equation are put together, authors reveal that the crash fatality rate increased with age. However, the comparison of both years' data (1990 and 1995) also exposed more interesting findings. In 1995 all groups of drivers had higher exposure prevalence (higher mean kilometres driven per subjects) compared with 1990. This means that from one year to another all drivers group drove more kilometres, leading to the supposition that, along the time, elderly drivers can be driving more and more.

Furthermore, it was also observed that the risk of having a crash (crash incidence density) decreased over time, revealing that the risk of having a crash changed, being lower in 1995. Consequently, the crash involvement rate remained stable over the time because the higher exposure prevalence was compensated by the lower risk of having a crash (Dellinger et al., 2002).

Besides the constant crash involvement rate over the time observed in this study the GAO report (GAO, 2007) stated that older drivers can be increasingly exposed to crash risks due to two distinct factors: the first is related with the increasing number of older drivers once it was reported that elderly are the fastest-growing segment of population in industrialized countries; the second is concerned with the expectation that, in future, elderly generations will drive more kilometres per year.

Another study concerning the crashes involving drivers aged 65 and over was conducted by Baldock and Mclean in 2005. They made comparisons on 195 reported crashes using characteristics like the type of vehicle being driven, the road in which the crash occurred, the nature of the crash itself, the environment, the outcome of the crash and also some characteristics of the driver. The crash data used, from the years 1994 to

1998, revealed that crashes involving older drivers were more likely to produce fatal injuries. Elderly drivers were also more frequently implicated in collisions at intersections (right turn, right angle crashes – not forgetting that the data was from Australia where driving is on the left-hand side of the road). Besides some of the crashes having occurred due to driver error, it was revealed that other factors unrelated with human error were found to contribute to its causation. In a number of intersections authors discovered that the layout of the road was found to be problematic and the difficulties imposed to all drivers at intersections could have interfered elderly drivers' performance disproportionately. These complications, related with the intersection layout, hindered some judgements concerning gap acceptance or the prediction of movement of other vehicles. Moreover, intersection crashes were also associated in several situations with vision restrictions of oncoming traffic (Baldock, & McLean, 2005).

Other authors have also reported that intersections pose a particular safety problem for older drivers. Performing an intersection requires rapid decisions and reactions, as well as accurate judgements on the speed and distance of other vehicles. With the diminishing abilities observed with ageing, navigating throughout an intersection becomes more difficult and elderly drivers have the tendency to be frequently involved in fatal crashes at these locations (GAO, 2007; European Conference of Ministers in Transport as cited in Merat et al., 2005; Hakamies-Blomqvist, 1996). This over-representation of elderly in accidents at intersections was also reported by Keltner and Johnson (as cited in Hole, 2007), suggesting that accidents that occur frequently with elderly are failure to yield right-of-way and accidents involving turns. In countries where subjects drive on the right-hand side of the road, the difficulty appears to be with left turns (comparatively to the left-hand side like in Australia or England). In these situations it is required that elderly drivers find suitable gaps to make the necessary turn manoeuvre. When it is not adequately performed, older drivers tend to be hit from the side (Hole, 2007).

Contrarily to the over-representation of elderly in accidents at intersections, they are infrequently involved in other types of accidents. It is not common to see this group of subjects involved in accidents attributed to high speed or situations where have been committed major traffic offences (e.g. aggressive driving or drunk driving). Older drivers tend to be less implicated in single vehicle accidents, being more represented in two-vehicle accidents (European Conference of Ministers in Transport as cited in Merat et al., 2005). Additionally, when they are involved in an accident they are more likely to have been guilty, and his or her vehicle is more likely to have been the one that was hit.

The causes of older road users crashes are complex and there is no unique unequivocal explanation for them. Explanations have been expressed by researchers to justify the over-representation of elderly drivers in fatal and serious injury crashes. Some argue that the older driver issue is mainly restricted to determined sub-groups of older people, rather than related to all older drivers indiscriminately. They believe that some clusters are more at risk and need to be identified in order to de done something about it (OECD, 2001). One important difference between these at-risk populations is the survival rate of crashes once it is reported that seniors have lower surviving possibilities. After a motor vehicle accident, older drivers are four times as likely to be hospitalized, having also slower recoveries when compared with younger drivers (Dobbs as cited in McGee, & Tuokko, 2003). This can also explain, at least partially, the elevated trauma of older road users. With increasing age, biological processes have the effect of reducing resilience to trauma and biomechanical tolerance to injury becomes lower. The reduction in bone and neuromuscular strength and also the diminution of the fracture tolerance make elderly drivers more fragile, susceptible to injury and with slower capacity to recover from trauma (Charlton, 2006). Seniors are more likely to have serious injuries or die from motor vehicle crashes because they are simply more medically delicate (Kam, 2003; Li et al., 2003; Massie et al., 1995).

With increasing age, most individuals experience some level of functional declines, specially associated with changes in sensation, perception, cognition and also motor functioning. Those changes may induce to some limitations in one or more activities of daily living and as age moves forward the declines become more evident and severe. One of those impaired activities may be driving. In fact, in order to drive safe and efficiently, adequate functioning of the sensory, perceptual, cognitive and physical abilities are needed. Consequently, it may appear reasonable to state that these age declines may influence negatively performance when driving, at least in some particular traffic circumstances. However, few relationships have been found between declines in single functions, poor driving performance and also on crash risk. This reveals that little evidence indicate that age per se is related to poor driving (ERSO 2006; Oxley et al., 2005; Parker et al., 2003; Canada Medical Association as cited in McGee, & Tuokko, 2003). Instead, it is argued that moderate changes occurred in normal and "healthy" ageing do not appear to conduct to a visible and significant increase in crash risk. Contrarily, simultaneous deterioration of multiple relevant functions or specific functional deficits as consequence of states of illness may increase considerably the risk of crash (OECD, 2001).

Individual differences are large in terms of chronological age but also in terms of the pace at which the age process develops. Studies have been giving an overview of the specific skills that deteriorate with age (e.g. Hakamies-Blomqvist et al., 2004; Holland, 2001; Eby, Trombley, Molnar, & Shope, 1998), being the most important functional changes that accompany normal ageing related to visual and perceptual abilities, cognitive abilities and also physical abilities.

a) Perceptual Abilities

Regarding perceptual abilities, one of the important aspects to be considered is the visual functions. Age-related declines in perceptual abilities such as vision have an impact on the input that the driver receives from the road environment (Eby et al., 1998). Ageing brings poor vision among subjects due to two main factors: the first one affects everybody and regards the natural deterioration in eyesight; the second is related with pathological changes. In what concerns the natural deterioration of the eye, neural and retinal changes occur, as well as modifications in the lens of the eye. These structure decrements may influence the visual acuity and the peripheral vision. Other visual functions like contrast sensitivity, sensitivity to glare, detection of movement and also colour vision are also affected with increasing age (Holland, 2001).

Frequently, the decrease of visual acuity occurs slowly and subjects may not notice that their visual perception is becoming worse, making driver unaware of their visual powers and also overestimate their capacity to perceive the road environment. A deteriorated visual acuity has strong impact on the detection of road environment elements, like other vehicles, pedestrians or even signs. Furthermore, the long distance view, needed for example for overtaking, deteriorates simultaneously with the decrement in visual acuity (Holland, 2001). In addition, peripheral vision can also deteriorate. This function is of extreme importance for driving once it is necessary to see cars in adjacent lanes when performing a lane change, to perceive a pedestrian that is not directly in front of the vehicle, or even to centre the car in the lane (see Eby, Trombley, Molnar, & Shope, 1998).

More frequently reported are the functional impairments essential for driving in the dark: night-time visual acuity and sensitivity to glare. Night-time visual acuity is the result of reduced pupil size and the yellowing of the lens that conducts to poor vision acuity at night. When it occurs, objects have to be illuminated intensely in order to be seen by elderly drivers. However, if the object is inappropriately illuminated, being the light not strictly directed to it, the increased sensitivity to glare of elderly drivers conducts to undesired effects (Holland, 2001). That's the reason why older drivers need longer period of time to recover from headlights and other reflecting sources. In what concerns the contrast sensitivity, elderly drivers have more difficulties discriminating small details and this situation is even worse if the illumination levels are low. This contrast sensitivity as well as colour vision, that also gets worse with age, helps drivers discriminating traffic signs being also believed to be important in distance perception and estimation of objects speed (Shinar, & Schieber as cited in ERSO, 2006; Holland, 2001).

Hearing acuity is another aspect included in the perceptual abilities that suffer some decrease with age. Hearing beguines to decline early (before 40 years old), and a more pronounced deteriorations can be observed over the time (Havlik as cited in Shahee & Niemeier, 2001). This deterioration process begins as consequence of several factors like structural changes, cumulative effects of exposure to noise during life, genetic influence, result of traumatic events, disease or even side effect of certain types of medication (Meyer, 2003; Shahee, & Niemeier, 2001). When subjects reach 50 years-old, there can be enough hearing loss to create impairment under more demanding listening situations like faint sounds, background noise, and audio inputs from multiple sources (Haigh, 1993). Hearing loss can result in increase pure-tone thresholds, difficulties in speech perception and greater susceptibility to the adverse affects of the environmental factors such as noise and reverberation (Baldwin, 2002). It is not reported that the hearing loss itself have direct implications on driving however, this reason can not justify lack of attention given to this issue. Auditory acuity is very important to the driving activity as the auditory stimuli guide the driver and provide warning information, essential to a safe driving (Meyer, 2003). Furthermore, auditory processing abilities are of major importance when the utilization of in-vehicle information and communication systems is considered (Baldwin, 2002).

b) Cognitive Abilities

The cognition refers the thought processes and all the factors related to it. It is involved in nearly every activity and includes the acquisition, storage, recovery and use of the information. Some processes related to cognition, like the attention and the memory, decline as people grow older. The attention ability is required for safe and effective driving once it is important to select the most relevant information from the road environment (Holland, 2001). Three attentional processes are essential to consider when it comes to study the elderly drivers' capabilities: sustained, divided, and selective attention (Parasuraman, & Davies as cited in Eby, Trombley, Molnar, & Shope, 1998).

The first one, sustained attention or vigilance, is defined as the ability to maintain attention to a critical stimulus for a continued period of time. It is believed to suffer a decline with ageing once older drivers' capacity to maintain attention over long periods of time becomes reduced (Maycock as cited in ERSO, 2006). Similarly, the divided attention, which occurs when a person must perform two tasks simultaneously, shows a significant decrease in elderly adults. When older drivers have to monitor two or more stimulus sources they get particularly hindered comparatively with younger drivers (Salthouse et al. as cited in Eby, Trombley, Molnar, & Shope, 1998).

Selective attention and attention switching are also abilities that get poorer as adults become older. The selective attention can be defined has the ability to ignore irrelevant stimuli while focusing attention on relevant ones (Parasuraman as cited in Eby, Trombley, Molnar, & Shope, 1998); attention switching happens when people quickly shift their attention among important stimuli. In order to drive effectively, subjects have to be able to ignore irrelevant inputs in order to focus attention on vehicle control and movements of nearby vehicles. The success of driving depends also in the ability to quickly shift their attention among important stimuli, being also demonstrated that this capacity also suffers a decline with ageing (ERSO, 2006).

Information processing speed is another aspect that has been reporting to change with age as it has been observed a slowing down in this processing. This decrease is seen as the main cause of elderly impaired performance on many tasks, not just on the speed with which drivers accomplish tasks but also regarding the number of errors they commit (Salthouse, 1996).

Another aspect that can change with age is memory. This process can be described as the one allowing drivers to recall traffic laws and driving skills, being able also to predict traffic situations, and to determine their location. Good memory ability is essential to safe and efficient driving. Compared with younger drivers, older individuals report having more problems with their memory and many problems are concerning the short-term memory. This short-term memory (STM) is the type of memory used to conduct ongoing cognitive activities and is sometimes called working memory (Eby, Trombley, Molnar, & Shope, 1998). As such, skilful functioning of short-term memory is critical for driving. Numerous studies that compared performances of subjects with distinct ages have shown that older adult performance declines even at lower levels of complexity (Maycock as cited in ERSO, 2006).

c) Physical abilities

Some physical ability declines can be observed with ageing. The most frequently reported ones are joint flexibility, muscular strength, and manual dexterity (ERSO, 2006). These changes can influence the ability of subjects to get in and out of cars but can also contribute to a decrement while operating the vehicle and while recovering after an accident. As a consequence of the physical and cognitive changing, slower motor performances can also be observed and probably contribute to the higher level of risk experienced by elderly drivers at intersections (Hole, 2007). One important example of the reduced physical ability of elderly drivers that influence driving is the limited joint flexibility for rotating the neck. This situation can hinder the driver while checking for approaching traffic at intersections. The importance of this gesture is more important than it can be thought once elderly rely in this action to get information from the environment, compensating for their restricted field of view (ERSO, 2006; Eby, Trombley, Molnar, & Shope, 1998).

5.2.2 Compensation Strategies

Older drivers are generally considered safe and cautious drivers and it is frequently claimed that older drivers “self-regulate” their driving behaviour (Charlton et al, 2006). Functional limitations and age related disorders can not directly lead to unsafe traffic behaviour once elderly drivers possess other characteristics that can help them to prevent safety problems. When performing a task, it is argued that, the same types of compensations for functional looses can be observed among the elderly drivers (Simões, 2003). These characteristics that act as a compensation to their declines, can include the insight to one’s own limitations, driving experience and some compensatory behaviours (ERSO, 2006).

Functional impairments can be to some extent compensated by changing driving habits and travel patterns like for example to drive less, to restrict driving to safe conditions (like driving outside the busy periods), in familiar territories, and only during daylight hours (Hole, 2007; Oxley et al., 2005). Indeed, there are studies that indicate that many older drivers do adjust their driving adequately and do it in a successful way (OECD, 2001). This self-regulation may be a consequence of the insight of their own limitation once it was already suggested that elderly drivers that fail in performing this self-regulations may be at higher risk involvement. The prolongation of driving after the eight or ninth decade and the refuse to stop driving can, in some cases, be caused by the lack of insight into the impact of ageing on driving skill and the inappropriate perception of risk (Cooper, 1990; Holland, & Rabbit, 1992)

The great amount of driving experience that elderly drivers possess is also an important factor. The traffic experience acquired may give them the ability to anticipate some problematic situations and avoid the risk. Charlton and colleagues (Charlton et al., 2006) refer examples of self-regulation behaviours: driving more slowly, travelling shorter distances, making fewer trips, avoiding driving under difficult conditions like driving at night or with a large amount of traffic, preference for longer time gaps when turning or entering a road, and avoidance of simultaneous activities while driving. Generally, elderly drivers tend to make trips shorter and closer to home (Rosenbloom as cited in Oxley et al., 2006), avoid to drive in freeways, plan to use only routes where protected left turns can be made (for those who drive in the right hand-side of the road) and also drive with a co-pilot (Eby et al, 2000). They tend also to be more conservative in their driving habits, limiting when and where they travel (see Table 6).

Charlton and his colleagues refer that the designation of “compensatory behaviours” may not be the most adequate label to characterize these adaptations. They suggest that while some behaviour may reflect an adaptation/compensation to age-related declines in performance, others may be explained by the fact of being mature judgements about road use as a consequence of years of experience, different lifestyle choices, and also some personal preferences. For that reason these authors consider as more adequate to talk about “self-regulation” (Charlton et al., 2006). Additionally, these authors mention five self-regulatory facilitating factors and five inhibitory factors for these same behaviours. The facilitator factors are: awareness of the impact of declines in functional abilities; influence from others; concerns for their own safety or the safety of others; lifestyle choice and comfort; and also good access alternative transports. Comparatively, there are some factors that can inhibit self-regulating behaviours like the lack of insight of their perceptual, cognitive and physical limitations, the lack of awareness of ageing impact on their performance; the inappropriate risk assessment; the perceptions of loss of independence; and also the inexistence of alternative transport; and the reluctance to become independent of others.

Table 6. Age-related declines and difficulties in driving (excerpts from Eby, Trombley, Molnar, & Shope 1998)

	Age-Related Declines	Declines in abilities related to driving	Difficulties in Driving	Compensation Behaviours
Visual declines	Sensitivity to light	Higher visual sensitivity threshold	Detect dim lights in a dark environment High sensitivity to glare	Avoid night driving
	Dark adaptation	Slower rate for dark adaptation	Increasing glare recovery	Avoid night driving
	Visual acuity	Static visual acuity Dynamic visual acuity	Reading a road sign at a distance Appreciating speeds and distances of moving objects	Avoid night driving Avoid complex traffic situations
	Spatial contrast sensitivity	Contrast sensitivity for high frequency gratins	Seeing unexpected vehicles in peripheral visual field Reading dim dashboard display panels Seeing through windshields Reading signs at a distance	Avoid night driving Slower driving Avoid complex traffic conditions
	Eye movements	Saccadic movements Pursuit movements	Longer time to locate objects Restriction in the maximum extent of gaze without head movement Perceiving details of moving objects	Compensation with head movements
	Space perception	Perception of relative distances	Perceiving distances between the car and the vehicle ahead, or the amount of traffic gap for merging with or crossing a traffic stream	Avoid complex traffic situations (merging traffic, lane changes and overtaking)
	Motion perception	Sensitivity to angular displacement	Perceiving depth motion Detecting the relative speed of objects	
	Colour perception	Colour vision	Discriminating traffic signs and lights	(non conclusive results)
	Visual field	Useful filed of view (UFOV)	Reduced UFOV, particularly when performing a secondary task or having distracting stimuli	Avoid distraction factors while driving
Cognitive declines	Attention	Divided attention	Performing simultaneous tasks	Avoid simultaneous tasks
		Selective attention and attention switching	Discriminating of the useful information due to difficulties in inhibiting irrelevant information processing	Concentration on the driving task, sometimes neglecting some displayed information
	Memory	Working memory (WM)	Long time to access information in the W M, hesitancy in decision making, both increasing with traffic complexity.	Slow driving, hesitant driving and unexpected manoeuvres
	Reaction time	Increased choice reaction time	Slower information processing	Slower driving
Physical ability declines	Motor coordination	Less accuracy in movement	Slower information processing	No significant influence in driving performance
	Range of motions and reaching distances Loss of muscle strength, endurance and tone	Reduced range of neck motion	Scanning road environment and performing reversing manoeuvres	Avoid parking manoeuvres, lane changes, merging traffic, overtaking and other high risk driving situations

CHAPTER 2. INTELLIGENT TRANSPORTATION SYSTEMS

1. Introduction of New Technologies

The development of new technologies and its introduction in everyday life has been a regular scenario in several areas, and the transportation context is not an exception. The introduction and development of new technology for the transportation field has been occurring with different rhythms, being expected that the future lead unconditionally to the presence of such systems in all transportation areas. Intelligent Transportation Systems (ITS), whose introduction has been bringing several benefits to the transportation field and, more specifically to transports users, are the most visible consequence of this evolution.

Since the eighties ITS has been attracting attention from many professionals in several countries all over the world. Groups of discussion have been created in order to contribute to the effective development of ITS and also to take an active role in sharing its future standards (Wu, & Lee, 2007).

A broader and common idea has been created revealing that ITS is a term used to describe developments in communication and computing technologies applied to transport services generally (ITS America). It is also considered as the application of advanced and emerging technologies (computers, sensors, control, communications, and electronic devices) in transportation to save lives, time, money, energy and the environment (ITS Canada; French as cited by Wu, & Lee, 2007). The primary focus of ITS is to provide improvements in safety, efficiency and environmental performance of all modes of transport including air, sea, road and rail. With numerous location or tracking devices, mobile charging devices, real time information services, and real time financial services, it plays a significant role in the transport management and operations all over the world (ITS Australia; ERTICO/ITS Europe).

Besides the common attention and interest given to ITS, the categories in which these systems can be divided are not universally accepted. Wu and Lee (2007) mentioned a first report made by ITS America, published in 1994, that tried to make a comparison between the Intelligent Transportation Systems developed in Japan, USA and Europe. This report, considered to be a very important base to built a common idea of ITS, opened way to the development of a second work, published in 1997 (HIDO, 1997). In this more recent report an international comparison between ITS and the related activities was made as an effort to collect information and gather consensus.

Wu and Lee (2007) suggested that categories for ITS technology need to be identified. Besides the classification in each country may not exactly be the same, they presented a table that indicate ITS technologies utilized for the three mentioned regions: Europe, Japan and America. Beside this observed division in the ITS subsystems, in order to accomplish for their work (related with patents) the authors choose to focus on the seven major categories of ITS commonly present in the three studied areas: ATMS, ATIS, AVCSS, CVO, APTS, EPS & ETC, and EMS.

Table 7. Major ITS technology categories in the US, Europe and Japan. Based in data collected from ERTICO, 2004; ITS Japan; and ITS America (Wu, & Lee, 2007).

Designation		Region		
		USA	Europe	Japan
ATMS	Advanced Traffic Management Systems	√	√	√
ATIS	Advanced Traveller Information Systems	√	√	√
AVCSS	Advanced Vehicle Control and Safety Systems	√	√	√
CVO	Commercial Vehicle Operations	√	√	√
APTS	Advanced Public Transportation Systems	√	√	√
EPS & ETC	Electronic Payment System and Electronic Toll Collection	√	√	√
EMS	Emergency Management System	√	√	√
Electronic Navigation System				√
Road and Safety Management System				√
Information Management		√		√
Maintenance and Establishment Management		√	√	

The ITS world is vast and includes a wide variety of sub-taxonomies and definitions that are currently utilized to describe intelligent systems. A considerable variety of equipments are exclusively dedicated to the road sector and much of them are directly related with single vehicles. A specific cluster of systems have received a great deal of attention from psychologists and human factor professionals that study road safety. This cluster is characterized by on-board systems that can, in a direct or indirect manner, influence the driving task and the driving activity. Two main categories are usually distinguished according to their impact on driving: In-Vehicle Information Systems (IVIS) and Advanced Driver Assistance Systems (ADAS). This classification have been used in some European scientific projects that aimed to study the implications of these new technological systems, like for example the CONSENSUS, AIDE, HASTE, COST Action 352 and HUMANIST. Each group of systems can be defined in the following manner:

The In-Vehicle Information Systems "provide drivers with information or communication while the vehicle is in motion. The delivered information may not be related to driving (e.g. conversing by phone, consulting emails, or listening to the radio) or related to the trip management (e.g. traffic or weather information, navigation map, or route guidance)." The Advanced Driver Assistance Systems "are designed to support the driving task on vehicle manoeuvring by informing, warning and actively assisting drivers on the basis of vehicle surroundings analysis and with the requirement of immediate driver actions (e.g. intelligent speed adaptation, lateral and longitudinal control, blind spot warning, or night vision)" (Brusque et al., 2007).

2. In-Vehicle Information Systems

Information systems are becoming more ubiquitous in everyday life and the automobile is a promising location for new devices. The even more frequent presence of In-Vehicle Information Systems is an example of that. They can be used by private and commercial drivers in a range of vehicles, for different applications and under different traffic conditions. One of the reasons that justified its appearance in the market was the desired optimal use of existing transportation facilities, issue that became a major priority in congested urban areas. Providing alternatives to the crowded roads or even presenting real-time in-vehicle traffic information to drivers, turned out to be one possibility of achieving this goal.

As it was mentioned earlier, In-Vehicle Information Systems make available to drivers several types of information that can be useful to the driving task, like information concerning road conditions, weather broadcast, maps of cities, guidance throughout specific places, vehicle diagnostics and in some situations warning systems and emergency help systems. All these equipments that have different specific functionalities are used to facilitate and manage the driving task, making it also more efficient and ecological (Ross, & Burnett, 2001; Adler, & Blue, 1998). These types of systems interact with the driver with the main purpose of support at targeting, monitoring and warning levels. Nevertheless other systems exist that are not directly related to the driving task, like mobile phones devices, equipments to send text messages, consulting the e-mail or even listen to the radio.

Due to their nature in supporting, or not, the driving task two different designations can be attributed to these groups of equipments. Systems that are directly related with driving, contributing to the improvement of its management and efficiency can be named as Safety Enhancing Systems. In fact, by giving the driver information about the road, weather conditions, guidance possibilities or even the vehicle diagnosis, these equipments contribute to the better information of the drivers which consequently allows them to take more efficient and safer decisions. In this perspective systems can be considered as enhancing the safety of the road users and of the entire road system.

On the other hand, systems that are not related with the driving task and are inside the vehicles to provide subjects information that do not benefit the driving safety can be called as Safety Impacting Systems. This designation impels to consider the consequences of the interaction with such devices while the vehicle is in motion once the impact on the driver behaviour can lead to negative outputs to safety.

From the users point of view both categories of IVIS can have several advantages as they bring the possibility to get extra information, to communicate with the "exterior world", i.e. to be linked with others that are outside the vehicle, and also to perform other enjoyable tasks (like watching TV or see a movie). This possibility of undertaking other tasks, weather or not they are related to the driving task and its safety, is the main reason to the development and utilisation of these types of systems.

Nevertheless, from the safety point of view, the importance and utility of interacting with each of these IVIS categories is not the same. Because the performance of additional tasks can compromise the road safety due to their capability of capturing attentional resources needed to the driving task (at least for brief moments), its possible impact on the road safety must be well known and documented. The nature of this impact can depend on several aspects like: the implementation mode of systems, the information available in such equipments, and also the type and specific characteristics of the devices used.

Once it is considered that some in-vehicle information systems can disturb driving by distracting, confusing and overloading drivers (as example see the work of Zaidel, & Noy, 1997) the nature of the driving task may be suffering considerable changes with the introduction of these new equipments. Therefore, it is important to understand its consequences on the drivers' performance in order to design the most adequate interfaces and to optimize the driving safety. Due to the advantages that these systems can bring, there is no turning back in undoing the introduction of new technologies inside vehicles. Hence, the challenge is to develop systems that provide adequate information so that drivers can readily comprehend it, without interfering with the driving task.

In order to accomplish the aim of this research, i.e. to study the impact of multiple visual and auditory inputs from IVIS on the driver behaviour and investigate the consequences of simultaneous inputs from more than one in-vehicle system, two different systems were chosen to be the focus of this work: a navigation system and a mobile phone. Each system belongs to a group of in-vehicle technologies: the navigation system can be considered as a safety enhancing system while the mobile phone is included in the group of the safety impacting systems. The reason why they were selected among other equipments was mainly due to their popularity amongst road users.

Mobile phone devices were introduced in car several years ago, still remaining nowadays. They allow subjects to communicate while driving; situation that is believed to happen quite frequently in several countries. On the other hand the use of navigation systems is increasing, being a frequent presence on board for many road users. The improvement of these guidance systems and their renovated form (portable/nomadic) are contributing factors to its crescent popularity and acceptability, being acquired by a higher number of drivers. For that reason, this research focused on the interaction with a navigation system and a mobile phone. Due to the fact that fewer studies analyzed the interference brought by several simultaneous sources of information, in the following paragraphs the problem will be address separately, i.e. the impact of those equipments will be discussed independently, in order to better understand each system and the possible consequences induced to the driving task.

2.1 Interaction With Mobile Phones While Driving

2.1.1 Introduction

The emergency of mobile phones and its rapid growth is an issue to which many authors have been investigating and writing about. Since its emergence it has suffered considerable changes and motivated several modifications on society. At the beginning, early models were very big and heavy once those devices included large battery packs and carrying cases. With the evolution of technology mobile phone became smaller, lighter, allowing also multitasking activities such as taking pictures, accede to the internet, communicate through e-mail, connect to others through voice-mail and also transmit computer files. In early years, mobile phones were mainly used for business purposes however its evolution induced to the utilization of a broader group of persons with different ages and different social and economic status. The higher use of such devices is also result of the widespread advantages that those systems brought in a variety of situations. Several benefits can be enumerated from the use of mobile phones, being some of them in situations where subjects are behind the wheel.

A focus group made by the Axion Research Company (reported by Lissy, Cohen, Park, & Graham, 2000) collected opinions from road users with the aim of understanding the major benefits identified for the mobile phone utilization. Respondents revealed that, concerning personal benefits, the use of a mobile phone could have some benefits like:

prevent unnecessary trips; diminish the tendency to speed specially when a person is running late; contribute to security and peace of mind (particularly when someone is lost); improve mental alertness on what might otherwise became a long and monotonous drive; facilitate privacy in communication mainly for people that are never alone because of their job; parental and familiar peace of mind by the fact that family can communicate while in traffic or in a dangerous situations; contribute to have more time at home by the fact that some phone calls could be made while driving instead of staying more time at the office; and can also increase coordination of social engagements. Moreover, for these focus group participants the use of mobile phones can also benefit peoples' business by expanding productivity through conducting personal or business maters while driving. There are also community benefits by improving knowledge of emergencies; enlarging the possibility to supply information to identify and apprehend criminals and contribute to decrease accident response time of emergency personnel.

The increased use of mobile phones occurred in the nineties, resulting in a higher number of subjects interacting with such devices in a variety of different places and situations. People started to use mobile phones not only at the office but also at home, in restaurants or even at the wheel. Some authors consider that the growing percentage of its overall use is strictly connected with an increased utilization of mobile phones while driving. Several studies made in USA found that 85-90% of cellular phone owners interact with these devices while driving and that only 10-15% of subjects never talks on the phone while inside a car (Goodman, 1997; Cain, 1999; Lissy et al., 2000). Furthermore, those investigations also indicated that in America 17% of the subjects using mobile phones at the wheel does it on most of the trips (Goodman, 1997; Cain, 1999). Personal Communication Industry Association (PCIA) in 1999 (as cited by Lissy et al., 2000) reported that this extent of use varies among owners: 15% do it for more that one hour per month, 35% between 60 and 10 minutes and almost 40% use it less than 10 minutes per month while driving. These data also indicated that the most frequent type of call lasted between 30 seconds to 2 minutes (per call), followed by calls that lasted less than 30 seconds.

Studies regarding the mobile phone use have been made based on the assumption that interacting with such devices while driving can contribute to increase the probability of road accidents, injuries and fatalities. In spite of the difficulty to prove that assumption through epidemiological works, due to several constraints related with data collection, some countries tried to quantify the number of crashes directly linked to the interaction with such devices. Statistics announced by the National Police Agency Traffic Bureau of Japan (as cited in Green, 2000) indicated that in 1997 the number of car accidents caused by the interaction with mobile phones was approximately 2000, while in 1999 it raised to 2500 accidents. Regarding the type of accidents occurred it was observed that the majority were collisions, having 41% of those accidents occurred when subjects tried to accept a phone call (Fuse, 2001).

Trying to determine the relationship between the use of mobile phones and the reported motor vehicle crashes, researchers in United States of America (state of North Carolina) analysed police reports belonging to 1989 and 1995. They found a positive correlation between mobile phone subscriptions and collisions; however they observed that the number of crashes had not increased in the same proportion as the number of cellular phone subscriptions. Due to this fact it could not be proved that the growth of the mobile phone use while driving contributed to the increased number of accidents (Lissy et al., 2000).

A more recent study, published in 2005 (Pöysti et al., 2005), had the aim of analysing the factors influencing the phone related decisions at two levels: a first one to determine the factors that induce drivers to use or not a mobile phone; and the second to discover which aspects predict a safe and appropriate use. Researchers collected opinions from 834 phone users with ages between 18 and 76 and results indicated that 81% of those drivers used their mobile phone in the car at least some times. It was also verified that young male drivers interacted with their phone more often than older female respondents. Subjects using their cars more often admitted to use the phone with higher frequently while driving, and drivers that consider themselves as more skilled were more likely to use that device at the wheel. Additionally, 44% of the sample admitted having had already a hazardous experience while using the phone in the past six month previous to the interview. The most common reported danger was a momentary lapse in attending to other traffic. Younger subjects (from 18 to 24 years old) were more represented in these types of situation, reporting having had hazard experiences eight times more often than the oldest drivers (more than 64 years-old) (Pöysti et al., 2005).

Besides the difficulty to establish a commonly accepted correlation between accidents and the mobile phone use, authors continue to affirm that mobile phone interaction while driving can induce to driver distraction, assumption made not only based on epidemiological studies but also due to results obtained in researches conducted in real and simulated environments. The earliest published investigation on the impact of mobile phone use while driving was conducted in 1969 by Brown, Tickner and Simmonds (as cited in McKnight, & McKnight, 1991). In this study authors simulated a hands-free mobile phone application and asked a sample of 24 males to drive a car on a closed circuit with approximately 2,4 kilometres. To complete the additional telephone task (a paced grammatical reasoning task) subjects had to decide whether a sentence was true or false and respond accordingly. Results form this study indicated that during conversation participants drove the car slowly, evidencing simultaneously some degradation on driving performance. When analysing the mobile phone task, experts found that performance was also reduced once decision times were longer and a high number of grammatical reasoning errors occurred.

In spite of being a pioneer study for the epoch, some authors identified limitations. The first one was the fact that speed was measured by the time that subjects took to complete the circuit. For Goodman et al. (1997) it was not possible to see a direct relation between conversation and speed because the longer circuit completion time could have be due to other factors besides the mobile phone task. It was also considered that the grammatical reasoning task was very difficult, probably more demanding than normal mobile phone conversations. Additionally, not having other vehicles on the closed circuit could have led subjects to consider that there were no serious consequences if an error or wrong judgment occurred. Besides the weaknesses pointed out to the research, this was an important first step to start the investigation on the influence of mobile phone conversations at the wheel.

2.1.2 Hand-Held and Hands-Free Mobile Phone Devices

Since the study of Brow and colleagues (in 1969, as cited in McKnight, & McKnight, 1991), other researches on the use of mobile phones while driving were developed with the main aim of understanding the consequences of receiving audio messages and also conducting a conversation. To accomplish this objective many authors have compared the use of mobile phones to other familiar situations like driving without performing any additional task; driving while conducting a conversation with a passenger; driving and listening to the radio or even compare with the performance of a driver under the effect of alcohol. In spite of the amount of possibilities to compare and study the interference caused by the use of a mobile phone, one of the first issues that have to be addressed is the nature of the task imposed by such interaction.

Experts consider that the use of the mobile phone while driving includes a number of sub-tasks that have to be classified. Brown and colleagues in 1969 (as cited in McKnight, & McKnight, 1991) had pointed out that mobile phone use can involve two distinct sources of interference: one source characterized by the manual-visual demand of dialling and handling the phone, and the other one regarded as the attentional demand of the communication task. Similar to Brown's idea is the one of Murray et al. (2001) who defends that phone tasks can be divided in two categories. The first one is related with the operational control of the telephone, which may take place in manual mode. It can involve "call placements, system menu action, numeric code entry, and other manipulations". The second is associated with the conversational engagement and it covers the driver's necessity to concentrate on the telephone discussion. Goodman et al. (1997) also defend that mobile phone use while driving can be characterized by tasks that include: accessing the mobile telephone (may include reaching for the phone or initiate a hands-free connection); dialling; voice communicating; and associated tasks (taking notes, look for a number in the phone, referencing a calendar or a map).

In this respect, one of the facts associated with the risk of using a mobile phone while driving is the type of equipment used. Early researches suggested that hand-held mobile phones are more dangerous due to the fact that drivers have to take a hand of the steering wheel to hold the phone. However, some researchers argue that the difference between hand-held and hands-free mobile phones is very small, specially while drivers are conducting a conversation, due to the continued presence of mental distraction (Cain & Burris, 1999).

Haigney, Taylor and Westerman (2000) conducted a simulator experiment with the purpose of investigate the extent to which cognitive versus physical factors are responsible for changes in effort. Thirty participants took part on this experiment and they were asked to complete four driving sessions: two using a hands-free and other two interacting with hand-held mobile phone equipment. Results showed that the mean heart rate was higher during the conversation period, compared with the pre and post periods of the conversation. Nevertheless, heart rate results were not significantly different for the phone type, leading authors to consider that this increase in heart rate during conversation was not directly related with the physical demands of holding the device. Moreover, the analysis of other variables revealed that the frequency of “driving off the carriageway” was higher when subjects talked on the hand-held mobile phone. These results led to conclude that, for this experiment, the negative effect of mobile phone usage was not reflected on the heart rate of the individuals but was particularly apparent for the driving performance (lateral control of the vehicle) when subjects interacted with the hand-held phone device.

More evident differences from simulator studies were observed by Burns, Parkes, Burton, Smith and Burch (2002). They quantified and compared the impairment of hand-held and hands-free phone conversations in a 15 Km simulated route. Results indicated that for hand-held situations, subjects’ performance was worse for the mean response time to warning signs, speed control (subjects drove slower than the instructed speed), and secondary task performance (more pauses in monologues and incorrect answers). Higher subjective mental effort was also attributed for the hand-held conversation. Thus, authors concluded that hand-held interaction with a mobile phone device influenced the performance on the driving task in a much more serious way.

Graham and Carter (2001) also conducted a study where participants had to perform a dialling task while driving on a simulator car. The 48 young adults had to dial in three types of phone interface: manual (with standard button phones); speech audio (speech recognition with auditory feedback); speech combined (speech recognition with auditory feedback plus visual display). Results indicated that dialling a number in the manual display caused an increase in tracking errors, a slowing down reaction time to peripheral targets and an increase in the mean number of crashes per minute. Subjective workload measurements also indicated higher ratings for the manual display. In their opinion, the study confirmed some finding of previous researches that indicated negative effects on driver's performance due to the physical, visual and cognitive effort induced by the manual use of a mobile phone. When these authors compared the voice with the manual dialling performances it was revealed that, in spite of the better results obtained by the voice dialling condition, some decrements could also be observed. Negative effects were expressed for the voice dialling when compared with the single task moments (only performing the driving task). For this reason authors suggested that the interaction with hands-free devices have reduced the risk but have not eliminated it.

Other studies show clearer evidences that the difference in performance between hand-held and the hand-free devices is practical inexistent. One example of that is the study conducted by Strayer and Jonhston (2001). Their simulated study was designed to analyse the effects of hand-held and hands-free conversations on the driving performance of 48 young adults. Measurements concerning a traffic light detection and reaction time showed no reliable differences between hand-held and hands-free devices, inducing authors to consider that the mobile phone negative influence didn't had any interference of marginal factors like holding the phone while talking. A similar opinion was expressed by other researchers like Consiglio and colleagues (2003) and also Strayer, Drews and Crouch (2004). For them, hands-free phones do not provide an advantage over the hand-held models because identical performance decrements were observed in conducted experiments. This happens because, even when using a hands-free device the attentional demand of the communication task is present. Additionally, these authors suggest that impairments in driving are due to the allocation of attention needed to process information from the mobile phone task; attention that is crucially necessary to drive safely. Thus, neither hands-free mobile phone devices nor voice-controlled interfaces remove the problem of driving performance impairment when using a phone while driving (Lamble, Kauranen, Laakso, & Summala, 1999).

2.1.3 Influence on Driver Performance

Besides the analysis on the influence of several mobile phone types, other studies tried simply to quantify the impact that these additional tasks impose to driving behaviour. Similarly to the already mentioned studies, the quantification is done throughout the measurement of several dependent variables, used to verify the consequences of dual-task performance. Nevertheless the diversity of variables, some are more frequent than another and have been commonly used in studies concerning the interaction with mobile phone equipments. An example is the reaction time to specific road events. Usually utilized in simulator studies, this variable measures the time that subjects take to react to an event, like for example a pedestrian that suddenly crosses the road or a traffic light that turns to red. The reaction measured can be related with the breaking or with other type of action that has to be performed to specific vehicle controls.

One of the earliest studies that measured reaction time of subjects was conducted by Alm and Nilsson in 1995. They studied in which way the reaction time of 40 subjects varied in a car following situation. Subjects were divided into two groups, each of one performing distinct conditions: a control group that drove in a simple traffic situation where no additional task was proposed and another group (experimental group) that drove while conducting a mobile phone conversation. During tests, critical situations occurred like a sudden break of the leading vehicle and also non-critical situations like a turn right manoeuvre of another leading car. Data analysis revealed that subjects in the experimental group (performing the mobile phone task) had longer reaction times compared to subjects in the control group. These results led authors to consider that accident risk can increase when drivers are using mobile phones in a car following situation as more time is needed to react to a critical event.

Other researchers confirmed this suggestion based on results obtained in other experiments. This was the case of Strayer and Johnston (2001) and their experiment concerning driver distraction. These authors aimed to determine the extent to which mobile phone conversations might interfere with the driving task and establish the precise nature of the interference. They realised that the phone conversation resulted in significant slowly breaking responses to a simulated traffic signal, representing this slower reaction a two-fold increase compared with situations where the phone was not present. This slower reaction time in braking was also testified by Consiglio et al., (2003) once they verified that while talking conducting a mobile phone conversation the reaction was slower in about 19%. Other results of longer reaction times were also confirmed by Patten, Kircher, Ostlund and Nilsson, 2004, Parkes and Hooijmeijer (2001), and also Graham and Carter (2001).

Responding to crucial events and crucial decision points was also analysed by Lesch and Hancock (2004). The researchers asked to 39 subjects to drive a vehicle in a closed-looped test track and analysed the behaviour of participants while approaching an intersection with a traffic light that turned to red in pre-determine moments. Trials were balanced to be performed with and without the additional memory phone task, and comparisons between both conditions expressed that in the presence of the mobile phone the break response time was slower by 0.18 seconds. Additionally, in that condition the driver stopped the car about 50% closer to the intersection and the success in stopping the car before the intersection line was reduced in 14%. Based on these results authors suggested that mobile phone interaction may induce to performance decrements that could lead to serious outcomes.

Another expressive outcome was obtained by Strayer and colleagues in 2004. For this experiment driving while talking on the phone was compared with driving with a high legal level of alcohol concentration on the blood. Surprisingly, data revealed that while conducting the phone conversation, reaction time values were higher when compared with the situations where drivers were “intoxicated”. This means that, while at the phone, subjects reacted in a less efficient way than when under the effect of alcohol. This result is also confirmed by Burns et al. (2002) in a similar experiment. Reaction times were significantly slower for drivers using phones when compared with situations where they had high concentrations of alcohol in the blood.

Reacting to a specific event implies that the subject actually sees the event; otherwise the expected reaction will not take place. This accuracy in what concerns observing the events that occur in the surroundings was also studied by some researchers. Due to some obtained results, certain authors defend that in situations where the mobile phone is present, subjects can pay less attention to the environment and consequently extract less information from the road (Drews, Pasupathi, & Strayer, 2004). For this reason the number of missed events can increase, like when a target should be verified and, due to the distraction caused by the phone conversation, it's not spotted (Burns et al., 2002; Strayer, & Jonhston, 2001).

A study conducted by Nunes and Recarte (2002) tried to provide evidences to support that the interference caused by an additional task should be attributed to its cognitive component. To accomplish that aim, 12 participants were asked to drive a real vehicle in different conditions that included driving without additional tasks and while talking on a hand-free mobile phone. The visual behaviour of participants was analysed throughout the measurement of fixation coordinated, fixation duration, pupil size, blinking rate and blinking duration. The analysis of the speedometer and mirrors inspection frequency was also verified. Results revealed while the phone task was present, there was an increment of the subject's pupil size, an increase on the blinking rate, and also a slight mean gaze shift upwards. It was also registered a spatial eye concentration, meaning that the percentage of time spent looking to the centre of the visual field (road immediately ahead) was higher. This higher spatial gaze concentration is confirmed by the data from the mirrors and speedometer inspection that suffered a considerable reduction. Moreover, in another experimental moment these researchers asked participants to perform a detection task, i.e. subjects had to push a button installed closer to the steering wheel in the case of seeing flashing light spots in their visual field (flash light spots electronically introduced in the experiment). Results showed that mental tasks from the mobile phone interaction produced decrements in the proportion of detections, meaning that a higher mental workload can induce drivers to fail to detect visual information from the surroundings.

Other experiments exposed that mental tasks brought by mobile phone tasks can not only induce to a failure in information detection but also induce to augment the number of errors. These errors can be expressed by inadequate response to signs (Burns et al., 2002), or other tracking errors like driving out-of-lane (Grahham, & Carter, 2001; de Waard et al., 2001). In fact, the lateral position of the vehicle is another variable frequently analysed, mainly in simulator studies. Nevertheless, this variable does not always express statistically significant results in what concerns the performance of a secondary task while driving. In their already mentioned study, Alm and Nilsson (1995) investigated the consequences on the lateral position of the interaction with a mobile phone. Results revealed no significant differences between the control group and the experimental group (that conducted a mobile phone conversation). More recently Parkes and Hooijmeijer (2001), that conducted an experiment with the objective of studying the driver performance of subjects in a simulated road environment with and without a phone conversation, also measured this dependent variable. Similarly, these authors revealed that the analysis of the standard deviation of the lateral position expressed no significant values between both conditions.

Haigney et al. (2000), with the purpose of investigating the changes in effort allocated to the task performance, analysed the lateral position of the vehicle throughout the measurement of off-road excursions. Thirty participants were asked to drive a road simulator with a hand-held and a hands-free mobile phone, being their performance while making a mobile phone call subdivided in three phases: pre-call, during-call and post-call moment. Results revealed that when all the moments were considered, participants revealed more off-road excursions. However, when a closer look was given to each separate moment, it was expressed that this variable did not change in the during-call periods. Thus, it was suggested that higher changes in vehicle lateral position can be seen for tasks with highly visual and manual demands (like dialling a number or even ending a call) but probably can not be expressed for conversation moments. Higher values for lateral deviation were also obtained for manual dialling tasks in the study of Salvucci and Macuga (2002).

Analysing the speed while conducting a mobile phone conversation was also objects of measurements in several researches. Results obtained from the comparison of single and double-task situations showed a speed reduction while drivers were engaged in mobile phone conversations. This was the case in an experiment designed by Haigney et al. (2000) where the analysis of driver’s behaviour indicated lower mean values of speed while interacting with mobile phone units. Similar results were achieved by Burns et al.

(2002) and also by Shinar, Tractinsky and Compton (2005). Patten and colleagues (2004) verified the mean speed in an on-road study in three different conditions: without any additional task (baseline condition); while interacting with a hand-held mobile phone, and with a hands-free device. Results showed a significant effect of the phone modality on the mean speed of each course. The mean speed while interacting with the hand-held equipment was the lowest of all conditions, whilst the values obtained for the hand-free phone were the greatest.

In many cases, the measurements obtained for this variable are seen as compensatory behaviours and an attempt to reduce the mental workload imposed by the additional tasks. Some authors believe that subjects adopt reduced speeds as a way to maintain control of the situation, or to keep the driving into safety limits (Haigney et al., 2000). If lower mean speeds can somehow be expressed as a consequence of higher mental workload, results mentioned by the previous studies can suggest that talking on the phone while driving imposes higher efforts than driving without an additional tasks and, moreover, interacting with a hand-held mobile phone can induce to even higher allocations of resources.

This speed reduction can happen even when participants are instructed to maintain a determined speed. It was already observed that their tendency can be to slow down the vehicle when interacting with a mobile phone, being this tendency even greater when the pre-determined required speed is higher (Shinar et al., 2005). Another event observed by Strayer et al. (2004) showed that, when talking on a mobile phone subjects can take more time to recover their speed after a breaking situation. This was confirmed by their study, where after a speed lost due to intensive breaking, subjects that were at the phone were 14.8% slower to reach over the pre-determined speed of the course.

The nature of the conversation is also a very important aspect that can, by itself, influence in different ways the performance of drivers. This aspect was object of attention in several researches, being considered as an important matter than can determine in which extend the conversation can influence the driving performance. Additionally, the degree of involvement in a determined conversation as well as the active contribution of subjects was already main theme of research.

A particular study recorded the performance of drivers in two distinct situations: when subjects were talking and when they were just listening. Results indicated that, in spite of the disruptive effects on both situations, negative consequences were greater when participants were talking than when they were listening (Strayer, & Jonhston, 2001). At the same experiment 12 young adults were asked to perform different tasks while at the phone: a shadowing task (to repeat the words that the experimenter was reading) and a word-generation task (to generate a new word that began with the last letter of the word read by the experimenter). Authors found out that the word-generation task produced significantly higher decrement in driving performance, being these effects specially pronounced when the course had a higher level of difficulty. This difference regarding the complexity of tasks was also evidenced by Nunes and Recarte (2002) when they asked participants to perform two distinct types of conversations: a simple and trivial low demanding conversation; and another high demanding phone conversation with space imagery contents, memory and arithmetic calculations. Results revealed that the low demanding phone conversation produced null or very small effects on the behaviour of participants while high demanding phone conversations affected them significantly.

Shinar et al. (2005) also studied the effects of different mobile phone conversations when they designed an experiment where two types of secondary-task were imposed to drivers: arithmetic calculations and emotionally involving conversation. Results showed that a maths operation “is a much more difficult task, as reflected in the poorer performance of the driving measures. An emotionally involving conversation is much less disruptive to driving than math operations, and in the case of many driving measures, it appears to be non disruptive at all” (compared to driving without distractions). Those authors also concluded that the difficulty of conversations is one of the factors that, combined with others (like for example higher speeds, lower experience and higher age), can increase the effects of distraction.

Besides all the visible consequences that can be reported in an experiment, one important variable must also be considered when conducting a study that aims to verify the consequences from the interaction with a mobile phone: the driver subjective analysis. Self-report measurements are very often considered when conducting a test, once the opinion of participants are utilized for several purposes like: categorize the effort imposed by a determined task; corroborate with the other types of measures; or even to contradict results given by other variables, evidencing some aspects that could not be determined by other means. Subjective mental workload methods are frequently used in experiments to evaluate in which conditions the effort felt was the greatest. Fussel et al. (2002) asked their participants to perform a task in which they had to make hotel reservations using a cellular phone with WAP (wireless application protocol) service. They were instructed to compare their performance in two different conditions: while seated in a usual chair outside a vehicle, or driving in a car simulator. Subjective workload ratings were registered in both situations and results revealed that participants reported higher workload levels in the driving condition (the dual-task situation).

In fact, dual-task performance situations were also reported in other experiments as more difficult (see Luke et al., 2004; and Mathews, Legg, & Charlton, 2003). Alm and Nilsson (1995) compared driving with and without the presence of a mobile phone conversation and verified that participants rated the mental workload as higher while talking on the mobile phone. Similar results were revealed by Burns et al., (2002) however additional conclusions were obtained from the type of device used. The comparison between the hands-held and hands-free devices evidenced that interacting with hand-held mobile phones gathered higher levels of difficulty and reported effort.

In sum, several are the experiments that have been conducted in order to analyse the influence of mobile phone interaction while driving. As it was explained, several evidences showed that talking on the phone while driving can affect the time needed to react to a critical event, induce to a non detection of important road environment information, or alter the capacity to control the vehicle in terms of lateral or longitudinal direction. Furthermore, it is also important to refer that these consequences are not always verified because they can depend on several aspects like: the type of conversation, the involvement of the driver and also on the complexity of the road environment and specific performed tasks.

2.2 Interaction With Navigation/Guidance Systems While Driving

2.2.1 Introduction

Driving in unfamiliar roads is a difficult and complex task that demands the driver to focus his/her attention on the driving task and, at the same time, to guide him/herself throughout an unknown course. For this reason, driving in such conditions can be considered as a task where divided attention is needed once the time is shared between the guidance and manoeuvring tasks (Summala, 2000). In moments like these, planning and selecting the routes in advance are extremely important activities. When it is not given opportunity for drivers to plan their course efficiently, they can get stressed, frustrated and adopt potentially unsafe behaviours to get to the desired destination (Ross, & Burnett, 2001).

In the last decades, with the introduction of new technologies, several systems have been developed with the main aim of present to drivers useful information for their navigation. Once navigation can be described as: “to achieve movement through a space” (Lee, Forlizzi, & Hudson, 2005) these systems can help drivers to travel throughout unfamiliar places and avoid making deviations from the wanted course (Brooks, Lenneman, George-Maletta, Hunter, & Green, 1999; Burnett, 2000).

To accomplish this task, systems can transmit guidance instructions in strategic decision points (Ross, & Burnett, 2001) so drivers can make a more efficient use of the road network (Jeffrey as cited in Burnett, 1998). In a broader way, the advantages obtained by their use include preventing drivers to get lost, and if traffic information is available, prevent them to travel through congested roads (Brooks, Lenneman, George-Maletta, Hunter, & Green, 1999). As a consequence to the presentation of other route options, these systems give the possibility of more equal distributions of the traffic through the transportation network, helping to solve quite a lot of congestion problems in several cities around the world (Jackson, 1998). Additionally, they can also contribute to a decrease in the consumption of fuel and to a decline in the release of pollutant gases (Adler, & Blue, 1998; Jackson, 1998; Jeffrey as cited in Burnett, 1998). The use of these equipments can also augment the confidence and security of road users, once they can receive useful instructions to avoid or outline dangerous situations (Adler, & Blue, 1998; Pauzié, 2003; Brooks, Nowakowski, & Green, 1999; Burnett, 2000).

In order to make the navigation possible, theses systems provide updated information about the place where the vehicle is at, offering also guidance instructions to select the most adequate roads. The information supplied can have different features, and be transmitted in different modes in order to guide the driver to the destination. Some of these systems are also capable of transmitting on-line information about traffic jam, to calculate the time needed to complete the course, or notify about incidents or other kinds of malfunctions on the road (Pauzié, 2001).

Some years ago, navigation systems could be characterized as being an electronic help that offered the driver several kinds of information upon request (Schraagen, 1993). Two main alternatives began to develop: equipments that displayed a map which could give current location of the vehicle as well as the destination position; or a display that used symbols or voice instructions. With the development of these equipments and also the increased variety of systems available in the market, these two groups of systems received different denominations: Navigation Systems and Route Guidance Systems. Navigation Systems are considered as passive systems due to the fact that they do not provide route guidance information, offering only "geomatic information" (Zaidel, & Noy, 1997). They usually display a digital map on a screen that might highlight a route, the current position of a vehicle and the destination point (Daimon, Kawashima & Akamatsu, 1997). With this information, drivers are expected to actively make their own navigation decisions at each intersection in order to get to the destination (Pauzié, 2000).

On the other hand, Route Guidance Systems are able to calculate the best route to follow, based on specific criteria. The suggestion of a course is given through specific instructions, also named as route guidance information, being these messages considered as important and useful to guide the driver (Daimon, Kawashima, & Akamatsu, 1997; Zaidel, & Noy, 1997; Pauzié, 2000).

Besides this systems' classification based on the type of the information transmitted, they can also be classified in a different way: those fitted as standard to the vehicle and the nomadic devices. Devices fitted as standard to the vehicle are originally installed in the car, meaning that when the driver buys the car the navigation systems is already in it. There are also some options that allow drivers to include a system afterwards; however theses aftermarket navigation devices are professionally installed and can only be used inside the vehicle.

Contrarily, nomadic systems are generally introduced inside vehicles by their own drivers and one of the characteristics that distinguish this type of system is the fact that they can be used for besides the driving context (Pauzié, 2005; Thomson, 2004). They can be activated in different situations and with different aims because these equipments can include also mobile phone functions, access to the internet, and electronic agenda, among several other utilities. This multifunctional capacity can be faced under a negative perspective if it is taken in to consideration that these utilities can be acceded while driving, being a potential distracting factor for subjects.

Concerning the man-machine interaction in a road environment, nomadic systems are similar to systems fitted as standard to the vehicle as they allow the transmission of audio and written messages that can help drivers guide themselves through the road network (Pauzié, 2005). However, the way they are positioned and attached inside the vehicle can be considerably different. Unlike the fitted as standard systems, nomadic devices are placed according to drivers' wish. This aspect can foresee two problems: the first is related with the proper positioning of the system and consequently with the efficiency on the acquisition of messages; the second is a safety concern as in case of accident the system can be loose and hurt the driver (Pauzié, 2005).

Besides the potential distracting effects of navigation and route guidance systems, there are few data indicating their direct relation with the risk of crash. Statistics of accidents related with the interaction with Intelligent Transportation Systems are not abundantly documented in United States or Europe. However in Japan information was already collected for mobile phones and navigation systems (Green, 2000; Green, 2004). The Japanese National Police Agency Traffic Planning Department gathered data for several years and their statistics identified mobile phones and navigation systems as being the causal or contributing factor for some crashes. This correlation was made with the help of narratives provided by drivers involved in crashes (Green, 2004). According to this information, in 1997, the navigation system-related crashes led to 117 injuries and 1 death. In 1998 caused 131 injuries and 2 deaths and in 1999 it induced to 205 injuries and 2 deaths. In order to contextualize this number it is also important to consider that the diffusion of navigation systems in Japan market is very high, different from any other country in Europe or in United States. Additionally, experts reveal that the number of drivers possessing such devices is increasing, being the cumulative numbers of navigation systems 2.4 millions, 3.5 millions and 4.7 millions in the end of 1997, 1998, 1999 respectively (Green, 2000; see also Burnett, 1998).

Due to these potential distracting effects, the design of guidance and navigation systems is of major importance. A proper design can truly help drivers, not inducing them to adopt risky behaviours that can endanger them and the other users of the road network (ESop, 2005). It is vital that appropriate information is supplied when and where is needed in order to avoid excessive allocation of the driver's attentional resources to the guidance task. Knowing that a distraction can happen during the introduction of a destination or while receiving navigation or guidance information, several investigators have been accomplishing several researches with the aim of study different types of interaction. In spite of the recognized importance of researches related with the entering destinations tasks, this issue will not be addressed in the present study once it is not part of the global aim of this work. Concerns will only be focused on the situations where the driver receives information from the device, leading other types of interaction apart from the discussion.

After entering a destination, the system calculates the most adequate course in order to present to drivers the needed information to reach the desired place. Several modern systems can calculate the course based on some specific criteria like: the shortest time, shortest distance, the maximum use of motorways or even avoid certain types of roads. The way in which information can be transmitted to drivers can also vary among several systems: it can be sent visually throughout a display; by auditory messages; or even both ways (Ross, & Burnett, 2001; Tijerina et al, 2000; Srinivasan, & Jouvanis, 1997). In what concerns the visual information, systems can present information using graphics, symbols or even written messages (Ross, & Burnett, 2001; Huska-Chiroussel, & Magalhães, 2002). Among the used systems, some display maps in two or three dimensions (2D or 3D) and can be named as electronic maps. Other frequently used devices present information by means of symbolic messages, like for example arrows. Theses symbols indicate each turn or manoeuvre that the driver has to perform, being also presented other types of information like, the distance to the next turn and the names of the streets (Ross, & Burnett, 2001). They are included in the "Route Guidance Systems" category and can be commonly named as "Turn-by-turn" systems.

In order to investigate the relevance and the efficiency of the type of information presented in navigation and route guidance systems, authors have been examinating which are the best ways to present information without impairing the driving task performance.

2.2.2 Traditional and New Navigation Methods

Maps, usually seen as a universal way of communication apart from language or culture, were defined in 1987, by Harley and Woodward in their book "The History of the Cartography"(as cited in Edson, 2001), as "graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes, or events in the human world". This concept does not consider maps as objective representations of physical world. Instead, includes all human documents that try to make a schematic representation of something, showing how things are arranged or related with each other. Maps are never a realistic representation of the world, in part because there are always errors of accuracy and precision during measurements, and also due to the fact that photographs and satellite images represent only certain parts of the light spectrum (Olson, 1993). A map can also be considered as a product of human endeavour of geographic reality and to reach a graphic representation, there must be a mental conception of it.

Maps have the aim to provide information on the existence, the location, and the distance between two places. There are several types of maps and they can be classified in distinct ways: by content; form; displayed technology; production technology; scale; resolution and other characteristics used for classification (Davidson, 2003). In this sense, paper maps and electronic map-based systems represent two types of maps that have different display technology and are still frequently used to guide drivers through unknown areas.

With the introduction of electronic devices inside vehicles and also with the possibility of being the main substitutes of paper maps, investigators started considering important to ensure that consulting such equipments should not interfere with the driving task. For that reason early studies compared paper maps with other forms of guidance information and observed main differences on the performance of drivers. Results indicated that interacting with a traditional paper map led to longer journey durations (Burnett, & Joyner, 1997), increased heart rate variability and induced to worse levels of subjective evaluations (Burnett, 1998; Daimon, & Kawashima, 1996). Contrarily, in spite of paper maps have obtained negative results in determined variables, other investigations revealed that no significant differences were observed between both methods. An example is the study of Wierwille and colleagues (as cited in Green, 2004) that found no major differences in what concerned the lane exceedences and the break behaviour of participants. Nevertheless, authors agree when suggesting that some cautions must be taken for the utilization of electronic map-based devices. They believe that such devices can induce to higher percentages of time looking to the on-board display and, as a consequence, decrease the time directing the gaze towards the road environment (Wierwille et al. as cited in Green, 2004; Daimon, 1996; Burnett, & Joyner, 1997).

Other aspects of the comparison of paper maps with navigation systems still remain contradictory, like for example the number of navigation errors. Navigation errors, which happen when the driver miss to follow the instruction given by the system, were observed as being more frequent when drivers interacted with paper maps (Srinivasan, & Jouvanis, 1997). Nevertheless, opposite results were verified in Burnett and Joyner's study (1997). This last study indicated higher number of navigation errors made when the interaction was performed with a moving-map system. The explanation for this contradictory information relies probably on the type of navigation systems used and in the accuracy and simplicity of the information sent by electronic devices. Burnett and Joyner (1997) found out that some characteristics of the information presented on the in-vehicle display caused serious difficulties to the guidance task of subjects, leading them to get confused and to perform more navigation errors.

In fact, the type of information presented in electronic devices makes all the difference and can determine the real advantages from old guidance methods. Some improvements allegedly brought by electronic map-based systems are not seen as a positive aspect by all investigators and the development of other in-vehicle systems proved that there are better ways to guide drivers to a destination. With the development of systems that present information under the form of simple pictograms and easily understood symbols, new comparisons and new results were obtained.

One example is the study accomplished by Wochinger and Boehm-Davis (1997) that sowed the performance of 28 drivers in two different conditions: while interacting with a paper map and with a turn-by-turn system (a device that displayed arrows indicating the direction in each manoeuvre). Better results were revealed for the turn-by-turn system in terms of navigation errors and decision times, leading authors to suggest that using a route guidance system can be much better than using a paper map. This can be justified by the fact that such guidance displays only present relevant messages for the accomplishment of the manoeuvre, eliminating all irrelevant information for that moment (Burnett, 2000; Burnett, & Joyner, 1997; Wochinger, & Boehm-Davis, 1997; Dingus et al., as cited in Young et al., 2003). Other studies corroborate with these findings indicating that paper maps could not only lead to higher navigation errors but also induce to slower driving speeds, which can be seen as a consequence of higher levels of mental workload (Burnett, & Lee 2005; Srinivasan, & Jouvanis, 1997).

With maps drivers can experience greater difficulties in guidance once they cannot apprehend from the environment all the important information needed (Burnett, 1998). Such situation can lead to a higher time to accomplish the course, like it happened in

Burnett and Joyner's study (1997) and Burnett and Lee's (2005). Due to these facts, authors suggest that using an adequate guidance system with simple and effective information is better than using a conventional map because they can help drivers in a more efficient way (Daimon, & kawashima, 1996; Burnett, & Joyner, 1997; Srinivasan, & Jouvanis, 1997; Wochinger, & Boehm-Davis,1997; Burnett, 1998; Dingus et al. as cited in Young, et al., 2003).

2.2.3 Route Guidance Systems

In spite of certain reported advantages to the use of maps in specific situations, its value is not consensual for all the driving moments. Maps can provide an overview of the route and surrounding area, and help drivers to previously plan the course, being for some drivers the preferred guidance method (Burnett, 2000). However, some investigators consider that there are better ways to send information to subjects when performing the driving task because spatial information can be very difficult to capture and interpret.

As it was already mentioned, in the last decade new forms of transmitting information and guiding the drivers emerged, not only as a consequence of the development of technology and knowledge but also as a way to compensate for the negative aspects that electronic maps could bring. In order to verify if new guidance systems are a true help for drivers, several researches have been conducted comparing the influence of navigation and route guidance systems on the individuals' driving performance. One of the first studies was accomplished in 1995, by Dingus, McGehee, Hulse, Jahns and Manakkal (as cited inYoung, et al., 2003). They compared four different systems: turn-by-turn guidance device with and without voice instructions and an electronic map also with and without voice messages. Results indicated that electronic map without voice instructions created high visual demand once it induced drivers to look longer to the display. This system also led to more braking errors and more lane deviations. The condition where drivers had better performance and less perceived mental workload was when using the turn-by-turn system with voice guidance instructions. To conclude, authors suggested that presenting turn-by-turn messages is more adequate then complex holistic route information because they are less distracting and induce to lower driving performance decrements (Dingus, et al. as cited in Young, et al., 2003).

In fact, route guidance systems are seen by many investigators as more adequate because it is believed that they induce to less dangerous behaviours. Brooks, Nowakowski, and Green (1999) also conducted a study where it was possible to compare the interaction with navigation and route guidance devices. On this on-road experiment, the vehicle had two display units mounted on the dashboard, one in each side of the steering wheel. One system had turn-by-turn messages and the other presented a route map indicating the way to a specific destination. During the test both map and guidance messages were shown at the same time, together with a voice message. When analysing the outputs, authors observed that drivers looked significantly often to the turn-by-turn display and that this frequency was even higher when the turn-by-turn system was positioned at the right side of the wheel (to be consider that this experiment was made in USA where the wheel is on the left side of the vehicle). When drivers were questioned about the reasons for that behaviour, the majority indicated that the turn-by-turn display was used more frequently because it contained the most useful information like the distance to next turn, the turn direction arrow and the name of the next road. For this motive, drivers relied primarily on the route guidance display (Brooks, Nowakowski, & Green 1999).

Instructions should be kept as simple as possible so that subjects don't feel uncomfortable or confused by receiving too much information at a time (Daimon et al., 1997). A road-based study explored the differences in some systems displays and concluded that for more complex visual displays drivers have to make longer and more frequent glances towards that screen. However, it was also revealed that subjects made more navigational errors when using the simple visual displays in more complex manoeuvres. Based on these results, authors indicated that choosing the type of graphics to present instructions is a very important matter to which should be given considerable attention (Dicks et al. as cited in Burnett, 2000). Generally, symbolic-based systems (like route guidance systems) are believed to be preferable than map-based displays because they can induce to better performance in terms of navigation errors and better levels of subjective evaluation (Schraagen, 1993; Burnett, & Joyner, 1997). An important aspect relies on the fact that symbolic based systems reduces the visual cost as they are less complex and induce to fewer time needed to apprehend important information (Burnett, & Joyner, 1997). More complex messages can induce to higher portion of visual resources allocated towards the system and, as a consequence, reduce the attention given to the road ahead and to other important elements like rear-view mirrors (Graham, & Mitchell, 1997).

Nevertheless, as it was suggested by Dicks and colleagues (as cited in Burnett, 2000), optimal solutions must also be found regarding the specific context in which the instructions are sent. Some degree of flexibility should be considered due to two reasons: the first one is concerning the different drivers' preferences; and the second one relies on the dissimilar needs of information dependent of the type of road environment. Nowadays, systems allow different forms of information, being possible to choose between a map view, a turn-by-turn view or even both at the same time. This outcome is justified by some evidences that indicate different preferences of drivers that can be related with their distinct driving experience or gender. For instance, males are considered to have a greater preference for using spatial information than females (Burnett, 1998). Thus the possibility for drivers to choose their optimal information must be considered as a consequence of different preferences and experiences in order to induce to the most adequate interaction.

This variety of instructions is useful also to be used in different types of road environment situations. Results from some surveys pointed out two different needs of information depending on the surrounding environment. A questionnaire made to 200 experienced drivers indicated that, in faster roads (like carriageways and motorways), formalized information like place names, road numbers and junction numbers are considered more suitable. However, in urban roads, drivers perceive a higher need for informal and context-based information, like for example landmarks, road layout and street names (Burnett, 1998). Schraagen (1993) also observed that some subjects mentioned preferred turn-by-turn arrows while driving on urban roads.

2.2.4 Voice Instructions

As it was mentioned earlier, navigation and route guidance systems can send information to drivers throughout visual messages. However, messages can be sent using other forms. For instance, when a passenger indicates the course to a driver, usually he/she uses voice instructions in order to guide the driver to the wanted destination. Some years ago, this idea of voice instructions was adapted and included in on-board electronic devices and since then several studies have been conducted to find out the real consequences of this type of instructions.

In 1985, Streeter and Vitello (as cited in Höök, 1998) conducted a study where two distinct systems were compared: a map and a device that transmitted only voice instructions. After subjects completed the experiment, the analysis of the results indicated that drivers who used the voice instructions arrived to their destination faster, travelled less miles, and had 70% less navigation errors than the drivers that used the map. As a consequence, authors suggested that messages presented through voice are more appropriate to help drivers in their guidance task.

Five years later, it was argued that using only voice instructions could be a disadvantage and more demanding than using other types of messages, like for example symbols in the form of arrows. Voice messages were mentioned as not adequate because they did not last through time and were only present to drivers for a short period. Drivers could forget easily the instruction or even not be able to listen to it if there was too much noise. As a consequence Parkes conducted a study with Coleman, in 1990 (Parkes, & Coleman as cited in Höök, 1998), with the intention of comparing the driver performance in three different situations: a first condition where symbolic information was presented; another one with written verbal instructions; and finally a condition where only auditory messages were transmitted. Results of this simulator study showed that drivers took less time to conclude the tasks for the auditory conditions and this situation was also considered as being the favourite one. However, it was also verified that this situation was not the one with lower percentage of navigation errors. For this reason, authors suggested that voice messages could be the best way to give instructions to drivers, though visual information should also be presented to provide an even better guidance task.

Despite the clear advantages of the auditory messages, there are also some advantages from the use of visual information. With a visual modality, drivers can choose when to glance away from the road scene to look for information. This is also the most adequate way to explain more complex situations, which can not be easily described throughout voice instructions (Burnett, 2000). The idea of combining these two types of information are considered the best approach to send a message. Auditory information could bring several advantages however its positive effects are more obvious with simple visual instructions (Zaidel, & Noy, 1997).

In fact, the presence of voice guidance instruction is believed to be critical for a safer use of navigation and route guidance systems. The most evident benefit relies on the assumption that drivers are not forced to look so frequently to the display in order to get some guidance information. This less visual demanding situation contributes to less time looking at the display and, consequently, more spear time paying attention to the surroundings (Burnett, 2000). The comparison of a voice instruction route guidance system with similar systems without voice interface showed some differences in visual behaviour of subjects. For example, when drivers approached intersections (over the last 200 meters) the glance frequency increased much more when the system didn’t possess voice output (Burnett, & Joyner, 1997). Glance frequency inside the vehicle and also mean glance durations can also be lower when using voice systems (Zaidel, & Noy, 1997).

Besides contributing to a decrease in the visual resources allocated to the guidance task, it is also believed that voice instruction can induce to less navigation errors (Burnett, & Joyner, 1997; Srinivasan, & Jouvanis, 1997), less time to understand display instructions (Tijerina et al., 2000; Zaidel, & Noy, 1997), fewer values of lateral deviation, and lower evaluation on the perceived workload (Tijerina et al., 2000). In fact, when it comes to subjective evaluation, several investigations have indicated that participants attribute a more positive opinion to systems with voice interface (Burnett, & Joyner, 1997; Srinivasan, & Jouvanis, 1997; Zaidel, & Noy, 1997). Additionally, high travelling speeds while interacting with voice systems are another aspect that induces some authors to suggest that such messages are able to reduce the cognitive demands of drivers (Srinivasan, & Jouvanis, 1997).

In spite of auditory instructions being considered as adequate to send information, leading to better driving performances, some researches pointed out that these outputs have to respect some requirements. If messages are not adequate or presented in appropriate moments, they can increase the driver's mental workload (Wiese, & Lee, 2004), and decrease the subjects' performance on the driving task (Jackson, 1998). Furthermore, some results from Srinivasan and Jouvanis' study (1997) revealed that some participants found the audio messages irritating and considered important having the opportunity to turn them off.

Due to this possible lack of adequacy and acceptance that may occur, it is considered that voice messages sent by route guidance systems must have some specific characteristics. Some of these features have been studied and as a consequence some guidelines are highlighted by researches. One of these features regards the type and intensity of the sounds sent by the system. It is said that voice messages should not cover important auditory information coming from the road environment (ESoP, 2005). Furthermore, drivers must have some control over that information, like for example the possibility to control the volume and turn it off whenever necessary (ESoP, 2005). Repeating instructions is also considered as important once the replication of messages at appropriate moments is consider to improve the efficiency of the information detection, reducing also the demands on memory in order to recall the needed information (Höök, 1998).

Specifications for the moment to send voice instructions deserve also important considerations. If messages are presented too early there could be a higher and unnecessary demand placed on the driver's memory, inducing additional glances towards the display. However, if messages are presented too late other undesired and unsafe driver behaviours can occur to compensate this latter reception of information. Empirical research on this area shows that the use of distance as the only criteria for sending the information to drivers before a specific manoeuvre is not enough and some times even inappropriate. The vehicle speed should also be considered for calculating the most adequate timing for the voice instruction (Burnett, 2000). Based on this fact, a simple equation is referred by Ross and colleagues (as cited in Burnett, 2000) as a predictor to define the adequate moment to send voice information. These authors conducted a road-based study and asked subjects to give subjective ratings of the timelines of auditory guidance instructions as they approached an intersection. Based on these rating, regression lines were developed leading to a series of equations. The most adequate was selected as being the following: speed (Km/h) X 2.222 + 37.144. Taking into account this equation, if a driver is travelling at 80 Km/h, the preferred maximum distance for sending the audio information is approximately 215 meters before the manoeuvre.

2.2.5 Position of the Display

Besides the type of information sent to drivers, the place where visual messages are showed is also crucial to an efficient apprehension of the guidance information. There are strong evidences indicating that drivers are unable to detect events like the brake lights of heading vehicles or pedestrians that appear suddenly, when looking at an in-vehicle display, specially if the display is located in a low position (Burnett, 2000).

Gish and Staplin (as cited in Hooey, & Gore, 1998) made a literature review and gathered the studies that focused on the most adequate displays to send information to drivers. These authors found out that the called "Head-up-Displays" (HUD) had the potential to improve the performance of drivers while accomplishing a secondary task, and also to increase its safety. These systems, usually placed on the upper part of the dashboard of the vehicle, near from the centre of the driver's field of vision (Hooey, & Gore, 1998) can have the advantage of minimizing the required eye accommodation when drivers change their focus from the road to observe images on the displays (Watanabe et al., 1999). When using a HUD, drivers don't have to move their heads to see the messages and as a consequence, they get more time to look to the road ahead and respective surroundings.

Hooey and Gore, in 1998, conducted an investigation to find out if the presentation of messages in HUD had a worse influence than those showed by “head-down-display” (HDD). In both systems “turn-by-turn” messages were presented at specific moments. Through the evaluation of the vehicle speed, lane position, steering wheel angle and number of collisions (simulated, once the experience occurred in a simulated environment) authors suggested that interacting with a HUD does not induce higher distraction than using a HDD.

Although many authors consider that the presence of in-vehicle messages can be dangerous and induce to driver distraction Watanabe, Yoo, Tsimhori and Green (1999) also consider that HUDs are the best solution. In their simulated study they discovered that the reaction time to critical events was not significantly affected by the use of a “Head-Up-Display”. Messages displayed in the centre of the drivers’ field of vision, or in a near position, were considered as the best place to detect a message, gathering also consensus in what concerns the preferences of some drivers (Watanabe et al., 1999; Tsimhoni et al., 2001). Thus, this message location is believed to induce to better driver performance while carrying out a secondary task (Burnett, 2000; Tsimhoni et al., 2001; Horrey et al., 2003; ESoP, 2005).

3. Ageing and ITS

Every year, more and more Intelligent Transportation Systems are introduced into the market. It is believed that these systems have the potential to change the driving experience, both in a near and far future, by promoting driving safety, the efficiency of trips, and also increase the drivers’ comfort (Green, 2001). Specially in what concerns In-Vehicle Information Systems (IVIS), the concept of providing real-time information to increase safety and improve mobility is very appealing. As it was already mentioned this technological progress have several advantages: they are capable of providing information regarding the access to roadways, the congestion levels in roads ahead, the existence of accidents, the potential alternative routes and also inform about which routes may be used to reach a specific destination (Stamatiadis, 1993). However, in some authors’ opinion, the mainstream motor industry has largely ignored an important group of drivers during this technology evolution and also in the process of the systems design: the elderly drivers (Harriots, 2005). As many transport technologies target drivers in private vehicles because cars are the dominant mode of transport and a high value consumer good, much more attention should be given to this driver group that has been increasing considerably. Meyer (2003) considers that "the face of ageing is rapidly changing". Nowadays, an increased number of elderly people hope to spend their latter years participating in several activities and living in a dynamic manner. A way of doing it is maintaining their independence throughout the use of their own vehicles, maintaining their driving as long as possible.

Other equipments that can have particular value for older drivers are the ones belonging to new technologies. These systems can assist drivers to expand their driving activity over time by helping them to manage their disabilities and consequently their difficulties to perform the driving task. They may allow them to drive in conditions in which may otherwise have refrained from driving and this is done by lessening some of the effects caused by the age-related changes (Meyer, 2003). In fact, the ageing population introduces a special challenge for the transport systems due to issues concerning functionality, safety and frailty of drivers. Freedom of movement provides innumerable opportunities related with social, functional, educational, medical and recreation aspects of life, activities that can be easily reached with the use of new technology devices (OECD, 2003). In order to be used in an efficient way, the development of new in-vehicle technology has to be based on the notion of "user centred design". This means that the needs of elderly users have to be considered in the entire process, in order to adapt adequately the product to the users' characteristics. These usability considerations are extremely important once it will define users' acceptance and satisfaction, as well as its safety and efficient utilization (Meyer, 2003).

In 2005, Harriots conducted several focus groups in United Kingdom to establish the type and degree of problems associated with automotive design for older drivers. Additionally it was intended to the study the development of equipments useful to drivers with that age. After the analysis of the focus group results, the author concluded that a significant proportion of elderly drivers reported difficulties with the following activities: seeing, hearing, walking, bending, reaching/stretching, grasping and twisting. Because cars are not traditionally designed with this age group in mind, several problems are compromising the elderly performance. Some of these problems are related to the physical aspects and were highlighted by several participants in Harriotts study: the height of cars that is not adequate to older drivers once they have to lower themselves into the car, and have to put themselves up to get out; the dimensions of the door aperture and the relation between the door and the position of the seat; and also the act of putting or taking heavy objects into the luggage compartment of the vehicle. In this respect, other investigators have identified the physical changes that occur with ageing and have considered some solutions, much of them possible through the use of new technological devices. Some of the revealed solutions consider: the use of steps to facilitate getting in and out of the car; turning seats and large doors to facilitate their way in; hard and flat seats to make it easier to sit; possibility to relocate primary vehicle controls closer to the driver; ameliorate the seat-belt anchorage points and system slack to reduce the discomfort of reaching and putting it; adapt/enlarge handles, knobs and steering wheels to meet the hands functioning needs of the elderly and facilitate single handed-tasks if possible (see Meyer, 2003; Shaheen & Niemeier, 2001).

Nevertheless, new technologies play also an important role when it concerns compensating for other physical decrements as well as some perception and cognition age-related impairments. Examples are problems that elderly experience in turning round the head to look out the environment (Harriotts, 2005). This limited ability to rotate the neck and upper body to look to the side and back, can be compensated by the introduction of rear-view systems that display a wide angle view of the area behind the car. A backup warning system that alerts drivers when they approach an object is also of great help when drivers are backing up (Meyer, 2003). Additionally, other systems can enlarge safety mobility and provide personal assistance to older drivers (see Davidse, 2004; Meyer, 2003; OECD, 2003) like:

- *collision avoiding systems* that can assist drivers at intersections; automated lane changing and merging systems that can help selecting gaps to cross and also take care of the changing or merging action;

- *blind spot and obstacle detection systems* providing support for the detection of close objects that are near a slow-moving vehicle, being also very useful while parking the car;

- *night vision displays* that enhance the vision during night by providing an intense image of the forward scene;

- *intelligent cruise control* that can help maintaining the same speed and also keep a determined safe distance from the vehicle ahead;

- *driver information systems* providing information about the roads, traffic, weather condition broadcasts, help to plan the trip, provide information about vehicle maintenance and can give many other important information.

Even knowing that the use of new technologies can be an advantage to elderly drivers, it should be clear that the introduction of a new device into the car is not always easy and it will not lead directly to an improvement in safety. First of all, it has to be considered that these systems may not be readily accepted due to a natural age-related aversion to new technologies. It is probable that, in future generations, this will be less of an issue due to the fact that elderly will be familiar with intelligent technologies at an early age (Shaheen, & Niemeier, 2001). However, nowadays is still evident that a great proportion of older drivers avoid using this type of technology due to their inexperience and also to the lack of user-friendly interfaces.

Even when considering that the acceptance of technology is done and the older driver really uses the device, the product of this interaction must be also considered. In some cases, the introduction of these equipments into the car may lead drivers to alter the pattern of behaviour usually activated in "normal" driving conditions (Meyer, 2003). The use of new technologies, specially in-vehicle information systems, can increase the amount of information presented to the driver. These additional inputs may overload the driving task by increasing the amount of information that drivers have to identify, perceive, process and respond to, and as a consequence lead to a worse driving situation (Green, 2001). Increase difficulty in the driving task can create serious problems to all drivers, but may have the most considerable effects on elderly drivers (Stamatiadis, 1993). In spite of being often difficult to predict how a device will affect driving, it must also be taken into account that the device can not be used in isolation. As it can be observed nowadays, the presence of more than one in-vehicle device is a reality (e.g. a mobile phone and a nomadic navigation system or an adaptive cruise control and a navigation system), and can in some specific moments be used simultaneously (Meyer, 2003). This joint use of devices can not only impair the efficient use of systems itself but also influence negatively the driving task and compromise the safety of the road system.

The key relies primarily on the design of in-vehicle systems. Well designed interfaces provide a mean of helping all groups of drivers, specially the elderly ones, because adequately adapted devices can augment impaired sensory abilities and reduce cognitive processing requirements (Baldwin, 2002). When age-related effects on the central nervous system are considered to develop new technology, the amount of knowledge that elderly driver possess have to come along. This knowledge, obtained with experience, includes declarative and procedural learning accumulated with age.

When the older driver has to deal with a new activity, like the one resulted from in-vehicle information systems interaction, he/she must develop new concepts, strategies and cognitive processes. Driver’s experience and also quality of these cognitive processes will determine the time needed to learn to perform this new activity. Numerous studies that focused the cognitive training of older drivers have found significant improvements in their performance as a result of training and behavioural interventions. The idea that elderly subjects can not learn new activities is confronted. Besides some declines in age-related intelligent abilities, there is a certain amount of cognitive energy or capacity held in reserve that can be used (Simões, 2003). This reserved capacity can be expressed as plasticity and when used can increase the cognitive performance. However, when the cognitive system is stressed, i.e. when the cognitive capacities of an individual are reached or surpassed, performance decrements can occur. These decrements can be more pronounced in elderly drivers, as it is believed that the cognitive reserve capacity is smaller than the one of the younger subjects (Park, 1992).

The introduction of a new task to interact with an in-vehicle system, combined with the driving task, may lead to the situation where the subject's cognitive system is stressed and their capacities are exceeded. Moreover, as the complexity of the tasks increases, the decrements in performance of elderly drivers decrease as it has been suggested that age-related declines in cognitive performance increase with task complexity (Cerella et al., 1980). These double task situations may also induce to negative consequences due to the already explained declines in selective attention and attention switching. The higher difficulty in identifying useful information and ignoring irrelevant contextual details may lead to an ineffective allocation of cognitive resources. On the other hand, ability to quickly shift their attention among several important stimuli also suffers a decline with ageing, indicating a clear disadvantage when performing a secondary task. These attention decrements influence the working memory capacity because with increasing age a portion of the reserved cognitive capacity is occupied by the interference of irrelevant information (Hasher, & Zacks, 1988). In this respect, recommendations have to be made for the system designer to develop devices that induce the minimum demand at the working memory level. This is possible when in-vehicle systems impose to drivers very simple tasks and adequately organized in term of information (Marin-Lamellet et al., 1993).When tasks are very simple or when the driver is intensively trained, the difficulty to divide attentional resources and switch from the driving task to the in-vehicle task, and vice-versa, is lessened (Somberg, & Salthouse as cited in Marin-Lamellet et al., 1993).

The simplicity of the inputs transmitted to drivers depend both on the application of adequate ergonomic criteria and also on the type of information sent. For this reason the specificity of each system and the nature of the inputs conveyed to drivers must be analysed for a system or group of systems in particular. Distinct results can be observed from the interaction with different kinds of systems and the specificities of these situations must be taken into account, starting with the purpose for which it was developed (if it's a device that will help the driving task or not). In the next paragraphs the influence that two different systems have on the elderly driving behaviour will be exposed. The results obtained by several researches concerning the interaction of this group of drivers with mobile phones and with navigation systems will be discussed.

3.1 Elderly Drivers and Mobile Phones

Kramer and Larish, in 1996, referred that one of the activities where large and robust differences can be observed between the young and the elderly is the dual-task processing. In fact, one of the daily situations that can be considered as an example is conducting a mobile phone conversation while driving. As it could be verified in a previous section concerning the general mobile phone use, driver behaviour changes can be observed from the interaction with mobile phones. However, are the consequences of such interaction similar for all the drivers' age-groups? Or different consequences may be expected when the situation involve elderly drivers?

Given that the driving is a complex task that involves the combination of other activities that are relevant to the driving activity, it is not surprising that the addition of a non-related driving task can produce some declines in older driver's behaviour (Strayer, & Drews, 2003). However, the magnitude of these declines and the comparison with behaviours from younger drivers has been object of investigation for several years. As the ability to identify useful information and ignore irrelevant details increase with age, accompanied by the higher difficulty in quickly shifting the attention among two stimuli, studies have been attempting to discover if the interaction with a mobile phone compromises significantly the road safety.

Early in 1991, McKnight and McKnight conducted a study in order to access the effects of using a mobile phone in the drivers' ability to cope with the driving task demands. Before presenting their study, the authors mentioned some previous studies that demonstrated a relationship between the age and the sharing attention process efficiency, like it is done when driving and conducting a mobile phone conversation. In their research, they asked participants to drive a simulated vehicle where several events were presented in the road environment. During the test, three mobile phone conversation moments were offered to drivers in order to evaluate their response accuracy and response time to the simulated road stimuli. Results revealed that, besides the mobile phone conversation had induced a considerable level of distraction in all drivers, the elderly ones showed higher proportions of failing to respond to the traffic events during the mobile phone conversation. When responses occurred, significantly longer reaction times were observed when compared with their younger counterparts. The authors concluded that the distracting effect of using a mobile phone among elderly drivers is greater than for the younger subjects (McKnight, & McKnight, 1991).

The reaction time variable was also measured in another study conducted by Alm and Nilsson (1995). Correspondingly to the results obtained by McKnight and McKnight (1991), data from the reaction times showed that elderly drivers took longer to react to an event on the simulated road. Additionally, another age difference was seen for the mean headway distance of the leading car. Elderly participants drove with longer headway distances compared with younger subjects' behaviours. This was observed for the control condition (no mobile phone) and also the mobile phone situation, where a higher difference was expressed between age groups. Theoretically, this could be seen as compensation behaviour for an increased reaction time in a car following situation. However, in order for this to happen, elderly drivers had to be aware of the impact caused by the mobile phone task, fact that was not highly probable. The authors made some calculations regarding their headway distance and the travelling speed and in the worse case scenario those distances were not enough to avoid a crash. For that reason it was believed that the headway was not large enough to compensate the increased risk caused by the increased reaction time.

The lateral position was also measured in this study however contradicting their hypothesis, there was no significant difference in the values in the variability of the lateral position. To conclude, the authors presented another difference observed between both participants groups: the subjective evaluation of the situation throughout the utilization of NASA-RTLX questionnaire. Results indicated that younger subjects rated higher efforts than elderly participants (Alm, & Nilsson, 1995).

More recently, age related differences could also be analysed in a simulator study conducted by Shinar et al. (2005). They grouped 30 drivers in three different clusters: young drivers (18 to 22 years); experienced drivers (30 to 33 years old); and older drivers (from 60 to 71 years old). In general, the performance of the two youngest groups was similar and richer compared with elderly drivers. Older subject's performance were characterized by having significantly lower mean speed values, increased speed variance; closer driving to the centre of the lane; more instability in lane position (higher variance); and lower reaction times. Despite the inferior results, elderly drivers showed the greatest improvements through the 5 simulator sessions. At the end, their overall performance was similar to their younger counterparts and no relevant differences were expressed. Additionally, elderly drivers performed better in the secondary-task (maths operations through mobile phone). The youngest group had the highest number of errors.

One of the most interesting aspects of this study, besides the differences observed between different age groups, is the fact that performance can change with training, supporting the already mentioned idea that there is a certain amount of cognitive capacity reserved that older drivers can use. Then, the effect of adequate practice and adjusted feedback can be seen as capable of decreasing risky situations (see also the study of Hancock et al., 2003). Another fact that converges to this finding is subjective workload evaluation that decreased through the experiment sessions. In conclusion, it could be said that "the deleterious effects of new in-vehicle technologies are there initially, but they may decrease considerably with practice". For those authors, results also demonstrated that drivers adjust their behaviour to compensate for some informational overload (Shinar et al., 2005).

A simulator study which results contradict the ones just mentioned was conducted by Strayer and Drews in 2003. They used a high fidelity simulator to study the effect of a mobile phone conversation, hypothesising that the driving performance of older drivers would deteriorate more rapidly than their younger counterparts. Participants had to drive in a freeway road with a car in the right-hand lane that braked intermittently. The researcher measured the time interval between the onset of the car ahead and the participant's breaking response; the following distance; the mean speed; and the time participants used to recover the speed that was lost with the braking activity. Results revealed that, besides data had demonstrated that conducting a mobile phone conversation impaired all subjects driving performance, older drivers did not suffer a great penalty for talking on the phone. These absences of age-related differences were justified by the authors as a consequence of the type of simulator used. In their opinion, the utilization of a high-fidelity driving simulator benefits the experience that elderly drivers possess with the driving task, meaning that novel laboratory-based tasks may significantly overestimate the age-related dual-task deficits as they are covered by the effect of experience.

To confirm or refute this opinion, results on real driving conditions have to be observed in order to verify if the higher experience possessed by elderly drivers help them to compensate and hide totally the possible dual-task effects expressed in a simulator situation. Cooper et al. (2003) design a study in a closed track road to investigate how mobile phone use could affect drivers on their information and decision-making process. Similarly to the conclusions obtained by Strayer and Drews in 2003, nothing in the results could refute the general-held argument that divided attention situations may impact the older drivers more adversely than younger ones. However an important limitation is referred by the authors that can influence this result: the most elderly drivers that participated in the experiment were under 65, being also the size of the sample relatively small.

Another closed-looped test track was conducted in 2003 by Hancock and colleagues. They aimed to evaluate the safety effect of in-vehicle phone use and also examine driver response to crucial decision points. Elderly (55 to 65 years-old) and younger groups were compared in the following measures: recall accuracy (recalling the number that had been memorized at the beginning of the experiment); brake response time (time between the onset of the stimuli to the first activation of the braking system); stopping time (time needed to brake); stopping distance (distance from the front of the vehicle to the stopping line in the road); and stopping accuracy (percentage of success in stopping the car before crossing the line). Results indicated that older drivers were at greater disadvantage in the presence of the mobile phone task because they were largely affected by it. Similar results were obtained in another on-road study (Lesch, & Hancock, 2004). In that particular situation, older drivers showed a larger distraction effect than younger drivers on all four performance measures: break response time; stopping time; stopping distance; and stop light compliance (if drivers stop in the presence of the red light). When it was needed to stop at an intersection with traffic lights, elderly ended braking about 70% closer to the intersection line in the presence of the mobile phone.

These results suggest that some evidences of the mobile phone negative influence on the elderly drivers' performance can also be observed in real live driving conditions. Thus, conducting a mobile phone conversation can result in driving performance decrements and more expressive results can be observed for the elderly drivers group.

3.2 Elderly Drivers and Navigation/Guidance Systems

As it could be verified in the above section regarding the interaction with navigation and guidance systems, several advantages can be attributed to the utilization of such devices. However these advantages are only present if the system possesses a proper design, and an adequate way of sending the information to the driver. Considering the special characteristics of older drivers and its perceptive and cognitive limitations, can these equipments be considered as an advantage in any situation or are they a safety concern when elderly drivers are considered?

One of the first considered issues related with elderly drivers' interaction with navigation/guidance systems is the acceptance of this technology. Considering that nowadays a considerable amount of elderly drivers are not very familiar with several forms of technology (something that can be changing), the acceptance and willingness to use a navigation system could interfere and change considerably the quality and the output of the interaction. In 1997, Wochinger and Boehm-Davis conducted a simulator study where participants had to interact with four types of guidance instructions: a big paper map with the route highlighted; a smaller standard street paper map with the route highlighted; some written text instructions, and a simulated turn-by-turn display with simple arrows, countdown bars and the names of the streets. The results from this experiment revealed that older participants preferred using the paper maps and at the beginning of the experiment they did not easily accept instructions from route guidance systems. This can suggest that they could be somehow reluctant to forego using maps even for electronic guidance systems with simple schemes. Authors also concluded that drivers tend to perform better with the type of navigational aid that they prefer and, curiously, those who seemed more reluctant to use the electronic equipment, performed worse in these conditions (Wochinger, & Boehm-Davis, 1997).

With the development of new route guidance devices, and also the increase advertisement on these equipments, a crescent number of drivers have been acquiring and interacting with such systems. The concept of providing real-time information to the driver in order to increase safety and improve mobility is very appealing. If, in a first contact, elderly drivers may feel hesitant to use such technology, with the constant promotion of its advantages the reluctance may fade away. For this reason, studying the influence that route guidance systems have on the performance of elderly drivers is of major importance because the acceptability of these new technologies by elderly population may no longer be an issue in some years. Therefore, the characteristics of the systems and also the way with which they transmit the guidance information have been object of attention and research.

Some authors have discovered that systems with characteristics that induce to a worse performance in adult drivers usually tend to impair even more the performance of older drivers (Green, & Williams, 1992; Brooks, Nowakowski, & Green, 1999). Evidences suggest that, when different age groups are compared, better guidance solutions benefit older drivers more then their younger counterparts. The simplification of an additional task and the adequacy of messages transmitted can reduce the performance dissimilarities between old and young drivers obtained by the interaction with a route guidance system (Pauzié, 2002). However, when elderly drivers' characteristics and limitations are not taken into account in the design process, some behavioural driving changes can be expected.

In 1997, Graham and Mitchell conducted an on-road study with 21 participants (11 young and 10 elderly drivers). During driving subjects interacted with a 4 inches LCD screen mounted in the dashboard of the car (a simulated in-vehicle system). A loudspeaker was also used to provide a beep whenever a new message appeared in the display. There were presented three types of messages: static information (names and numbers of junctions and distances); dynamic advisory information (weather conditions, road and traffic conditions); and also dynamic hazard information (urgent warnings of road and traffic events). Those were fictional information that the driver had to read and remember.

Results showed that, in what concern the memory recall performance, elderly drivers were no worse than young drivers as there was no significant effect of age on the number of incorrect information recalled. The only detected difference was that older drivers had more difficulty in recalling information from more complex messages. Age related differences were also showed for the eye glance behaviour results. When messages were displayed, large differences between the two age groups emerged. Older drivers spent more time looking at the display, being their visual allocation significantly smaller to the road ahead. Glances towards the dashboard were also longer for older drivers and, in spite of non significant, the average frequency of glances to the dashboard to assimilate the displayed messages was higher for the elderly participants. Naturally, the more complex messages (dynamic hazard information) were the ones that took longer to read, and this was true for both age groups. This increased attention to the screen reduced the attention paid to the road ahead and the rear view mirrors. This experiment showed that more complex and difficult information can impair the behaviour of a younger driver, but the consequences on the older driver performance can be even greater because they may took longer to apprehend a message. When getting information from a visual display, older drivers can spend more time looking to the device than younger drivers. Glances towards the system can be longer, and the frequency of glances can also be higher for this group of drivers. As a consequence, their visual allocation to the road ahead can be significantly smaller (Graham, & Mitchell, 1997).

When it concerns the type of visual messages, another aspect to consider is the size of the images presented on the display as they can contribute to augment or reduce the difficulty to read. Small characters can force aged subjects to look longer to the screen to apprehend messages. When characters are bigger, the time older drivers need to obtain information from the screen is reduced and in these cases there are no significant differences between adult and older drivers. Therefore, optimal legibility allow elderly to perform similar to adult drivers (Pauzié, 2002; Pauzié, 2003).

One study that can confirm this aspect is the one conducted by Brooks and his colleagues (Brooks, Lenneman, George-Maletta, Hunter, & Green, 1999). In a simulated environment, they tried to develop a model to predict the time required to read various electronic maps according to its characteristics. Participants were asked to read the names of different streets in the display while driving. Several maps were presented each one possessing different characteristics: they could present different number of streets (6, 12, 18, 24 or 36 streets); two distinct size of text (12 or 18 points); three different orientations of the street names (horizontal, vertical and stacked); and two types of street layout (with grid or no grid). In what concerns the results from the comparison of both age group performances, it could be observed that age had a significant effect on the error rate, being the number of errors to read maps and identify streets higher than their younger counterparts. Older drivers also took longer to respond to the street identification questions (35% longer than young participants). Authors reveal also that the number of streets, the street label orientation, and the text point size affected more older drivers than younger. A higher number of streets in the map, with labels written in small size texts and oriented horizontally or in a stacked way can lead to higher difficulties in reading the information by elderly drivers.

Other studies have indicated that older drivers tend to take longer to complete a task related to navigation (Green, & Williams, 1992; Brooks, Lenneman, George-Maletta, Hunter, & Green, 1999), and also to make a higher number of errors (Green, & Williams, 1992), specially when faced with more difficult situations (Brooks, Lenneman, George-Maletta, Hunter, & Green, 1999). In a general way, navigation systems (e.g. electronic maps) are considered to be specially difficult for older drivers and route guidance information systems (e.g. turn-by-turn displays) believed to be more adequate and inducing to less impact on their performance (Pauzié, 2002; Brooks, Nowakowski, & Green, 1999).

Another important aspect that has been considered in researches related with the route guidance systems is the position of the visual display. The ability to detect targets away from the centre of the field of view (eccentric targets) while accomplishing a secondary task varies in accordance with the complexity of the task, being also detected an age effect. Older drivers find it harder to look for information away from the centre of the field of view, specially if the complexity of the task increases. This disparity is even more pronounced as the eccentricity increases (Pauzié, 2002). Equipments indicated as more adequate are the Head-Up-Displays. They are generally more beneficial for elderly drivers because they can improve their performance and lessen the differences between them and younger drivers (Green, & Williams, 1992).

CHAPTER 3. Research Questions

The driving task is frequently characterized by being a complex and dynamic task because the individual has to deal simultaneously with several elements of a system that is constantly changing. The development of new technologies and their introduction on the transportation context are an example that confirms its complexity and also mutability. More and more systems are developed and introduced into the driving environment, having this situation induced drivers to additional challenges as well as professionals that study the impact of such devices on the road safety.

A considerable amount of these systems, specially the ones present inside vehicles, are programmed to send information to drivers via visual and/or voice messages, being this messages sent while the vehicle is on the move. This situation, which is typically considered as a multiple-task scenario because the subject is performing an additional task besides driving, has been the focus of attention in several researchers.

Driving and conducting additional tasks like talking on the mobile phone or looking to a display to get a specific information, are considered activities that can potentially distract the driver from the main task – driving. In that situation, subjects can divert their attentional resources to the secondary task, neglecting the driving activity and/or the information from the road environment. Additionally, the debate on the multiple-task performance raises questions concerning the drivers' mental workload: it is also considered that conducting an additional task can increase the individual mental workload and if a determined level is reached, the performance on the driving task can be compromised. The limited capacity that subjects have to process the information is a reason to justify the restricted availability of the attentional resources to cope with several tasks simultaneously. When the limit is reached or exceeded, it is believed that the driving task can suffer a decrement and no longer be safe.

As technology continues to develop, new challenges arrive. The creation of systems that made available new functions and/or are capable of gathering a considerable amount of functions in a unique device creates novel realities. Moreover, with the growing diversity of on-board systems, the likelihood of having more than one product of technology inside the vehicle is even bigger (Ranney, Harbluk, Smith, Huener, Parmer, & Barickman, 2003). Their new features and also the higher number of equipments introduced in the market are believed to change the driving task and produce unpredicted consequences to the road safety. As a consequence of this scenario, in-vehicle systems can become more popular and accepted, even for groups of drivers that were not used to new technologies. One example is the group of elderly drivers to which in-vehicle information systems can become appealing as they are each day more familiar and enthusiastic to utilize products of new technology. It is important to foresee that the elderly drivers of “today” are not the same as the ones driving vehicles “tomorrow”. This means that elderly drivers of the future will probably have different behaviours concerning new technologies. They will be more familiar with it and the interactions with such devices can happen more frequently. For that reason this scenario must be considered, studied and safety considerations must be developed.

Facing this scenario, it is imperative to investigate if multiple visual and auditory inputs from in-vehicle information systems can induce to an impact over the driver behaviour. In this respect, it must be examined the simultaneous interaction with more than one in-vehicle system and verify the consequences on the activity of the driver. Thus, in order to reach this aim, specific research questions must be answered:

1. What are the consequences of the simultaneous interaction with more than one in-vehicle information system on the driving task?

2. Does the level of mental workload increases with the joint interaction of two in-vehicle information systems?

3. What are the effects produced by the multiple-task scenario on the performance of both in-vehicle tasks?

4. In which extent age-related differences produce dissimilar consequences for the driving task on this multiple-task scenario?

PART TWO: METHODOLOGY

Introduction to the Experimental Framework

The research questions elaborated on the previous part, emerging from the literature review and also from the development of Intelligent Transportation Systems, are in correlation with the objectives of the present investigation. Hence, as it was already mentioned, the aim of the present research was to study the impact of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. It was intended to investigate the simultaneous interaction with more than one in-vehicle system and verify the consequences of this scenario on the activity of the driver. In a more specific approach, the objectives of this research were:

1. to determine the consequences on the driving task produced by the simultaneous interaction with a guidance system and a mobile phone device;

2. to identify changes on the driver mental workload while receiving information from both in-vehicle information systems;

3. to verify the effects that this multiple-task scenario had on the guidance and on the mobile phone task performance;

4. to determine the age-related differences on the driver performance produced by the simultaneous interaction with two in-vehicle systems.

Based on the collection of the existing knowledge elaborated to frame this research topic, a general hypothesis could be drawn:

> **Hypothesis -** The interaction with more than one in-vehicle information system can lead to an increase on the driver's mental workload, inducing to an impact on the driving performance and on the road safety.

This general premise was the basis for the generation of hypotheses with a higher degree of specificity that helped to develop and frame the experimental work. Thus, it was hypothesised that:

1. the simultaneous interaction with a guidance and a mobile phone device while driving will have an impact on the driving task performance;

2. receiving information from both in-vehicle information systems will change the drivers' mental workload;

3. interacting with both in-vehicle devices at the wheel will also have an effect on the performance of the guidance and of the mobile phone task;

4. the multiple-task scenario will lead to distinct consequences on the different age-group drivers.

In order to accomplish the aims and objectives proposed for the present research, two experimental moments were planned. One experiment was conducted in a real context and the other in a simulated environment. The reasons justifying the elaboration of two experiments with different natures are related with the adequacy of the methods to examine the influence of in-vehicle information systems. As it could be verified in chapter three of the previous part (Intelligent Transportation System topic), several were the researchers that conducted experiments in on-road environments and also in simulated contexts. Each experiment type has different advantages and disadvantages, and the possibility to conduct both types of surveys enriches the research work by enlarging the results and knowledge obtained.

In what concerns on-road experiments, they are generally conducted in the real environment, with a real vehicle and in real roads. Their major advantage is related with the fact that they are closer to the reality and the results obtained are expected to be similar to the outputs that could be obtained in reality. Once the driving task is complex and dynamic, when the experiment is accomplished in a real scenario this complexity and dynamism is probably assured. The importance of conducting experiments in real contexts is verified because performing a driving task in a much simpler scenario can modify the driving performance of participants, leading to different results and conclusions.

Simulator studies are also very common and important as they can compensate for some disadvantages and unfeasible aspects of the on-road experiments. Normally, a simulator is constituted by a cockpit of a car that can be real or not, and by a screen that reproduce more or less realistic scenes of a road environment. With the help of this informational device the atmosphere of a driving situation can be easily reproduced, with the advantage that researchers have a total control of all the variables and conditions. Due to the fact that it is a simulated situation, many variables can be controlled (aspect that can't be done in a real scenario) and the behaviour of the driver can be studied without interfering with road safety. For numerous authors the validity of the studies made in a simulated scenario is high and although some results can be different from on-road evaluations, their contributions are of major importance for the development of the knowledge in this area.

In the following chapters both on-road and simulator experiments will be described in detail. As it was already mentioned in the first part of this work, in order to verify the consequences of simultaneous inputs from more than one in-vehicle system, two different systems were chosen to be the focus of this research: a guidance system and a mobile phone. They were integrated in both experiments so that results from this interaction could be analysed.

CHAPTER 1. ON-ROAD EXPERIMENT

In the following paragraphs the experiment conducted in real environment is described with detail. This experiment had the aim of investigating the influence of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. More specifically, it was intended to investigate how the inputs from a navigation system and a mobile phone would be received and managed, verifying also the consequences of this simultaneous interaction on the activity of the driver. Once this on-road experiment intended to respond to all of the aims of the entire investigation, its specific objectives were also formulated to correspond to the ones already mentioned in the introduction of the experimental framework. Thus, the specific objectives of the on-road experiment were:

1. to know the consequences on the driving task produced by the simultaneous interaction with a guidance system and a mobile phone device;

2. to assess the driver mental workload and verify load changes through the comparison between situations where the driver interacts with one or with two in-vehicle information systems;

3. to analyse the effects that this multiple-task scenario has on the guidance and on the mobile phone task performance;

4. to examine if the simultaneous interaction with two in-vehicle systems induce to age-related differences on the performance of any task (driving, guidance and mobile phone conversation).

1. Method

1.1 Test Participants

Thirty two subjects took part on this experiment. They were split into two different age groups: 16 elderly drivers aged from 62 to 78 years old (mean age 69.4; S.D. = 4.0); and 16 reference drivers with 34 to 47 years old (mean age 39.6; S.D. = 4.0). The youngest group of drivers was named as "reference" instead of "young" (like it is frequently done) so that readers do not get confused with "novice drivers", designation characterizing drivers with little driving experience. The sample was composed by an equal number of males and females (8 males and 8 females) in each age group. Participants were recruited from the general public via local advertisements at the institute where tests were conducted.

In order for subjects to participate in this experiment, besides the age condition they had to satisfy the following criteria: to have driving licence for at least five years; to have driven at least 10000 kilometres and to possess a mobile phone. Drivers that had less than 30 years old and had not driven the established number of kilometres were not included in the sample. This age requirement was imposed because the behaviour of experienced drivers is considered to be different from the one that novice drivers have. The higher practice increases the driver's knowledge about the traffic system and the information that is relevant to be captured, allowing them also to make better predictions of the other road users' behaviour. On the other hand, the pre-requisite concerning the kilometres driven was related to some evidences indicating a major change in the cognitive skills occurring during the first thousands of kilometres (Summala, 2000). This acquired practice allows drivers to use less attentional resources and effort, providing them with more time for additional tasks in safer conditions.

Table 8. Characterization of the sample's age

Age Group	N	Maximum	Minimum	Mean	Std. Deviation
Elderly driver group	16	78	62	69.4	4.0
Reference driver group	16	47	34	39.6	4.0
Total Sample	32	78	34	54.5	15.6

All subjects had already a job experience in their lives; however at the moment of the experiment half of them (sixteen) were not professionally active. In the elderly drivers group the majority of participants were already retired and in the reference drivers group only two were between jobs.

Table 9. Occupation at the moment of the experiment per driver group

	Age Group		**Total**
	Elderly group	Reference group	
Have a job at the moment	2	14	16
Doesn't have a job at the moment	14	2	16
Total Sample	16	16	32

Regarding the type of professional occupation, subjects were asked about the longest job they had. Their answers were grouped based on the International Standard Classification of Occupations (International Labour Organization, 1988). As it can be seen in the next table "Service Workers and Shop and Market Sales Workers" and "Craft and Related Trades Workers" were the more representative groups.

Table 10. The longest job by the International Standard Classification of Occupations

Major Groups		Elderly	Reference	**Total**
1	Legislators, Senior Officials and Managers	1	1	2
2	Professionals	2	2	4
3	Technicians and Associate Professionals	1	1	2
4	Clerks	3	3	6
5	Service Workers and Shop and Market Sales Workers	3	6	9
7	Craft and Related Trades Workers	5	3	8
8	Plant and Machine Operators and Assemblers	1	0	1

Regarding the driving experience and frequency of driving, questionnaires indicated that elderly drivers had, in average, more years of driving experience (elderly: mean = 44.6, S.D. = 7.7; reference: mean = 18.9, S.D. = 6.1).

However, as it can be seen in the following figures (Figure 13 and Figure 14), in spite of the higher number of driving experience, the members of the elderly group drove less kilometres in the past 12 month and a lower number of subjects used their car everyday.

Within all the subject of this sample, only one person belonging to the elderly group didn't possess a car of its own.

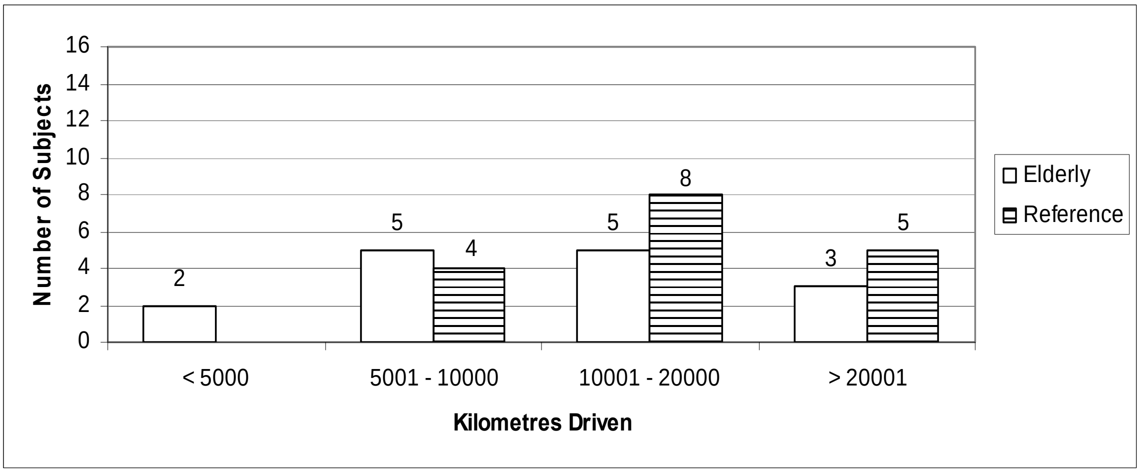

Figure 13. Number of kilometres driven in the past 12 months, per driver group

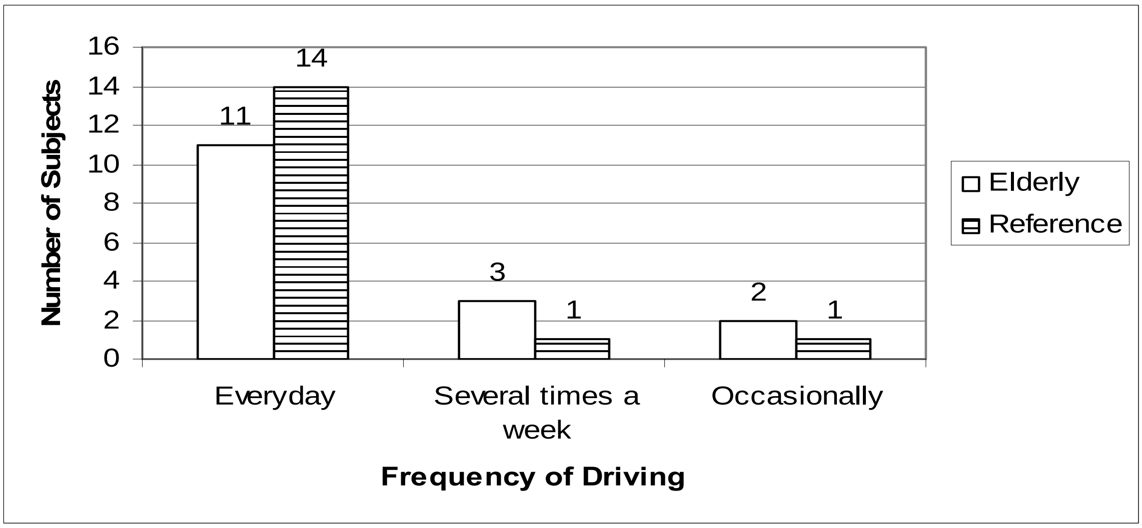

Figure 14. Frequency of car utilization, per driver group

Subjects were asked about their habits concerning the mobile phone use. Elderly subjects possessed their mobile phones, in average, for almost 5 years (S.D. =3.49) while the youngest reference group had their mobile phones for approximately 7 years (S.D. =2.19). When asked about the use of mobile phone while driving, only four elderly participants stated never using the phone in the car.

Observing the data regarding the number of calls done while driving, it can be seen that the majority of elderly respondents affirmed having phone conversations while driving less frequently that “some per month”. Comparatively, most reference group participants mentioned having a phone conversation while driving at least “several times per week”. The majority of the respondents stated not having the habit of answering mobile phone calls systematically, avoiding doing it specially when surrounded by intense traffic. Participants also stated avoiding taking a call in roundabouts and in the presence of police officers.

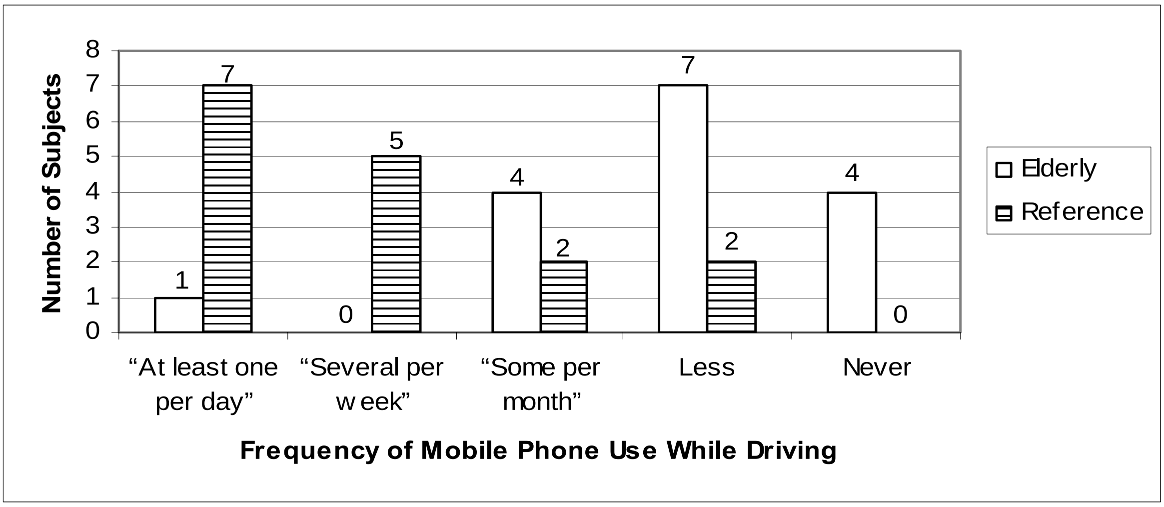

Figure 15. Frequency of mobile phone use while driving

Considering the subjects that had already interact with a mobile phone while driving, 20 did not possess a hands-free kit or other type of loudspeaker installed in the car. None of the elderly drivers possessed such equipment and half of the reference participants had a hands-free kit.

In what regards the number of mobile phone calls made while driving, the majority of elderly respondents stated not making any calls. The only three subjects of that group that answered positively affirmed to do it only when the car was stopped (in a parking or at the traffic lights). Regarding reference group participants, the majority referred to choose specific moments to make a phone call, like stopped in traffic lights, when the car was parked and also in motorways. Only three reference group respondents affirmed not making calls while driving.

Of the 32 participants that composed the sample only two had a navigation system (one belonging to the elderly group and another to the reference group). However, in spite of not possessing such system, other four participants had already used a guidance device (1 elderly driver and three reference drivers). Regarding the two participants that purchased one of these equipments, they both positioned their nomadic systems on the upper part of the dashboard on the right side of the steering wheel. The messages more frequently used where pictograms (turn-by-turn function) and both used the voice output. They used the navigation system mainly in unfamiliar courses, however the subject belonging to the reference group affirmed that he usually used it also in other situations like familiar roads; rural environments; urban environments; and also if there were works on the street. When asked about the possibility of connecting the mobile phone to their navigation system, the older subject didn’t know if such connection could be established. On the other hand, the younger participant affirmed that it was possible to do it, however no special action occurred when both systems displayed voice messages at the same time. They both sent information simultaneously.

1.2 Test Vehicle and Instrumentation

The on-road experiment took place in Lyon (France) at INRETS (Institut National de Recherche sur les Transports et leur Sécurité) between the months of March and September of 2006. The vehicle used was a Renault "Scenic" equipped with several additional equipments to allow the performance of supplementary tasks and also to capture its dynamic data. In what concerns the equipment used to capture the dynamic information of the vehicle it was used one computer (Pentium III with 1 Ghz) placed in the luggage compartment. It was connected to several systems of the car in order to receive information from the vehicle dynamics like the pedals, steering wheel, gear, turn indicator signs, speed, acceleration and braking.

Four mini video-cameras were placed in the vehicle to capture images from specific points. One camera was pointed towards the face of the driver to obtain data from his/her visual behaviour (1); the second camera was faced towards the centre of the dashboard to register the visual messages sent by the guidance system display and also to capture the image from the mobile phone interface (2); the third mini camera registered the road environment ahead of the experimental vehicle (3); the fourth was placed in the back of the vehicle to capture the backward road environment (4). In the luggage compartment was also placed a VCR and a multiplexer. The multiplexer received the images from all the cameras and also a fifth image that belonged to the interface of a computer program developed to show the vehicle dynamic parameters (5). This program image displayed the speed of the vehicle, the multiplexer timecode, the distance travelled since the beginning of the course, the pressure (in percentage) imposed to the three pedals, the gear and also the turning indicator activation. All this information was combined in the multiplexer so that it could be registered by the VCR. The VCR also received the sound from the microphone that was attached near the sun visor of the driver, intended to capture the voice of the participant during the experiment.

Figure 16. Combination of all the images from the cameras and also from the program that gathered the dynamic data of the vehicle

The experimental vehicle had an extra set of pedals mounted in front of the passenger place, beside the driver. Those three pedals were used in the tests for security reasons as it will be further explained. Inside the car there was also an extra pair of mirrors strategically placed to be used by the passenger travelling beside the participant. Those mirrors allowed this passenger to see the surrounding environment as well as the face of the driver.

Figure 17. Vehicle used in the on-road experiment

The car was also equipped with a navigation/guidance system of Carminat, fitted as standard to the vehicle. This system was placed on the dashboard to the right of the steering wheel and above to the control panel of the vehicle. It displayed schematic information of the roads through the presentation of a map and had also the possibility of transmitting guidance instructions with the help a of turn-by-turn display.

For the present experiment, only the guidance system (with the arrows) was exhibited to participants once it is referred by several authors that this simpler type of information is more adequate because is less distracting to drivers (Dingus, et al. in Young, et al., 2003). It is also referred that induce to less dangerous behaviours (Brooks, Nowakowski, and Green, 1999; Graham, & Mitchell, 1997) and also leads to fewer errors (Schraagen, 1993; Burnett, & Joyner, 1997).

Other two reasons supported the use of the turn-by-turn modality: 1) the fact that numerous route guidance systems in the market have already this form of displaying information; 2) and because during the experiment participants had to perform another additional task during driving. As it was not intended to put participants in extremely difficult and stressful situations, simpler messages were selected.

Figure 18. Guidance system display and bellow the two interface buttons for the mobile phone

For besides the visual information, the system used in the experiment had also voice instructions. They were sent by a female voice throughout the two loudspeakers of the vehicle. There were two types of audio information: when the course allowed it, and the road had enough length, a message was sent approximately 400 meters before the intersection to warn the driver to prepare him/herself to next turn (Example: "*Prepare yourself to turn left*"); the other message was sent 100 meters before the intersection or, if the distance between two intersection was less than 100 meters, immediately after the last intersection (Example: "*In 100 meters, turn left*"). Beside the turn-by-turn arrows there was a countdown bar indicating the distance to the manoeuvre. Before the voice message the system displayed the distance counting down to 100 in 50 meter increments; after this voice message it counted down to zero in 10 meter increments. The name of the current road and also the name of the road being turned to were also showed visually in order to provide additional information. In between manoeuvres the guidance system displayed an arrow pointing forward and there were no audio messages.

A hands-free mobile phone (*Sony Ericsson T610*) was installed in the car, connected to the audio system of the vehicle. The connection was made throughout bluetooth (*Parrot system*) and the interface to receive and hang up a call consisted in two buttons mounted in the centre of the dashboard: a left one with a green symbol to answer the call and the one in the right with a red symbol to hang up (see Figure 18).

A microphone was attached near the sun visor of the driver in order to capture the voice of participants while talking on the phone.

Figure 19. Guidance system image 20 meters to a turn left manoeuvre

In spite of both systems being integrated in the vehicle and their output transmitted through the same loudspeakers, they were not connected to each other. The voices of the different sources were sent independently. (To get a complete overview of the position of each equipment see appendix I)

1.3 Experimental Course and Tasks

1.3.1 Development of the Course

In order to accomplish the objectives proposed by this work it was decided to perform a detailed analysis on the moments where participants had to make manoeuvres. Thus, a specific course was prepared to have a pre-determined number of "target" manoeuvres to be analysed in each experimental condition.

The development of the course followed some specifications. Once it was intended to have a part of the course where participants interacted just with one system and the other part where subjects had to interact with both devices simultaneously, it was important to have the same number of intersections in both conditions. Those two groups of manoeuvres should be similar so that they could be further compared and analysed. Thus, an equal number of manoeuvres to the right and to the left were imposed. Roundabouts were chosen not to be part of the junctions that would be studied with more detail in order to simplify the trajectory and also the posterior analysis. Intersections that would be object of analysis were called as *target intersections.* To be a *target*, intersections had to allow the driver to make all the decisions as freely as possible, meaning that the driver had to decide where to turn and when. Participants had to be the ones to actively choose the correct moment to turn not being that decision substituted by traffic lights or other types of vertical signs that gave the participant the priority over the other road users.

It was decided that participants would use instructions from the guidance system during the entire experiment. Due to that reason a specific final destination was entered in the system, as well as 10 intermediate points. These intermediate points were introduced as a strategy to enlarge the course in the city centre and augment the number of manoeuvres made by participants. These points were characterized by being specific places pre-entered in the guidance system, where drivers had to pass by and not to stop completely.

The complete course was in Bron (a city near Lyon, where was the headquarters of the institute) and had approximately 20 Km long. It included several streets in the city centre and also some roads in a more industrial area. The entire course contained 31 junctions and 3 roundabouts, however only 20 of those junctions were considered as "*target intersections*". It was intended to have a considerable number of manoeuvres so results could be significant. Intersections were also chosen to be subdivided into left and right manoeuvres: the 20 target intersections were composed by 8 intersections that had to be performed to the right and 12 to the left. The unequal number of manoeuvres to the right and to the left was due to the specific characteristics of the course. The higher easiness to pass through intersections performing left manoeuvres fulfilling the predetermined requisites for being a target intersection, led to a higher number of left turns in the experimental course.

Additionally, some constraints related with the guidance system and the middle point destinations hindered the development of the course. The lack of upgraded information regarding some new and old paths also conditioned the course development, inducing to a lower number of right turn manoeuvres. (To a complete overview of the course see Appendix II)

1.3.2 The Main Task

The goal of the test was to drive to a specific destination with the help of a guidance system. Before arriving to the final address, the navigation system guided the participants throughout a pre-determined path that included 10 intermediate passing points. The final destination, as well as the 10 intermediate points, were entered before the beginning of the experiment and always in the same order so that all the participants made the same course, followed the same instructions and drove through the same routes. Nevertheless this equal pre-determined course, some deviations were expected.

Whenever participants didn't comply with navigation instructions, the system recalculated the route in order to get to the following intermediate point. The introduction of these points was also important to control and reduce the time participants spent away from the "original" course. As the course had 20 target intersections, between two middle points were, in average, two target manoeuvres. Thus, whenever an error occurred in a target or non target junction, fewer intersections would be lost for analysis.

In some specific parts of the course participants were asked to interact with the mobile phone by conducting a conversation with a researcher that was at the office. It was decided that the 20 target intersections would be split into two sub-groups so that a group of 10 manoeuvres would be performed without the mobile phone interaction and the other 10 with this simultaneous additional task. Participants only drove the course once. The strategy of asking drivers to perform two courses, one with and the other without mobile phone, was rejected in order to avoid some eventual learning effect that could influence their navigation behaviour and compromise the results.

1.3.3 The Mobile Phone Task

In order to select the adequate mobile phone task, i.e. the type of conversation that should be held while at the phone, two main objectives were considered: it was intended that the additional mobile phone task could have an effect as similar as possible to a real mobile phone conversation; and the conversation should also be subject of quantification in order to be measured and compared between subjects. A normal and free conversation was the best solution to induce normal reactions from subjects but had the disadvantage of not being easily measured. Simple arithmetic calculations could be easily quantified but were very different from a natural conversation and could be more difficult to perform. As a consequence, a task was chosen that tried to combine these two considerations.

The mobile phone conversation was compiled of a series of sentences sent by a researcher in the laboratory. The rhythm with which they were presented depended on the pace of the driver to answer the preceding question. In order to do the mobile phone task, participants had to listen to each sentence, repeated it and answer “yes” if the sentence was sensible, and “no” if it was not. For example: “Usually, bicycles are bigger than cars” to which the subjects had to repeat and then answer “No”. This mobile phone task was based on the “decision part” of the Working Memory Span Test (Baddeley, Logie, Nimmo-Smith, & Brerefon, 1985; Alm, & Nilsson, 1995). A repetition part was added in order to ensure that the correct sentence was heard and to better evaluate the accuracy of the answer. All sentences contained 11 or 12 syllables and equivalent duration of time to be said. The test contained 50% of sensible phrases and 50% nonsensical sentences. The order in which they were presented was selected randomly by the computer utilising a visual basic program made specifically for ordering the sentences. (To a complete overview of the sentences see Appendix III)

In order for participants to receive the mobile phone calls always at the same moment, a researcher travelling on the back seat of the experimental vehicle sent a signal to the other researcher in the laboratory utilizing another mobile phone (*Nokia 6210*). Signals were sent some meters before the start of the guidance system voice message and in predefined points of the course. As soon as the signal was received in the laboratory, the researcher made a phone call to the mobile phone of the vehicle to begin the task. In order to accept the call, subjects were instructed to press the green button on the dashboard. They didn't have to perform any action to hang up the call once they were informed that the researcher in the back was in charge of that action. The call was ended by the researcher in the car when the specific area of the target intersection ended.

1.4 Variables Definition

1.4.1 Independent Variables

To achieve the objectives proposed for this on-road experiment, specific independent variables were determined. The first independent variable imposed allowed the division of the experiment into two different situations: interacting with one in-vehicle system and with two in-vehicle systems. This variable was designated as *system condition* as it defined the number of systems subjects interacted with. The two different situations that defined this independent variable were named as: *one-system condition* and *two-system condition*. For the first one, subjects were instructed to perform manoeuvres only with the help of the guidance system while in the *two-system condition* they had to receive instructions from the guidance system and also conduct the mobile phone conversation simultaneously.

The second independent variable allowed the comparison between two distinct groups of drivers. Designated as *age condition* it included two driver groups with distinct ages: a group with younger but experienced drivers called *reference group* and the other one composed by older drivers, the *elderly group.*

The experimental design included one within-subjects factor: the system conditions (one-system and two-system conditions); and one between-subjects factor: the driver groups (elderly and reference participants). To sum up and clarify, the independent variables used in this on-road experiment are expressed in the next table.

Table 11. Independent variables considered for the on-road experiment

Variable Name	Levels	Description
System Condition	One-system condition	Manoeuvres made with the help of the guidance system. The system transmitted visual and voice instructions. No other interactions with in-vehicle information systems were asked.
	Two-system condition	Manoeuvres made with the help of the same guidance system as for the previous condition. In addition, subjects were asked to conduct a mobile phone conversation that lasted the entire intersection area (100 meters before the centre of the intersection and 50 meters after).
Age condition	Elderly drivers	Drivers aged from 62 to 78 years old
	Reference drivers	Drivers aged from 34 to 47 years old

1.4.2 Dependent Variables

Dependent variables selected to measure the effect of the interaction with this type of in-vehicle systems, as well as for discovering age related differences, were established. In order to accomplish the objectives defined for the on-road experiment and also in accordance with the reviewed literature, a number of measures were selected to assess the driver mental workload. These variables belonged to three distinct categories: performance measures, subjective measures and also physiological measures (de Waard, 1996; Rubio, Díaz, Martín & Puente, 2004). A brief description of each category (performance measures, physiological measures and subjective measures) and also of each assessment technique used in the present experiment is given below.

Starting with performance measures, they can be split into two groups: primary and secondary task performance measures. For the present experiment primary task measurements were evaluated throughout turning indicators activation, breaking behaviour and moment to perform the turn. It was also included in this primary-task analysis data regarding the guidance performance: navigation errors and navigation behaviour. The evaluation of the guidance task in the primary task measures group is justified by the fact of being an embedded task, necessary to the execution of the driving task and to the completion of the main objective of the experiment. In what concerns the secondary-task performance measures it was included the evaluation of the mobile phone conversation, more specifically, what concerned the existence of a feedback given by the driver to the speaker, its moment and accuracy.

Additionally, physiological measures were also used for this experiment. The visual behaviour of the participants towards the on-road environment and also the guidance system display were analysed. This variable can be difficult to classify as it is related with the primary task performance, however it is reported as making part of the physiological measures. In opinion of de Waard (1996), the inclusion of visual behaviour in the physiological measurement group is due to one of the measurement techniques: the ElectroOculoGram.

The subjective workload assessment was performed via a global questionnaire and not throughout any of the techniques mentioned in the theoretical review (consult “Assessing the mental workload”). Those referred techniques were not applied due to the particular design of the experiment as well as due to some subjects’ characteristics.

Driving only one course was an advantage to avoid the learning effect but conditioned the application of a subjective method to measure the workload. These workload techniques are advised to be completed after each task or groups of tasks (see as example NASA, 1987). For its application in this specific context, and in order to evaluate the effects of an in-vehicle system with other reference situation, it is indicated to have a two trial experiment design. The immediate application of the technique after the trial completion is the most adequate procedure because it is reported that delays of more than 30 minutes in workload evaluation do not lead to significant differences (Eggmeier & Wilson, 1991). A two trial test would allow a proper application of the technique but could compromise the results of the experiment due to some learning effect.

Another reason that conditioned the choice of a subjective workload assessment technique was the time needed for its application. As the entire experiment was long and very demanding it was wanted a fast application technique in order not to fatigue subjects or compromise negatively their subjective evaluation. Techniques like SWAT and NASA-TLX were put away also for this reason (see Zhang, & Luximon, 2005; Rubio, Díaz, Martín, & Puente, 2004).

The last concern was the subjects' age. Once half of the participants were elderly (more than 62 years old) the choice of a subjective workload assessment technique required extra caution. One of the disadvantages of some techniques, specially of the multidimensional ones, is that they were originally developed for the aviation field and expected to be used by professionals (pilots) that have a more formal and profound conceptualization of their tasks. Even with the simplification of these techniques and its application to the road context, some still hold a great amount of complexity and can be hard to use, specially by some participants. One example of this difficulty and confusion regarding the different factors/dimensions can be seen in elderly drivers. In spite of not being a settle and confirmed disadvantage, there are cases reporting the complexity of application and lack of significant results within the elderly driver group (specially concerning the NASA-TLX).

Thus, it was decided not to apply a technique inadequately as it could compromise its validity. It was also stipulated that neither subjects should not get extremely tired or bored with the application of these types of assessment methods, nor elderly subjects should be confounded with too specific and technical terms. As a result, it was decided that none of the previously mentioned subjective workload assessment techniques were used and the self report evaluations would be presented by means of a simple questionnaire.

As various subjective techniques for the workload assessment are based on the reported "difficulty" to perform a task, at the end of the test participants had the opportunity to evaluate the difficulty of the course in both situations (with one system and with two systems) and indicate how they managed the different inputs. Modifications to the normal activity of driving were also encouraged to be reported in order to understand the consequences felt on the driving task.

To summarize, the following table shows the dependent variables used for this simulator experiment.

Table 12. Dependent variables used for the on-road experiment

Type of Variable		Object of Measure	Variable Name
Performance	Primary-task	**a.** Turning Indicators	• Omission errors • Timing errors
		b. Braking Behaviour	• Abrupt braking
		c. Moment to Turn	• Hesitations • Abrupt turns • Turn with vehicle near
		d. Dangerous Situations	• Near crash situations
		e. Navigation Errors	• Navigation errors
		f. Navigation Behaviour	• Help demanding • Hesitations • Expression of difficulty
	Secondary-task	**g.** Mobile Phone Task Performance	• Absence of repetition • Absence of answer • Incorrect answers
Physiological		**h.** Visual Behaviour	• Errors on glances towards intersection • Errors on glances towards mirrors • Number of glances towards guidance system • Mean glance duration towards guidance system
Self-Report		**i.** Perception of difficulty, distraction and behaviour changing	• Level of difficulty of the interaction with system(s) • Level of distraction felt due to interaction with system(s) • Level of difficulty to manage all inputs • Behaviour changing in the driving task

In the following paragraphs a deeper description of each dependent variable will be done in order to frame the measurements and justify some of the decisions taken during the analysis of the data.

a. Turning Indicators

The examination of the turning indicators was performed in order to register and evaluate some errors related with the driving task. This analysis was divided into two major categories of error: *omission* errors and *timing* errors. The first type of error was noted down when subjects forgot to activate the turning indicator during a turn manoeuvre. The second type was considered when the turning indicator was activated too late, i.e., a pair of meters or less from the beginning of the manoeuvre. By activating the turning indicator and by doing it in a proper moment, the driver informs the other road users of its intentions. The importance of this action is justified as it avoids possible communication conflicts between road users. Through its analysis, it is intended to observe if the hypothetical distraction imposed by an in-vehicle system leads to some changing in the turning indicator activation.

These variables (omission errors and timing errors) were analysed only for the target manoeuvres in two different moments: a first one through direct observation and a second by the surveillance of the video recordings of the test. The first codification was made by a driver instructor that travelled beside the participant during the experiment. This instructor marked down the referred errors by using an observational table specially adapted for this experiment, as it will be further explained in the following sub-chapters. Afterwards, these observational tables were compared with the video recording of the experiments. This validation was made by the researchers with the objective of verify if any register was missing.

b. Braking Behaviour

The braking behaviour was characterized by being a specific type of braking performed by the driver, more specifically when abrupt brakings occurred. Abrupt brakes are usually performed in emergency situations in order to compensate for inadequate actions like improper speed, unobserved events or lack of anticipation of some situations. This variable measures the longitudinal control of the driving performance by the quantification of the number of times the brake pedal is activated with higher force than usual. Throughout its analysis, it was intended to verify if the different conditions imposed to drivers lead to his/her distraction inducing to an impact on the number of abrupt braking performed.

The braking behaviour variable was analysed for the target manoeuvres based on the data collected and registered on the observational table mentioned earlier. In this table filled by the driving instructor, the abrupt brakes were marked down when arriving to a target intersection. This register was important to get to know the moments where participants felt the need to suddenly change their speed trajectory. It were not included situations where participants had to brake due to other driver or pedestrian unexpected or incoherent behaviour. It included only the moments where the participants changed their speed in order to correct their inadequate pace or attention behaviour.

c. Moment to Turn

With this dependent variable it was analysed the moment chosen by drivers to perform the turn manoeuvre and also some additional behaviours associated with that choice. When arriving to the centre of the intersection and immediately before performing the manoeuvre, three major aspects were observed: the continuity of the manoeuvre; the speed or sudden acceleration with witch it was made; and also the near presence of other vehicle with a “colliding trajectory”. Based on these three items three distinct dependent measures were analysed: *hesitation; abrupt turn*; and *turn with vehicle near*.

The first behaviour, *hesitation*, was characterized by an interruption on the continuity of the turn manoeuvre. It was coded when the driver started to turn and stopped or reduced suddenly the speed, showing evidently a changing in his/her first intention to turn.

The second behaviour named as *abrupt turn* was registered when the driver started the turn too fast, increasing the acceleration for its completion. This variable could be expressed by an abrupt turn of the steering wheel and/or an inappropriate speed increase at the turning moment.

Lastly, the third variable, *turn with vehicle near*, was registered when the driver choose to turn with another vehicle too close, i.e. a car that was close and which trajectory intercepted the course of the vehicle in test (some examples in Figure 20).

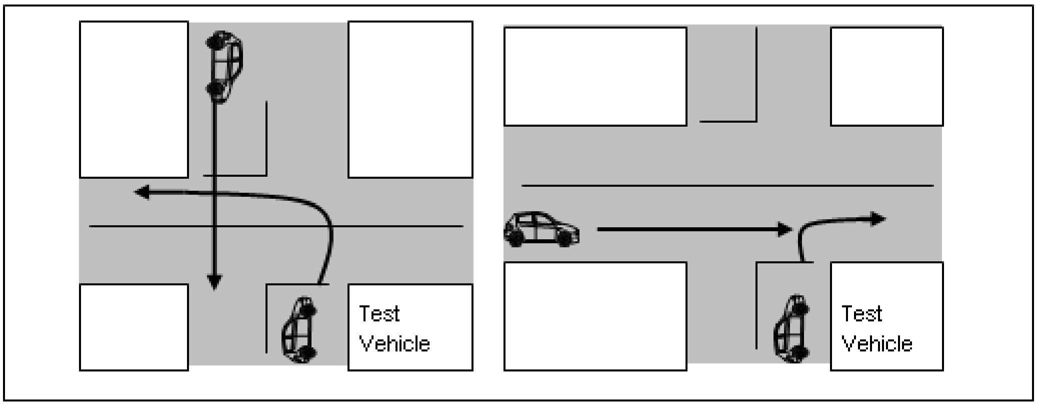

Figure 20. Examples of the *turn with vehicle near* situation

These types of behaviours, which can not be considered as belonging to a safe style of driving, may reveal some inadequacy in the moment chosen to perform the turn or in an unsafe way to do it. By analysing these variables, it is intended to observe if the different independent variables imposed to the experiment induce to a higher different of unsafe actions regarded with this decision process.
These data were collected for the target intersections with the help of the already mentioned observational table. Behaviours that revealed an inadequacy of the moment chosen to turn were noted down by the driver instructor. Like it was done for the turning indicator variables, the behaviours related with the moment to turn were later observed and confirmed by the researchers with the help of the video recordings.

d. Dangerous Situations

Dangerous situation variable represents the moments of imminent crash, meaning that a traffic conflict have occurred. This type of variable was already used in simulator studies (see as example Shinar, Tractinsky, & Compton, 2005) and can also be measured in on-road studies. For the present experiment traffic conflicts were marked whenever the participant placed him/herself in a safety critical situation and the instructor that travelled besides him/her had to interfere. These interventions from the instructor were crucial to avoid a crash or near crash situation between the participant and other road users. The instructor could intercede throughout activating the additional pedals installed in front of his seat and also by means of direct control of the steering wheel. These traffic conflicts were registered for target manoeuvres by the driver instructor with the help of the observational table and were latter on confirmed by the researchers through the observation of the video recordings.

e. Navigation Errors

Navigation errors can be considered as incoherencies between the instruction given by the guidance system and the action made by the driver. It happens when the participant stray from the route recommended by the system. If a system informs the subject that within 150 meters he/she has to turn left and if the driver continues in front, turns right or even turns left but in a wrong road, this can be considered as a navigation error. This variable allows analysing the guidance performance through the evaluation of the interaction between the driver and the in-vehicle system. The existence of such errors can reveal some inadequacy on the type of message transmitted or reveal that some kind of disturbance occurred while this message was sent.

The quantification of this variable was often used in studies that aimed to analyse the interaction with a navigation/guidance system. Some examples are: Burnett (2004); Burnett, & Joyner (1997); Srinivasan, & Jouvanis (1997); Wochinger, & Boehm-Davis (1997); Schraagen (1993). In the present experiment, this variable was measured for the target manoeuvres throughout the observation of the video recordings of the test.

f. Navigation Behaviour

During the course and while interacting with the guidance system, participants could react to the visual and voice messages sent. These visible reactions were also important to be analysed as they could reveal the doubts and difficulties felt while interacting with the guidance system. They could be a complement to the navigation errors analysis by showing the near errors and the main problems. For this experiment three dependent variables were considered in order to study the navigation behaviour: "*help*", "*hesitation*", and "*difficulty*". As for the other dependent variables, these measures were only observed for the target manoeuvres. The following table shows the behaviours categories and also their meaning.

Table 13. Behaviour categories and its description for the interaction with the guidance system

Behaviour	Description
Help	When the driver demands some help to the instructor that travels beside him/her, always regarding guidance instructions information.
Hesitation	When the driver begins an action and stops before its completion, like: activation of turning indicator and deactivation soon after; starting to turn the steering wheel to perform a turn and giving up the next moment.
Difficulty	When the driver express some difficulty verbally. Usually it is expressed by sentences like: "I don't understand the message!"; "What is it saying?

A similar examination was made by Burnett (2004) when he analysed the behaviour of the participants by coding the “near errors of navigation” that were defined “*as having occurred when participants behaviour suggested an obvious intention to make a wrong manoeuvre (e.g. incorrect indicating or slowing down) although they were able to correct themselves in time to make the turn*”. The usefulness of this type of analysis is justified because it reveals the driver’s difficulties even if no navigation errors occur. The categories “help”, “hesitation”, and “difficulty”, can be seen as expressions of the difficulty of drivers to cope with all information. However it is important to remember that not every participant expressed verbally their difficulties and many could felt uncomfortable doing it. Thus, even if the total number of reactions towards the guidance messages is not important, some comparison can be done between system conditions and drivers group. These variables were analysed throughout the video recordings of the experiment.

g. Mobile Phone Task Performance

The performance of the secondary task was also evaluated. Based on the video recordings of the experiment that included the audio data, responses of the participants were registered. As drivers were supposed to repeat the sentence and then evaluate if it was sensible or not, the analysis included the measurement of three distinct variables: *absence of repetition*, *absence of answer* and also *incorrect answers*. These variables that can be seen as incorrect performances on the secondary task, are important to understand if the mobile phone conversation was influenced by the simultaneous task performance. Similar studies have examined the mobile phone conversation and proved that performing simultaneous tasks (e.g. driving and conduct a conversation) has also a negative impact on the conversation. Some examples can be found in Luke, Smith, Parkes, and Burns, (2004) and in Burns, Parkes, Burton, Smith, and Burch (2002).

h. Visual Behaviour

It is reported that 90% of the information input in driving depends on the visual channel (Noguchi as cited in Akamatsu, Yoshioka, Imacho, Daimon, & Kawashima, 1997) and due to this fact the measurement of the visual performance is important on the analysis and evaluation of the human interaction with an in-vehicle information system. Its importance is also justified because this variable is directly related with the time drivers need to read the information in the systems displays. The interaction with an in-vehicle display can lead to driver distraction due to the allocation of their visual resources. The longer the driver looks away from the road scene the more likely is it that he/she will misses some safety critical information from the road environment (Lamble, Laakso, & Summala, 1999).

Two most commonly used visual behaviour variables for this type of analysis are the frequency and glance duration (Spyropoulou, Golias, Karlaftis as cited in HUMANIST, 2004). The glance frequency can be considered has the number of times a driver looks to a specific feature of the driving scene or of the in-vehicle display (HUMANIST, 2004). This eye pattern frequency was found to be related with the importance of the information from the instrument/equipment (Wilson, & Eggmeier, 1991). On the other hand, the glance duration quantifies the amount of time it takes a driver to extract information from a visual scene (HUMANIST, 2004) and was already related with the difficulty to obtain/interpret the information from the display (Wilson, & Eggmeier, 1991). These visual behaviour measurements have been used by several authors in their experiments. Some examples are: Lee, Forlizzi, & Hudson (2005); Burnet (2004); Huska-Chiroussel, & Magalhães (2002); Nunes, & Recarte (2002); Salvucci, & Macuga (2002); Gärtner, König, & Wittig, (2001); Tijerina, Johnston, Parmer, Winterbottom, & Goodman (2000); Burnett, & Joyner (1997); Graham, & Mitchell (1997); Zaidel, & Noy (1997); Daimon, & Kawashima (1996).

These two measures were used for the present experiment with two distinct objectives: the first one to study the visual behaviour of drivers towards the road environment before the beginning of the turn manoeuvre; the second to investigate the visual behaviour towards the guidance system. Based in these two goals, the analysis of the visual behaviour of participants during the on-road experiment was split into two distinct parts named as following: the *visual behaviour errors* and the *visual behaviour towards the guidance system*.

The first analysis, *visual behaviour errors*, was obtained throughout the direct observation of the driving instructor that filled out the observational table for all the target intersections. Based on the assumption that, to perform an intersection subjects have to look to specific points of the environment to collect information, the objective was to mark down every time those check point were not confirmed. Whenever the drivers missed to check visually an important point of the environment before starting to turn, the driver instructor coded it in the observational table as one error. Errors were subdivided into two different areas: *errors towards the intersection* and *errors towards the rear mirrors*. Checking the intersection area included looking to the junction to see if it was clear of vehicles and persons, but consisted also in verifying the oncoming traffic from different roads and also checking crosswalks. Checking the rear mirrors allowed participants to confirm if any vehicle was behind the participant’s car, avoiding accidents like for example overtake when the intention was turning left. It was not expected that drivers looked to all areas in all intersections. This means that for each junction only the relevant areas to perform a safe manoeuvre were considered and pointed down if not checked visually.

The annotations made by the instructor were later analysed and validated with the help of the video recording of the tests. This validation was made by the researchers with the objective of verifying if none of the observations were missing.

For the second analysis, *visual behaviour towards the guidance system*, the frequency and duration of glances towards the system display were registered. The goal was to know how often participants needed to get visual information from the system. Those two types of visual analysis were made only for each target intersection throughout the video recording of the test trials. As the objective was to analyse the same moments during the course, the period between the guidance system voice instruction and the centre of the target intersections were selected.

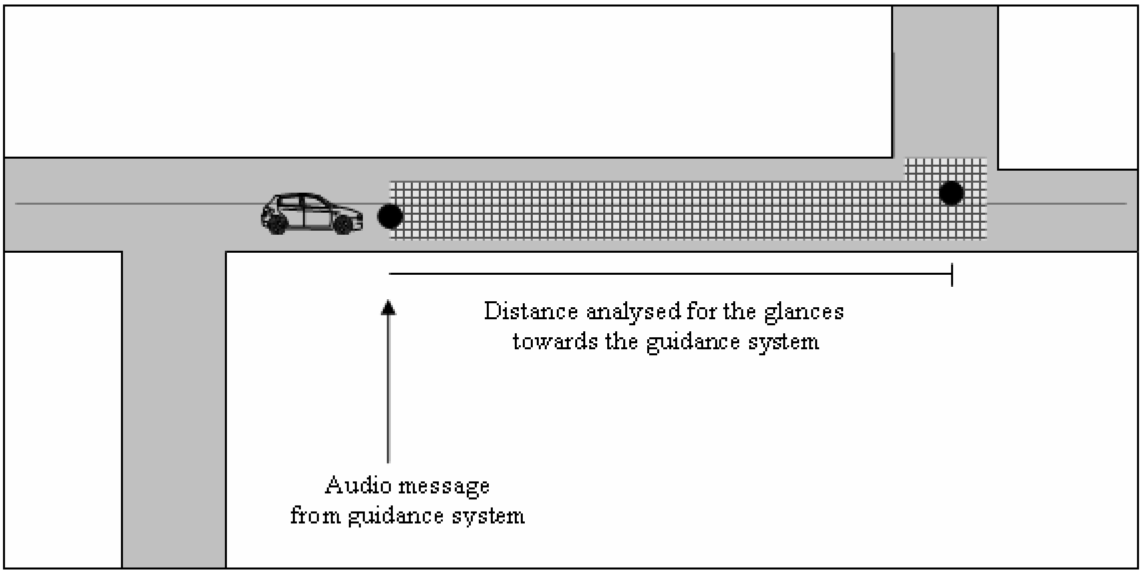

Figure 21. Sketch of the moment selected for analyse the glances towards the guidance system

To sum up, the visual behaviour analysis included the following measures:

Table 14. Measures included in the visual behaviour analysis

Visual Behaviour Errors	Glances towards the intersection
	Glances towards the rear mirrors
Visual Behaviour towards the guidance system	Average number of glances
	Mean glance duration

i. Self-Reports

After the completion of the on-road test, participants were asked to answer to some questions regarding the course. A questionnaire was prepared with the aim of register the opinions of participants about the entire experiment, the in-vehicle systems and also the interactions with those systems. It contained questions concerning the interaction with the guidance system alone, like the level of difficulty to understand its voice and visual information, the level of help given by it, and also the disturbance felt on the driving task during this interaction. Following, questions concerning the simultaneous interaction with both guidance and mobile phone systems were made, like the level of difficulty to manage all the inputs, to which source of information they had given priority and if participants felt having modified their driving behaviour (see complete questionnaire in Appendix IV).

2. Data Collection

The collection of all data was performed mainly throughout the recording of the dynamic parameters of the vehicle, the video recording of tests, by the use of an observational table and also a questionnaire.

The collection of the dynamic parameters of the vehicle was done by means of a PC installed in the luggage compartment of the car. A program made specially for this on-road experiment was installed in the computer for recording the data into a file. During the experiment, the values obtained from the vehicle speed, the pressure on the pedals, the turning indicator activation and also the distance driven were shown by means of an image on the display mounted in the back seat area of the vehicle. This image was also captured by the multiplexer and registered by the VCR together with the other four images from the mini-cameras. Thus, the collection of dynamic data allowed the production of two separate forms of information: 1) a text file that could be later converted to an excel file; 2) a visual interface that could be observed in the video recordings.

The video recording of the tests, that contained the image of the four cameras and also of the program interface that captured the dynamic parameters of the vehicle, were used to analyse the activation of the turning indicators, the navigation errors, the navigation behaviour, the performance on the mobile phone task (since the sound was also recorded) and the visual behaviour of the driver. The video recordings were also used to verify some variables analysed through the observational table like the moment to turn and the dangerous situations.

As it was already mentioned, some variables were measured using an observational table developed specially for this experiment. This observational table was built based on the structure and principles of "The Wiener Fahrprobe". The Wiener Fahrprobe is a method that aims for registering the participants' behaviour while driving, pointing down several variables. It can be used by either one or two observers and the register is done throughout standardised and non-standardised topics, i.e., expected behaviours or actions and also non-predictable events. Its original idea of application was to analyse the driving behaviour in order to assure that a subject was apt for driving a vehicle (Risser, 1985; Turetschek, & Risser, 2004).

For the present experiment, the table was built to register the behaviour of the driver during intersections, including the preparation phase after the guidance system voice instruction. It was composed by eight main topics that were discriminated with more detail in an adjacent column. The main topics were actions regarded with:

- the *navigation*;
- the *turning indicator signs*;
- the *driving behaviour* for the moment of the turn;
- the *trajectory* of the vehicle;
- the *interaction with the other road users*;
- the *road signs*;
- the *visual behaviour* towards the more important areas of the road environment (like the rear mirrors and the intersections itself);
- and also the *gear management*.

In each main topic, the more probable and frequently predicted actions were pointed down in order to be ticked during the observation, if it was the case. However, non-predicted actions should also be registered in a specific area that was added in each table.

For each target intersections there was a single table printed in a sheet in order to register only the behaviour of the driver for that specific manoeuvre. Tables were adequately marked with a specific header for each target intersection.

Due to the complex logistic of the experience, specially concerning the mobile phone calls and the moments in which they should be done, the observation table had to be filled in by other person besides the researcher. Since it was deliberated by the group of researchers and technical team that, for security reasons, a driver instructor was always travelling besides participants, it was decided to investigate with the instructor the possibility of being him to fill out the observational table. A meeting was prepared with the driver instructor and, after explaining the objectives of the experiment, the driver instructor agreed to be the one in charge to complete the table. Before the beginning of the tests, the observational grid was showed to the instructor in order to inform him how to register the actions and in which moments. Taking advantage of his advises and expertise, the grid was improved and the final version was elaborated. (To complete overview of the observational table see Appendix V)

3. Experiment Procedure

The procedure of the on-road experiment was composed by three distinct phases: the first one regarding the presentation of the experiment, the systems that would be used and the specific tasks that had to be performed; the second phase related with the training period in order for participants to get familiar with the vehicle, to the navigation system and also to the mobile phone system; and finally the third moment that included the test itself.

Experiments occurred between the end of July and the beginning of September of 2006, from Monday to Friday. In average, two subjects performed the experiment per day, one in the morning period and another one in the afternoon. The moments with higher picks of traffic were avoided; the morning test started always after 9.30 am and ended before 13.00 am and in the afternoon test started after 2.00 pm and ended before 6.00 pm. The complete procedures will be described with further detail in the following paragraphs.

3.1 Presentation of the Experiment

Upon arrival at the laboratory, participants were accompanied to an office near the garage where the test vehicle was parked. In this room subjects were welcomed by the researchers and the context in which the experiment was being carried out was explained. A paper with the main objectives of the experiment as well as the tasks that had to be performed was read to subjects. After all the test explanations, and if subjects still agreed to participate, a consent term was presented in order to validate their willingness to continue with the experiment. The consent term described briefly once again the context and main objectives of the experiment, the anonymity of the participants' identity and what was going to be done with the results of the tests. Subjects were also asked to fill a paper with their name, address and number of bank account so that they could be paid (80€) for their participation.

Afterwards, subjects were submitted to some vision and audition tests (ergovision and audiometer) in order to assure that they didn't had any problems that could interfere with the experiment and compromise the results. At the ergovision, binocular vision-sharpness was observed for close, far and intermediate vision; the audiometer tests were made in accordance with the age of each subject, witnessing also the hearing acuity needed for this experiment. The performed tests didn't exclude any subject: all the selected participants had an acceptable level of vision and audio-sharpness. In spite of some participants had some vision problems, mainly in the far and close vision, they were corrected through the use of their own glasses.

Following the audition and vision testes, participants answered to a questionnaire containing topics related to their socio-demographic characteristics, driving habits, and attitudes towards the mobile phones and navigation systems (Appendix VI). It contained also questions to investigate their opinion about new technologies inside the vehicle and also their attitudes toward the use of this type of in-vehicle equipments, specially mobile phones and navigation /guidance systems. Answers given by participants were filled in the questionnaire by the researcher. During the application of the questionnaire the researcher and the participant were conveniently seated inside the office near the garage.

To complete the first part of the experiment the tasks that had to be performed during the experiment were explained with more detail to participants. The navigation system was presented as well as its main functions and features exhibit on the display. The additional task of conducting a mobile phone conversation was also described in detail. A small training was conducted face-to-face in order to practice the questions that would be performed and the type of answers that should be given.

This first part lasted between 30 to 40 minutes and at the end participants were accompanied to the garage where the test vehicle was parked.

3.2 Training Period

Before the test itself, subjects had the opportunity to get to know the test vehicle and the other instruments with which they had to interact. In order to do so, researchers prepared previously a smaller course that was done with the help of the guidance system instructions. Before starting it, a final destination of a parking area near the institute was entered in the system as well as two intermediate points, used to enlarge the training course. Participants were asked to step into the vehicle and to adjust the seat and the rear mirrors as they pleased. The display of the guidance system was showed as well as the interface buttons to the mobile phone. The driver instructor that was going to accompany the driver for safety reasons was also present in the training course. He sat up beside the driver and before the training period adjusted also the mirrors used to observe the driver behaviour. A researcher was also travelling in the back seat of the car. The objective of these training periods was mainly to allow participants to get to know the vehicle and the other systems, but also to check if all the equipments were functioning properly and if everyone involved in the experiment was prepared.

After all the adjustments inside the vehicle and also the introduction of the destination in the guidance system, the training period began.

In the first moments of the training period participants got familiarized with the vehicle and also with the guidance system as it was activated since the beginning of the training course. The driver instructor and also the researcher were allowed to give some help or to provide additional information whenever the driver requested to. After a period of approximately 15 minutes the researcher advised the participant that the additional mobile phone task would be added.

In order to start the mobile phone task the researcher travelling in the experimental car sent a signal to the researcher in the laboratory. This signal (a call that was disconnected after the first ring was heard) was made throughout another mobile phone different from the one that was installed in the vehicle. After the researcher in the laboratory received the signal, a call was made to the mobile phone of the vehicle. To answer the call the driver had to push the green button placed in the centre of the dashboard. Each call lasted in average 20 seconds so that participants could give feedback to three or four questions. A minimum of three calls were performed so that subjects could get used to the additional task.

If needed participants could always extend their period of training. After the training period reached its end participant were also questioned if they had some doubts or if some things were not explained properly.

Before starting the test, the researcher entered the final destination and the intermediate points for the course completion. The program to record the dynamic data of the vehicle was turned on as well as the VCR and the multiplexer for capturing the images of the mini-cameras.

The complete training period lasted approximately 20 to 30 minutes and when everything was prepared the experiment began.

3.3 On-Road Test

After the training period, the on-road test started. As it was a very demanding test due to the fact that participants had to interact with two distinct in-vehicle systems, and also because the sample was composed by half of elderly drivers, it was decided that a driver instructor should accompany the subjects and use the second set of pedals installed in the vehicle. The driver instructor was always the same and present at all times for the tests and training periods. During the tests the driver instructor had also to evaluate the behaviour of the participant in the target intersections using the observational table previously built by the researchers. He was chosen to perform this task because he was the one travelling besides the driver and could make a better observation of the participant. Additionally, due to his professional experience, he had a better ability and train to observe the drivers' actions and evaluate their behaviour.

The researcher that travelled in the back seat of the vehicle was assigned to send the signal to the researcher in the laboratory, in order to initiate the mobile phone task at the correct moment. In spite of these being pre-determined moments, the researcher had to make small adjustments to compensate for the traffic, the speed of the participant or even some traffic lights. The researcher had also the mission to monitor the PC display that was in front of her. This screen was placed behind the driver instructor's seat and showed the interface of the program conceived to capture the dynamic parameters of the vehicle. This task was important to verify if these data was being properly recorded to the PC.

Contrarily to the training period, during tests neither the instructor nor the researcher was allowed to communicate with the driver. Participants were previously informed about this rule and its justification. This communication could not be done specially during the target intersections, even if subjects had doubts or questions concerning the guidance system instructions. This situation occurred because participants should not be influenced by the guidance opinions of others. They should make their own decisions based on their perception of the guidance system messages even if that decision led to a navigation error. Whenever a navigation system error occurred, i.e. when the guidance system indicated a manoeuvre that was not followed by the driver, the system recalculated a new path so that the driver could reach to destination.

As there was only one course to avoid that participants learned the path, the moments where the mobile phone task was performed had to be distributed equally throughout the target intersections. Half of the target manoeuvres had to be performed with the mobile phone conversation and the other half without. However the target intersections done in the presence of the additional task should not always be the same for all participants. To manage this situation two different orders in the allocation of the mobile phone task were made: the *order A* and the *order B*. The intersections that include the mobile phone conversation in the order *A* were performed without it in the order *B*, and vice-versa (a schematic form of this information can be seen in the Appendix VII).

Subjects were balanced throughout these two orders being taken into account their age group and gender. Each subject only drove the course once being previously allocated the order A or B. The following table elucidates about the number of subjects in each order.

Table 15 . Subjects' balancing throughout the orders for the completion of the experiment

	Order A (10 intersections with the mobile phone)	**Order B** (other different 10 intersections with the mobile phone)
Elderly Group	N= 8 (4 men, 4 women)	N= 8 (4 men, 4 women)
Reference Group	N= 8 (4 men, 4 women)	N= 8 (4 men, 4 women)

The duration of each course depended on the driving speed of each subject, the traffic conditions and also on the number of navigation errors made. It lasted approximately between 35 to 50 minutes. The final destination was the institute and at the arrival the vehicle was left in front of the garage. Participants were accompanied into the office where they were welcomed and a final questionnaire was filled in. In this questionnaire subjects had the opportunity to give their opinion about the test itself, the guidance system and its instructions, the mobile phone task, the disturbance induced by these systems on the driving task and also the level of difficulty felt to perform the intersection while interacting with one or two in-vehicle equipments. When completed participants were thanked by their participation.

The complete experiment including the three mentioned parts lasted approximately 90 to 120 minutes to be completed.

CHAPTER 2: SIMULATOR EXPERIMENT

In order to fulfil the objectives established at the beginning of the research, a simulator experiment was also conducted. As for the on-road tests, this second experiment had the aim of investigate the influence of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. Thus, the driver interaction with a navigation system and a mobile phone was also analysed.

Three other reasons justified the development of this simulator experiment. The first one was related with the intention of confirming some results obtained in the on-road experiment in order to present more consistent conclusions. The second one regarded the purpose of measuring specific variables that could not be measured for the on-road experiment or their measurement would have been very difficult to analyse and could not produce trustworthy outcomes. The third reason for conducting a simulated experiment was linked with the intention of having a baseline condition that didn't impose to drivers an interaction with an in-vehicle system. This baseline condition was very difficult to implement on the on-road experiment because drivers had to perform the same number of manoeuvres and in similar conditions without a guidance device. As the baseline course had to be equal for every subject, the possibility of another passenger sending the guidance instructions did not appear to be the most ideal baseline and the option of giving guidance instructions previously to the course could had a non-desired effect, being also very time consuming.

For those reasons the simulated experiment had a similar design to the on-road tests but with an additional condition: a baseline without the presence of an in-vehicle information system. Thus, in the simulator experiment it was intended to compare these three distinct conditions: driving without an on-board device; driving with the presence of one in-vehicle system; and driving with the presence of two-in-vehicle equipments.

Knowing that in-vehicle systems are very different from one another and that generalisations are very dangerous to be made, in a more specific manner it was intended to compare: driving; driving with a guidance system; and driving with a guidance system and a mobile phone device. The inclusion of this baseline was expected to bring some additional knowledge regarding the effect of a guidance system on the driving behaviour and also help to highlight and justify the consequences that both in-vehicle systems could produce on the driving activity.

Therefore, the objectives of the simulator experiment were:

1. to verify the consequences on the driving task induced by the interaction with one in-vehicle device: a guidance system;

2. to determine the consequences on the driving task produced by the simultaneous interaction with a guidance system and a mobile phone device;

3. to identify changes on the driver mental workload while receiving information from one and two in-vehicle information systems;

4. to verify the effects that the interaction with both in-vehicle devices produce on the guidance and on the mobile phone task performance;

5. to determine age-related differences in the driving task performance produced by the interaction with the guidance system and also by the simultaneous interaction with the guidance equipment and the mobile phone device.

1. Method

1.1 Test Participants

Thirty two subjects took part on this experiment. They were divided into two different age categories: 16 elderly drivers aged from 59 to 79 years old (mean age 64,7 ; S.D.=5,1); and 16 reference drivers with 29 to 46 years old (mean age 33,8 ; S.D.= 5,0). The sample was composed by an equal number of males and females (8 males and 8 females in each age group). Participants were recruited from the general public, via local advertisements at the university where the tests were conducted, web notices and also trough mail messages that were sent to all students, teachers and other professionals.

In order for subjects to participate in the simulator experiment, besides the age condition, they had to satisfy the following criteria: to have driving licence for at least five years; to have driven at least 10000 kilometres and to possess a mobile phone. For besides these criteria, subjects had also to report normal or corrected-to-normal vision and no severe hearing problem that could stop them to hear other people talking.

Table 16. Characterization of the sample's age

Age Group	N	Maximum	Minimum	Mean	Std. Deviation
Elderly driver group	16	79	59	64.7	5.1
Reference driver group	16	46	29	33.8	5.0
Total Sample	32	79	29	49.2	16.4

From the 16 elderly drivers, 12 were already retired being the other 4 still actively working. All reference drivers had a job at the current moment. Every subject had a car of their own and the average of kilometres driven in the last 12 months was a bit higher for the elderly group (13 400 Km for the reference drivers and 15 300 Km for the elderly drivers). Almost all reference participants drove seven days per week while their older counterparts drove, in average, six days a week. The majority of drivers (thirty) stated to frequently use the vehicle to go working or to do other daily activities. City roads and also highways were frequently referred as the most used by respondents.

Every inquired subject had a mobile phone and in terms of general frequency of use both age groups had similar mean frequency of daily usage (elderly drivers= 6.7 times/day; reference drivers= 6.5 times/day). In average, reference drivers had their mobile phones for 10 years while elderly drivers only for 7. When asked about the use of mobile phones while driving, almost all subject affirmed that they had already interacted with a mobile phone in a recent past during driving. Only two women answered negatively to that question, one belonging to the reference group and other to the elderly group. As it can be seen in the following figure, more reference subjects used the mobile phone in the car daily (meaning that they interact with it at least once per day). A higher number of elderly subjects had lower frequency of use of such device. When compared it can be observed that 10 older participants affirmed to use their mobile phone in the car "monthly" (some times per month) or even less ("rarely") and only 7 reference subjects are in this category.

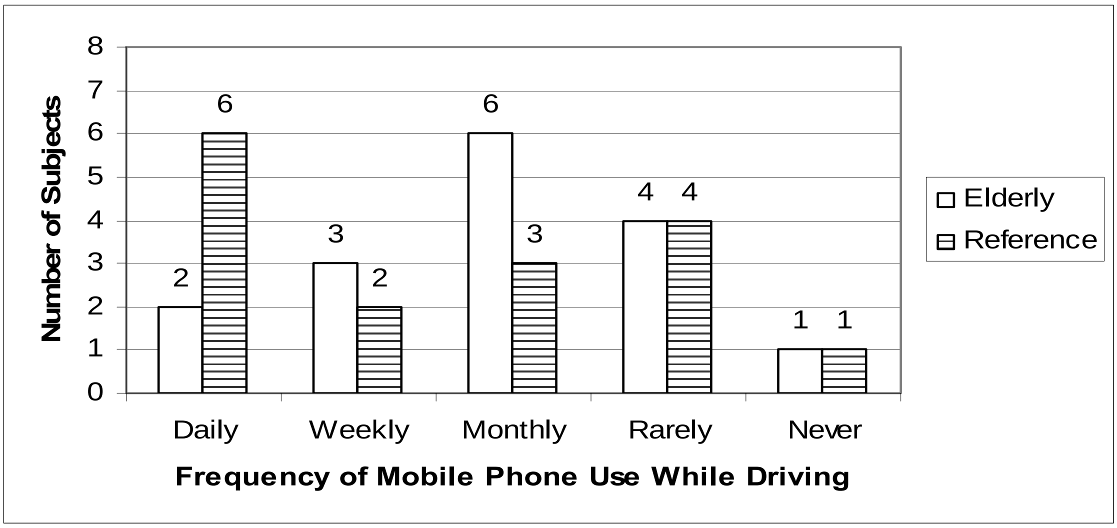

Figure 22. Frequency of mobile phone use while driving for each driver group

Considering participants that used their mobile phone in the car (30 subjects), nineteen had a hands-free system (hander-free kit or a loudspeaker), 11 belonging to the elderly group and 8 to the younger cluster. This means that, in this sample, a higher frequency of elderly drivers possessed a hands-free system. However, having such system doesn't mean that it is always used. As it can be seen in the next table, only 5 of the 19 subjects used it every time they interacted with the mobile phone call in the car. Nine subjects use it rarely or have never used it. When a comparison within groups is made, it is observed that a higher percentage of reference drivers use the hands-free system at least "frequently".

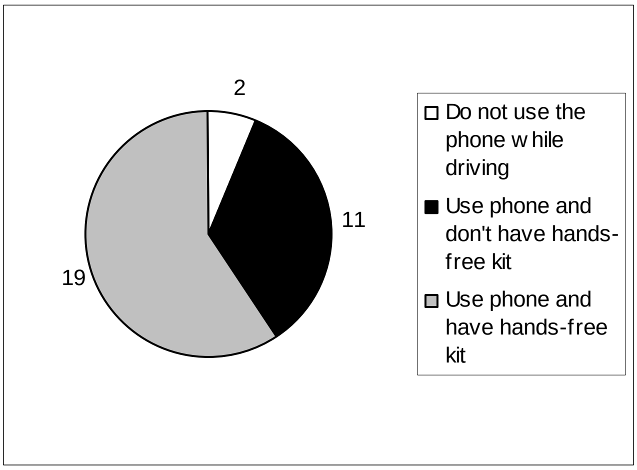

Figure 23. Percentage of subjects that use the mobile phone and the hands-free kit while driving

Table 17. Frequency of use of a hands-free system

	Always	**Frequently**	**Occasionally**	**Rarely**	**Never**	**Total**
Reference	3 (37,5%)	2 (25,0%)	1 (12,5%)	2 (25,0%)	0 (0%)	8 (100%)
Elderly	2 (18,2%)	1 (9,1%)	1 (9,1%)	3 (27,3%)	4 (36,4%)	11 (100%)

Participants were asked about when they have bought the hands-free system and if it was related with the recently approved law that forbidden drivers to handle the phone while driving. Nine subjects affirmed to have bought the system when acquired the mobile phone, being this acquisition not directly related with the law. Five referred having bought the kit after the new code and just one when the law changed. The fact of being safer to conduct a mobile phone conversation while driving with a hands-free kit, was presented as the reason more frequently mentioned to justify its purchase (8 subjects).

When asked if participants avoided answering calls in specific situations, almost all (26 subjects) answers positively. The situations more frequently referred as dangerous were "intense traffic" and also "intersections and roundabouts". When driver groups were compared, it could be observed that elderly participants affirmed to avoid a higher number of situations. Three elderly participants stated avoiding practically all mentioned situations and tried only to answer the mobile phone when they could stop the car. Other situation that elderly also avoided was making phone calls. When asked about it, only two confirmed making phone calls while driving compared to six of their younger counterparts. All participants affirming to make calls after select specific moments like roads with hardly any traffic, straight roads, traffic jams and also when stopped at traffic lights.

While interacting with the mobile phone almost all drivers (27 subjects) reported adopting a different behaviour. After analysing this question it could be observed that reference drivers mentioned more often to “reducing the speed” while elderly referred repeatedly “stop on the road hard shoulder” to interact with the mobile phone.

Sending or reading sms (short message service) is something that elderly drivers reported not to do, being the only positive answers (six subjects) obtained from reference participants. Three mentioned doing it “once in a while” and the other three “rarely”.

Regarding the use of navigation systems, six subjects reported having already tried to interact with such equipments (three belonged to the reference group and the other three to the elderly group). However, only two subjects possessed a navigation system: one elderly driver that had a nomadic system and reported using it “rarely”; and a reference driver with a navigation system fitted as standard that indicated using it “once in a while”.

From the other 30 subjects that didn’t possess a navigation system, 17 declared the desire to have one. Nevertheless, despite this desire much consider that it is not an object of extreme importance (19 subjects). Five participants didn’t point out a specific justification for not having a guidance system, answering that it was a matter that they didn’t give much attention to. Two subjects revealed that they didn’t want an equipment like this because they only travelled in familiar areas; two consider that it could be a bit dangerous and distractive and the other two consider them very expensive.

Regarding both participants that possessed a navigation system, when questioned about the instructions they prefer to receive, two different answers were given: the elderly driver preferred instructions given throughout a map and the reference driver liked the arrows (turn-by-turn function). Both navigation systems were positioned in distinct places inside the vehicle. The elderly driver, which had a nomadic system, placed it on the top/centre of the dashboard to the right of the steering wheel; the system fitted as standard of the reference driver displayed visual information on the control panel of the car and also in the centre of the dashboard (a lower position when compared with the nomadic system of the other subject). Both systems had audio instructions that were used frequently by both drivers however the elderly driver reported avoiding using the system in some occasions because it was annoying and sent too much information.

When questioned if they had already experienced the interference of a phone call while receiving navigation instructions, both subjects answered affirmatively. The younger driver stated that, after accepting the call, he received audio messages from both systems at the same time. At that similar situation, the participant from the elderly group chose not to answer the call.

1.2 Test Vehicle and Instrumentation

The simulator experiment took place in Porto (Portugal) at FEUP (Faculdade de Engenharia da Universidade do Porto) between the months of January and May 2007. The simulator was located in a room that belonged to the Traffic Analysis Laboratory (LAT - Laboratório de Análise de Tráfego), a space specially allocated for these types of experiments. Inside this room there was a real vehicle (Volvo 440 turbo), a video projector hung to the ceiling above the car, and one screen (2,5 meters height and 3,5 meters length) in front of the vehicle to project the simulated road environment. In order to allow an in-car environment as real as possible during the experiment, almost all instruments inside the car were functioning: the three pedals, steering wheel, turning indicators, gear, and control panel (to know more about the technical features see Campos, 2006). The control panel of the car was composed by digital screen that was placed behind the steering wheel and displayed the speed of the vehicle, the motor rotation and also the gear.

The driver's seat could be adjusted so that participants could reach comfortably the pedals; the seatbelt could also be utilized. In order to add reality into the experiment, the simulator had a force feedback system mounted on the steering wheel and the pressure needed to activate the three pedals was adjusted in order to be compatible with a regular car. To compensate the fact of not having a dynamic feedback (once it was a fixed-base simulator), a sound system with two audio amplifiers and a group of four loudspeakers was mounted. These equipments reproduced the sound effects of the car depending on the driving speed and the motor rotation. In order to improve the drivers' vision towards the screen the curtains of the room were closed during the experiment.

Figure 24. Image of the simulator room with the car and the screen for the projection of the road scenario

The car was equipped with a simulated guidance system placed in the centre of the dashboard to the right side of the steering wheel. It was composed by a TFT display with 6.5 inches and displayed guidance instructions indicating the directions to the following manoeuvre (throughout arrows). Between turn manoeuvres the system showed an arrow pointing forward. This simulated guidance system also sent voice messages 200 meters before manoeuvres. Messages were short and broadcast the direction that participant should take (e.g. "At the next intersection turn left.").

For besides the guidance instructions, the TFT screen was also programmed to be the interface to the mobile phone. On the left side of the guidance instructions two simulated buttons were always showed, a green one to answer a call and a red one to hang up. The voice messages of both systems (guidance system and mobile phone) were transmitted throughout the loudspeakers of the car. To capture the conversation that had to be held by participants to perform the mobile phone task, a microphone was hidden in the dashboard (see "Development of road scenarios" for further details).

To register all the important data four mini video-cameras were strategically placed to capture images from specific points. One of the cameras was directed towards the face of participants in order to get data from the driver's visual behaviour. The second camera was registering the road scenario and the third one the visual guidance messages that were sent to the subject. The fourth camera was faced to the mobile phone buttons so that the interaction between the driver and this system could be seen.

In the experiment room, there was also a table with two chairs. They were utilized in the beginning, when the researcher explained the objectives of the experiment and also the tasks that participants had to perform. A first questionnaire was also filled in this place. Next to this experiment area there was another room with three computers that generated the road scenario, the sound, the guidance messages and also the mobile phone task. In this adjacent room there was also a multiplexer that gathered the images sent by the cameras and another computer allocated to record those images. (See Appendix VIII)

1.3 Experiment Scenarios and Tasks

1.3.1 Development of the Road Scenarios

In order to make this experiment possible it was elaborated a base scenario that was used in three distinct situations. This base scenario represented a single carriageway road in a rural environment with two-way traffic, and approximately 6400 meters long.

It had seven junctions along the entire course, belonging to two types of road configuration: five with X shape and two T shape (Figure 26).

Figure 25. Image of the simulated road environment

Almost all intersections had a distance from each other of 600 meters, except intersection 5 and 6 that were 2000 meters apart. The course began with a road with an extension of 1400 meters followed by the first intersection in X shape. These 1400 meters were designed to give participants the opportunity to adjust and adapt to the course before beginning the manoeuvres. The longer road section between intersection 5 and 6 was intentionally placed on the second half of the course, allowing drivers to change road configuration to avoid potential sickness caused by the turn manoeuvres. As it was intended that participants reached the end of the course even if any navigation errors occurred, the course was prepared so that drivers could continue driving independently of the direction chosen.

The presence of other elements in the road environment was considered important to add realism to the scenario. Hence, some cars travelled along the course and the test participants could encounter them in the straight road sections and also at intersections. The main objective for the introduction of these vehicles was to approach the simulated scenario as much as possible to real conditions, transmitting to drivers that they were not alone on the road, encouraging them to comply the road traffic rules.

During each straight road section, one to two regular cars crossed the participant as incoming traffic. For junctions two possible situations were designed: 1) intersections where the driver had to yield right-of-way to the other vehicles in the road; 2) intersections where the driver had the priority over the other cars. The six intersections where subjects had to perform turn manoeuvres were split into these two situations, leading to three manoeuvres in each group. There were always one or more cars arriving to intersections, approximately at the same time as participants. However, its actions were depending on the type of priority given. For intersections where test participants didn't have priority, the other vehicles passed through intersections without stopping. In these cases there were stop or give way signs to inform subjects. For junctions where participants had priority of passage, the other cars arriving to the intersection stopped to let the test car pass. In any case vertical signs indicating the proximity of a junction were present 150 meters before.

The main goal was to get to a specific destination: "Areosa", the real name of a little village in the north of Portugal, near the university where participants were performing the tests. It was intended that drivers reached the destination using two different guidance methods and, in a third situation, using one of the guidance methods and performing another additional task. Thus, using this base scenario, three different courses were elaborated, each of them with specific characteristics.

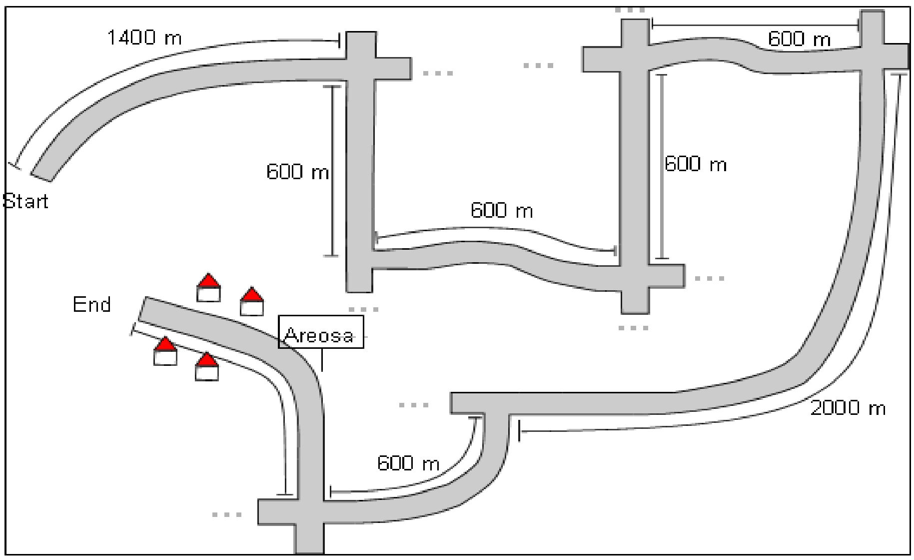

Figure 26. Sketch of the base scenario

The first course, named as *baseline* course, contained direction signs along the road to guide drivers to “Areosa”. The signs were located in two different places: 200 meters before an intersection and in the road hard shoulder near the intersection. Direction signs had a maximum of four plaques with names of villages pointing to different directions. Depending on the direction indicated by the plaque with the name “Areosa”, subjects had to perform the manoeuvre to the right or to the left. Six of the seven intersections had information to instruct drivers to make a turn: three to the right and three to the left. The sequence in which turns were supposed to be performed in this scenario can be clearly seen in the next table.

Figure 27. Example of a direction sign placed in the first course (baseline course)

Table 18. Sequence of manoeuvres for the first course (baseline course)

Intersection number	Type of Intersection	Direction to Take
1	┼	Turn right
2	├	Turn left
3	┼	Go straight
4	┼	Turn right
5	┼	Turn right
6	├	Turn left
7	┼	Turn left

For the second course, the base scenario was also used but there were no vertical signs on the road. In order to reach “Areosa” a simulated route guidance system was mounted inside the vehicle to send instructions to participants. The system sent information through arrows that indicated the direction for each intersection (turn-by-turn instructions). Bellow the direction arrow was the distance countdown bar indicating the remained distance to the following manoeuvre. In between manoeuvres an arrow pointing forward was showed and there was no distance indication.

Figure 28. Location of the simulated route guidance system inside the vehicle

The system had also voice instructions: a male voice indicated the existence of an intersection and the direction to take ("*At the next intersection, turn left*" or "*At the next intersection, turn right*"). Another voice message was sent to participants at the end of the course: "*You arrived to the destination. Please, stop the car*". No other audio messages were sent by the simulated route guidance system during the course.

The visual and the voice messages were sent both at the same time two hundred meters before an intersection. This information was previously programmed to be transmitted automatically at the same distance in all junctions. As participants approached the intersection the system displayed the distance, counting down to 0 in 50 meter increments: from "200m" to "150m", to "100m", to "50m" and finally to "0m" when the vehicle reached the centre of the intersection. This countdown information was also done automatically by the simulator and appeared always at the same moments for all the junctions.

In this second scenario, which was called *one-system* course, the manoeuvres sequence was different from the baseline course because it was intended to avoid a learning effect. Hence, the order of the one-system course was the following:

Table 19. Sequence of intersections for the one-system course

Intersection number	**Type of Intersection**	**Direction to Take**
1	┼	Turn right
2	├	Turn left
3	┼	Turn right
4	┼	Turn right
5	┼	Go straight
6	├	Turn left
7	┼	Turn left

The third course of this experiment included also the simulated route guidance system. However, another system was added once it was intended that participants conducted a mobile phone conversation while driving.

The course was prepared to send a mobile phone call in two specific moments of the trip: approximately 400 meters before the first intersection and also 400 meters before the sixth junction. The duration of each call was dependent on the travel speed, being the experiment designed to have the mobile phone conversation during six turn manoeuvres. Hanging up a call was not a responsibility of participants but of the researcher, to which subjects were advised in advance.

Figure 29. Image of a guidance instruction and the mobile phone interface

The mobile phone task (sentences) was previously recorded to a computer in order to provide to subjects always the same inputs. Whenever the mobile phone task was activated by the computer (done automatically), the researcher started to send the pre-recorded sentences via computer once at a time. The pace to which sentences were transmitted to drivers could be controlled by the investigator. Nevertheless, their rhythm depended on the pace of the driver to answer the previous question. The mobile phone interface was in an adjacent position to the guidance instructions (Figure 29). This interface was composed by a green button to answer the call and a red one to hang up (that was not used by participants at the experiment).

Once again, the sequence of turns was not the same as for the other two courses in order to avoid a learning effect. The order to the *two-system* course was as following:

Table 20. Sequence of intersections for the two-system course

Intersection number	**Type of Intersection**	**Direction to Take**
1	┼	Turn left
2	├	Turn left
3	┼	Turn right
4	┼	Turn right
5	┼	Go straight
6	├	Turn left
7	┼	Turn right

1.3.2 The Mobile Phone Task

As it was previously explained, in the third course (two-system situation), participants were asked to drive the simulator oriented by a guidance system, and at the same time to conduct a mobile phone conversation. This simulated conversation consisted in a series of sentences previously recorded and sent by the experimenter through a computer. This additional task was the same as for the on-road experiment.

In order to complete the task, subjects had to listen to a sentence, repeated it, and answer "*yes*" if the sentence was sensible, and "*no*" if it was not. For example: "*Usually, weeks have 9 days*" to which subjects had to repeat and then answer "*No*". This mobile phone task was based on the "decision part" of the Working Memory Span Test (Baddeley et al., 1985; Alm & Nilsson, 1995). A repetition part was added in order to certify that the correct sentence was heard and to better judge the accuracy of the answer. All the sentences had 14 syllables and took the same time to be pronounced (approximately 3 seconds).

The order in which sentences were presented was always the same for all subjects. This order was randomly created by the computer, throughout a visual basic program specially created for that purpose. The test contained 50% sensible and 50% nonsensical sentences. In the first mobile phone call, this additional task started with the first sentence of the list; however for the second call the first sentence could differ from subjects to subject because it depended on the number of sentences answered before. The rhythm with which they were sent depended on the pace of the driver to answer the previous question (See Appendix III).

1.4 Variables Definition

1.4.1 Independent Variables

To accomplish the objectives proposed for this study, the design of the present experiment included specific independent variables. The influence of in-vehicle technology on the driver behaviour was the basis for the establishment of the first independent variable named *system condition*. This condition included the three distinct courses already exposed above, being each designated as: *baseline* condition; *one-system* condition, and *two-system* condition.

A second independent variable was defined in order to study the performance differences between two groups of participants. Designated as *age condition* it included two driver groups with distinct ages: *elderly drivers* that had more than 60 years old and *reference drivers* that were composed by younger but experienced drivers.

Those two independent variables were considered for the analysis of all the measures performed in this simulator experience. The experimental design included one within-subjects factor: the system condition (baseline, one-system and two-system conditions); and one between-subjects factor: the driver groups (elderly and reference participants). To sum up and clarify, the independent variables used in this simulator experiment are expressed in the next table.

Table 21. Independent variables considered for the simulator experiment

Variable Name	**Levels**	**Description**
System condition	Baseline	Course with direction signs placed along the road that guided subjects to the destination. There was no in-vehicle systems active inside the vehicle during this test course.
	One-System	Course made with the help of a simulated route guidance system. No direction signs were placed on the road. No other types of voice messages were sent by the guidance system.
	Two-System	Course made with the help of the same guidance system as for the previous condition. In addition, it was added a mobile phone conversation during almost all the course
Age condition	Elderly Drivers	Drivers aged from 29 to 46 years old
	Reference Drivers	Drivers aged from 59 to 79 years old

1.4.2 Dependent Variables

Several dependent measures were considered to obtain the results from the influence of the installed in-vehicle systems, as well as the age differences from both driver groups. Thus, in order to examine performance changes in the participants' mental workload three types of measures were taken into account: performance measures, subjective measures and also one physiological measure. The performance parameters included in this simulated experiment were subdivided in two groups: primary-task measures and secondary-task measures. For the primary-task measurement variables were directly related with the driving task and included the lateral and longitudinal control of the vehicle as well as some driving errors. As participants needed to know the way in order to complete the course, the guidance task was considered as being part of the primary task, independently of the method used to receive the guidance instructions. Thus, its measurement was included in the primary-task performance with the designation of "navigation errors".

Being the mobile phone conversation considered an additional task, secondary-task measures included the performance of participants on that specific task, i.e. the feedback regarding the sentences repetition and also the accuracy of the answers given.

One physiological measure was undertaken: the visual behaviour of participants towards the control panel of the vehicle and towards the guidance system display. Eye fixations are related to the primary and secondary tasks since they support performances however, they are not coded in those categories. They are traditionally listed in the physiological parameters as reported by de Waard in 1996.

The last group of dependent variables used in this simulator experience are the self-reported ones. A questionnaire was prepared to be applied after each test course (each system conditions). Participants had the opportunity to evaluate the general difficulty of courses as well as report the effort felt during each trial. The preferred guidance method and the level of distraction caused by the simulated guidance system and the mobile phone task were also quantified.

The following table shows in a clearer way the dependent variables used for this simulator experiment.

Moreover, in the following paragraphs a deeper description of each dependent variable will be done to frame the measurements and justify some of the decisions taken during the analysis of the data.

Table 22. Dependent variables used for the simulator experiment

Type of variable		Object of measure	Variable name
Performance	Primary-task	**a.** Lateral control of the vehicle	• Lane exceedences
		b. Longitudinal control of the vehicle	• Mean speed • Violations of speed limit
		c. Driving errors	• Turning indicator activations
		d. Navigation errors	• Navigation errors
	Secondary-Task	**e.** Mobile phone task performance	• Time to answer (hesitation) • Incorrect answers • Absence of answer
Physiological		**f.** Visual Behaviour	• Glance frequency towards the control panel • Glance frequency towards the guidance system display
Self-Report		**g.** Perception of difficulty, effort and distraction	• Level of difficulty of the course • Level of effort felt during the course • Preferred guidance method • Level of distraction caused by guidance system and mobile phone

a. Lateral control of the vehicle

The analysis of the lateral position of the vehicle in the lane has been utilized in several studies. The position of the vehicle regarding the centre of the lane and also its lateral limits are measures frequently used to analyse driver distraction, more specifically the influence of in-vehicle systems on the driver behaviour. Some researches (eg. Tijerina et al., 1998; Jeness et al., 2007; Wikman et al., 1998; Hooey, & Gore, 1998; Hoorey et al., 2003) noted that while performing a demanding task with an on-board system, subjects could change their driving behaviour and modify the lateral control over the car.

One of the measures of the lateral control frequently used is the lane exceedences. This type of measure can range from the tyre touching the white line of the lane to the complete surpass of the vehicle to the lane limits. It analyses the lateral control of the driving performance which can be considered as an indirect measure of the visual distraction from the road scene (HUMANIST, 2004). Some examples of its utilization can be seen on the following researches: Dingus et al., 1989; Nowakowski et al., 2000; Tijerina et al., 2000. When examining the lane exceedences, analyses can be made to verify the number of excursions made during the course or the duration of each exceedence and its percentage in relation with the time spent inside the lane limits.

For the present experiment, these deviations from lane limits were registered in all three courses in order to compare the effect of the information systems on the lateral control of the car. Every time the front right wheel crossed the right hand lane marking or the front left wheel crossed the central marking, one lane deviation was registered. In order to analyse all subjects in an equal way, the number of lane exceedences was counted and divided by the exact number of kilometres driven in each course. Based on a value of lane exceedences per kilometre (LE/Km), average values were calculated to compare system conditions and driver groups.

b. Longitudinal control of the vehicle

The speed analysis importance is supported by the assumption that whenever the driver's attention changes some driving parameters change also.

Speed can be used for the estimation of vehicle distraction from the use of on-board systems due to the principle that this interaction can result in lower vehicle speeds. This measure of longitudinal control of the vehicle can be an indicator of whether or not a system is imposing high levels of workload to the driver. With the intension of decreasing the mental workload imposed by the performance of an additional task, subjects may adopt certain behaviours to compensate for this situation (like reducing the speed). Several are the researches that have used this measure: Spyropouloy et al. as cited in HUMANIST, 2004; Hooey, & Gore, 1998; Lansdown et al., 2004; Burnes et al., 2002; Haigney, Taylor, & Westerman, 2000.

In order to analyse the speed in the present study, the average speed of each complete course was calculated for every participant in each condition. Those values were compared between and within driver group as well as system conditions.

In what concerns the violations of speed limits, before starting the test experiments participants were advised of the speed limits, which were the same for the three different courses. Two main reasons justified the recommendation given not to drive over the 100 Km/h: 1) with superior speeds subjects could have higher propensity to feel sick (simulator sickness causing nauseas); 2) and quicker reactions to the guidance instructions were requested, augmenting the probability to miss some manoeuvres.

Due to the fact that this experience was performed in a fixed-base simulator the sensation of speed usually felt while driving in the real world didn’t exist. In order to control the speed, participants had to hear the simulated motor sounds of the car and also look to the control panel of the vehicle. Thus, violations of the speed limit could be seen as a consequence of a deliberated behaviour or as a result of distraction (reduction in the number of checks to the control panel). For this experiment the analysis of the speed limit violations could contribute to elucidate about the effects of in-vehicle technologies and also to know the major differences between drivers belonging to distinct age groups.

The violation of the speed limits were analysed for all participants and in every system conditions. Based on the data collected from vehicle dynamics, the number of times participants exceed the speed limit was registered and examined.

c. Driving Errors (turning indicator activation)

The activation of the turning indicator and the moment in which this signal was turned on were registered. A sensor installed in the driving simulator captured the activation of the turning indicator lever, being this signal sent afterwards to a computer that recorded the dynamic parameters of the vehicle. The analysis of the turning indicators was done in two separate parts. In a first moment the objective was to evaluate the expression of the “non-activations”, being this type of error was named as “omission” error.

Additionally, in the second part of the analysis, it was studied the moment where the activation was performed. The distance between this moment and the moment where subjects started to do the manoeuvre was measured in order to define a mean value for the moment of activation to each subject.

The moment for the activation of the turning indicator was obviously dependent on the moment subjects received the information regarding the direction to follow. Depending on the course, this information was sent via written instructions (baseline course, where instructions were written in the vertical direction signs) or via voice instructions (one-system and two system conditions). Written instructions were placed 200 meters before the intersections and, for the other courses, voice instructions started to be sent at the same moment. For this reason, a comparison of these values will not be done for the baseline because the moment where participants perceive this information could be entirely different. This is justified by the fact that, in the baseline condition, participants could read the arrows some meters before the place where the direction signs were located, becoming aware of this information more than 200 meters before the intersection. In the other two conditions, where directions were sent by the navigation system, voice messages started to be sent 200 meter from the intersection, being participants aware of the complete information some meters ahead (less than 200 meters before the manoeuvre) (Figure 30 and Figure 31). Thus, the baseline situation will not be object of comparison. The probable earlier activation of the turning indicator in that condition could be a clear consequence of receiving the information sooner. Statistical tests presented in the results section will only show the comparison between the one-system and the two-system conditions.

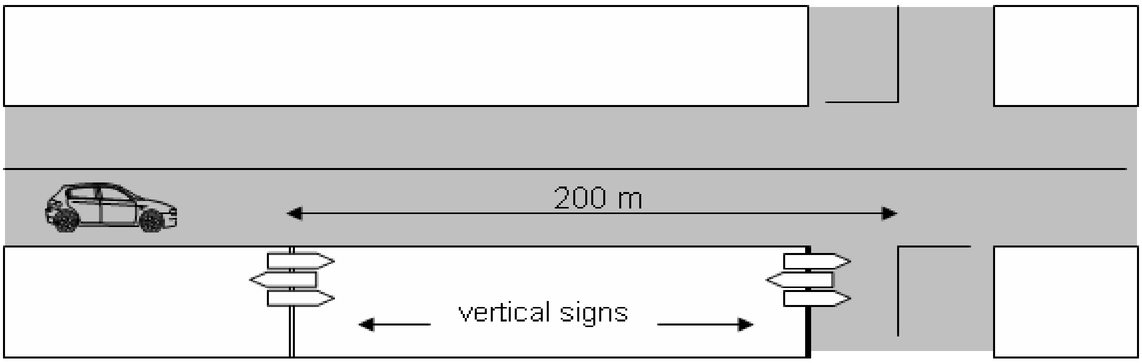

Figure 30. Graphical representation of an intersection in the Baseline condition

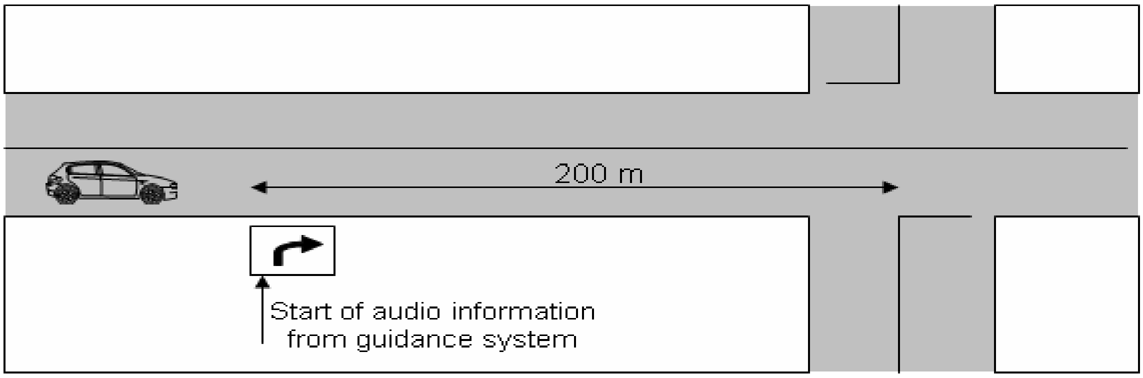

Figure 31. Graphical representation of an intersection in the one-system and two-system conditions

d. Navigation Errors

Navigation errors are commonly analysed in studies where the guidance task is important and can reveal the quality of the interaction between drivers and the navigation system itself. As it was already explained for the on-road experiment, a navigation error can be considered as a discrepancy between the information sent by the system and the action made by the driver. For example, the system informs the driver to turn right at the following intersection and at that specific moment the driver continues in front. Due to the fact that it's not a real road environment, navigation tasks can be generated through a simulated navigation system. For the present experiment, despite the effort to approach the simulated system to an authentic one, it was recognized that the environment created was simpler that in real life.

e. Mobile Phone Task Performance

In the two-system condition participants were asked to conduct a mobile phone conversation while receiving visual and voice instructions from the guidance system. As it was explained earlier, the mobile phone task consisted in a series of sentences that were sent via phone to participants. They were instructed to listen a sentence, repeated it, and answer "*yes*" if the sentence was sensible, and "*no*" if it was not. Subjects had to maintain this "conversation" while guiding themselves throughout the intersections until reaching the final destination.

In order to analyse this variable, the mobile phone performance was organized into categories. As this mobile phone task was composed by two parts (a first one of repetition and a second of decision) both were object of scrutiny. The primary part (repetition of the sentence) had the objective of certify that the correct sentence was heard. If the subject understood a different word in the sentence, that could change its meaning and influence the success of the response. For example, if the original sentence "*Bats are flying animals*" was heard like "*Cats are flying animals*" the evaluation of the answer had to be in accordance with what was understood.

In what concerns the responses to the logic sense of the phrases, three major categories emerged: *hesitations*; *incorrect answers*; and *absence of response*. *Hesitations* occurred when subjects took more than three seconds to give an answer, after having repeated the sentence. These moments could be in silence or be filled by interjections like: "*uhhh*"; "*errr*"; or "*ummm*". The second variable worth to analyse was *incorrect answers*. In these cases participants fail to acknowledge the logical sense of phrases, answering "*yes*" to the illogical sentences and "*no*" to the sensible ones. Additionally, the *absence of response* was also registered, being characterized by a long moment of silence until the next phrase was sent by the researcher. This variable analysis exposes the influence of simultaneous task performance on the mobile phone conversation.

The number of hesitations, incorrect answers and absence of responses were counted separately. As the mobile phone conversation was only present in one course (the two-system condition) the analysis could not compare the performance of subjects between systems conditions. The presence of the mobile phone task in the entire course allowed separating the path into two independent zones: during the intersections (intersection zone) and between intersections (out of intersection zone). This distinction made possible to compare the influence of simultaneous tasks performance on the phone conversation in different moments. The next figure elucidates about these two distinct areas.

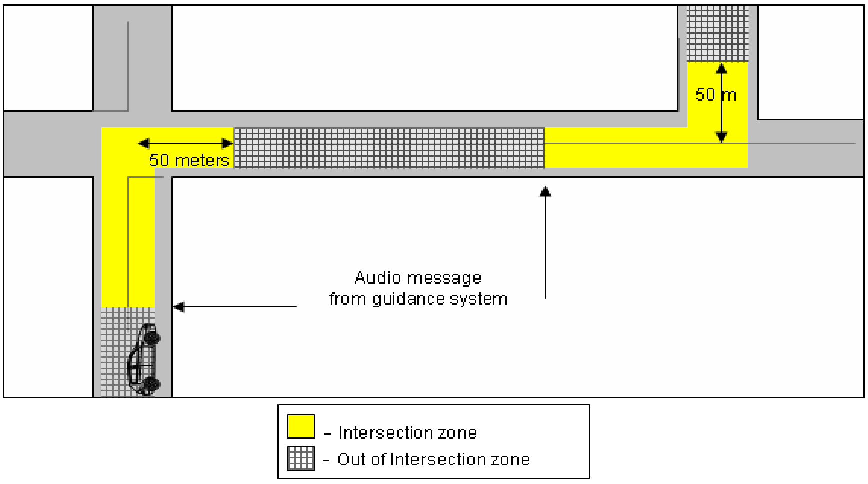

Figure 32. Sketch from the "two-System" condition course representing the two zones for analysing the mobile phone task performance.

f. Visual Behaviour

As for the on-road experiment, the visual behaviour of participants was recorded in order to study how frequently subjects would search for visual information inside the vehicle. Besides the information present on the simulated road environment, subjects looked also for information inside the vehicle: in the control panel and guidance system display. The control panel of the car was placed behind the steering wheel and showed the speed of the vehicle, the motor rotation and also the gear position. Those three types of information were important so drivers didn't exceed the speed limit and could also manage adequately the gear. Additionally, to perform the guidance task, subjects could get guidance information by diverting their gaze towards the navigation display.

In order to study how frequently participants searched for these types of information, the number of gazes towards the control panel and also the guidance system display was measured. The number of gazes in each course and also for each driver group was compared so that statistically significant differences could be brought up.

To compare all participants in an equal manner, courses were subdivided into sections. Each section was composed by two distinct areas: the 600 meters of road before the voice output of the guidance system (which will be named as "Out of intersection" area); and also the intersection zone that goes from this voice instruction to the centre of the junction (named as “Intersection” area). In the next figure a sketch of sections can be observed. After counting all the glances towards the control panel and also to the guidance system, the total number of gazes was divided by the number of sections performed in the course. As a consequence, a mean number of glances per section were obtained in order to be compared for the system conditions and driver groups.

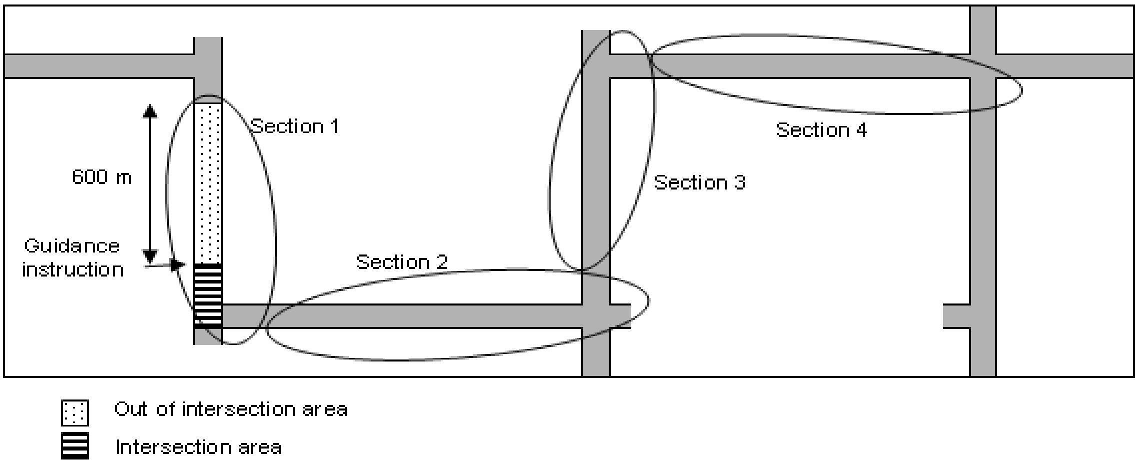

Figure 33. Sections used to analyse the visual behaviour towards the control panel and guidance system

g. Self-Reports

After each course condition, a questionnaire was applied in order to register the opinion of participants about the general level of difficulty, the effort made and also other specificities of the course. Thus, three different questionnaires were prepared to be filled after each course performance.

The baseline condition questionnaire was directed exclusively to register the opinion regarding the guidance instructions received from the direction signs of the road environment. It aimed also to know the difficulty and the effort felt for accomplish that specific course and verify in which way that type of guidance instructions interfered on the driving task. The one-system condition questionnaire had a similar aim: it registered the opinion regarding the instructions received from the guidance system. Questions regarded the level of difficulty to understand the visual and voice messages, and also the general effort felt while accomplishing that specific course.

A last questionnaire was prepared to be filled in after the two-system condition and had the objective of register the opinions of subjects while interacting simultaneously with the guidance device and the mobile phone task. Some specific questions intended to record the difficulty to understand the phone conversation and also the guidance messages. Additionally, the general level of difficulty to perform the course as well as the level of effort needed to accomplish that specific condition was also questioned (see questionnaire in Appendix IX).

2. Experiment Procedure

The experiment procedure had three distinct phases: the first one related with the presentation of the simulator and experiment objectives; the second part reserved for a training period and the third moment where the test itself was conducted. All three phases will be further described with more detail.

2.1 Presentation of the Experiment

Right after participants arrived to the laboratory the researcher welcomed him/her and started with the presentation of facilities and instruments. Afterwards, the researcher and the driver sat down near the table placed beside the simulated vehicle. The investigator explained the main goals of the experiment as well as the context in which it was being accomplished. Participants were also elucidated about the tasks that had to be performed and also its sequence.

Only after all the explanations a paper with a consent term was presented to them. The consent term described briefly once again the context and main objectives of the experiment, the anonymity of the participants' identity and what would be done with the results of the tests (See Appendix X). Subjects were asked to sign the consent term. This first part lasted between 10 to 15 minutes.

2.2 Training Period

Before the test itself, subjects had the opportunity to get to know the simulated vehicle and the other instruments with which they were going to interact. A specific base course was developed to be used for training. It contained a road of 1400 meters followed by three different intersections that were apart 600 meters from each other. At the end of this small course it returned automatically to the starting point, allowing participants to do the entire training course the desired number of times, in a looping mode. The training course had this design to allow subject to drive the simulator as much as they feel needed without losing time to restart the simulator.

With this base scenario, three different versions were created:

- Training/Baseline course: a road with vertical signs indicating the way to different cities (like the baseline condition);
- Training/One-System course: a road without vertical signs but where participants received guidance instructions from the simulated guidance system (like the one-system condition);
- Training/Two-System course: a road without vertical signs but with guidance instructions from the guidance system and with the interference of a mobile phone call that arrived in a predefined moment (like the two-system condition).

Before being explained some details concerning the in-vehicle equipment that could be used inside the vehicle, participants started this familiarization with the training/baseline course. They were instructed to try the simulated vehicle freely and to take as long as they needed. When they felt comfortable manoeuvring the vehicle, the simulation was stopped and they were asked to try the second course that had the visual and voice instructions from the guidance system. In order to try the training/two-system course it was explained to participants how should the additional mobile phone task be done and also which interface they should use to answer the calls.

Between training courses participants were asked if they were feeling comfortable (not experiencing any nausea sensation) being also invited to step out of the vehicle and relax a bit if they feel needed.

This second training part lasted 20 to 25 minutes and at the end subjects were invited to step out of the car and to relax for some minutes before the experiment itself. This moment was provided in order to avoid subjects feeling extremely tired and also prevent simulator sickness.

2.3 Simulator Test

Following the training, participants answered a questionnaire containing topics related to their socio-demographic characteristics, driving habits, and attitudes towards the mobile phones and navigation systems (Appendix XI). This questionnaire was applied after this period so that participants could rest for at least 10 minutes, in order to diminish the possible effects of simulation sickness. Afterwards they were invited to step into the car and start the test. The order in which conditions were presented to subjects was balanced to avoid the learning effect on the results. For that reason four different sequences were made and subjects were distributed equally. The sample was composed by 32 subjects and all drove in all three conditions.

Table 23. Balancing of the orders for completing all conditions of the experiment

	Order A	Order B	Order C	Order D
	1. Baseline 2. One-System 3. Two-System	1. Baseline 2. Two-System 3. One-System	1. One-System 2. Two-System 3. Baseline	1. Two-System 2. One-System 3. Baseline
Elderly Group	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)
Reference Group	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)	N= 4 (2 men, 2 women)

The duration of each course depended on the driving speed of each subjects, lasting approximately between 7 to 15 minutes. After each course condition, subjects had the opportunity to step out of the car and make a pause. In this period they answered a questionnaire to register their opinion about the difficulty of the course. This third part of the experiment could last approximately 45 minutes.

PART THREE: RESULTS AND DISCUSSION

CHAPTER 1. RESULTS

In the following sections the results of both on-road and simulator experiments will be presented. As for the previous methodology section, results will be showed separately and the outputs of each dependent variable will be drawn. Before its presentation some important considerations regarding the analysis will be expressed, specially regarding the accomplishment of the tests and the statistical analysis made to the data.

In what concerns the experiment done in real environment, the presented measures were collected for all the 20 target intersections of the course. However, due to some navigation errors that occurred during the experiment, some subjects missed to perform a certain number of intersections (only 1 elderly driver and 8 reference drivers made all the 20 intersections; the others missed at least one intersection during the course). At the end, subjects had an unequal number of manoeuvres. Similarly, certain participants of the simulator study did not perform every intersection in all the presented conditions. During tests a problem in the simulator forced some subjects not to perform the complete course, leaving one or two intersections to be done. Additionally, due to the fact that some participants felt sick and tired at the end of the experiment, another few didn’t accomplish all 18 manoeuvres (5 elderly drivers and 7 reference drivers did not accomplish all the manouvres).

As it was also intended to study the guidance task performance, the on-road and simulator data from subjects that haven’t made all the manoeuvres was kept and analysed. Moreover, the difficulty for finding participants/volunteers within the defined range of ages and available to perform this type of experiment justified keeping the data of drivers that had not complete entirely the simulator test.

The different number of intersections performed and kilometres driven led to a distinct type of calculations in order to compare fairly the data recorded. Thus, while in some cases it was possible to compare the mean values, in other cases the percentage of error was calculated based on the number of situations actually performed. The output of results was based on descriptive and inferential statistics and dependent on the type of data acquired, different hypothesis tests were performed.

For variables expressed in terms of percentage a specific test to compare proportions was made: Fisher Test (an exact test from the chi-square tests). For variables where a mean value could be extracted it was verified the homogeneity of variance, the assumption of sphericity (when applicable), and also the normal distribution of the data in order to know if parametric or non parametric tests should be applied. Two-Way ANOVA (mixed) was used to compare more than one independent variable while t-tests were made for evaluating two unique mean values. In cases where the normal distribution of data was not verified Wilcoxon and Mann Whitney tests produced the inferential outputs. For any of the cases, a significance threshold of 0.05 was accepted ($p<5\%$). Main system condition effects, main age effects and interaction effects between both independent variables were analysed for all the measures. Nevertheless only the statistically significant results will be expressed to simplify the exposure of results.

1. On-Road Experiment Results

The following results will be presented in accordance with the measured dependent variables. The order in which they will be presented will be the same as for their description in the methodology part.

1.1 Turning Indicators

1.1.1 Omission Errors

The analysis of the number of intersections where the turning indicator was not activated revealed that, in a general overview, the two-system condition led to a higher percentage of omission errors (one-system condition=5.1%, two-system condition=8.1%). This difference only show a slight tendency since no statistical significance was observed. In what concerns the difference between drivers group, as it can be verified in the next figure, elderly drivers were the ones that forgot to activate the turning indicator more frequently in both moments (one-system and two-system). This difference was more pronounced in the two-system condition, where the older participants forgot even more often to indicate previously the direction of the manoeuvre. Once again, in spite of the difference between groups, no statistical significance was observed. This means that it was only registered a slight tendency of elderly drivers in forgetting to activate the turning indicator more often than their younger counterparts.

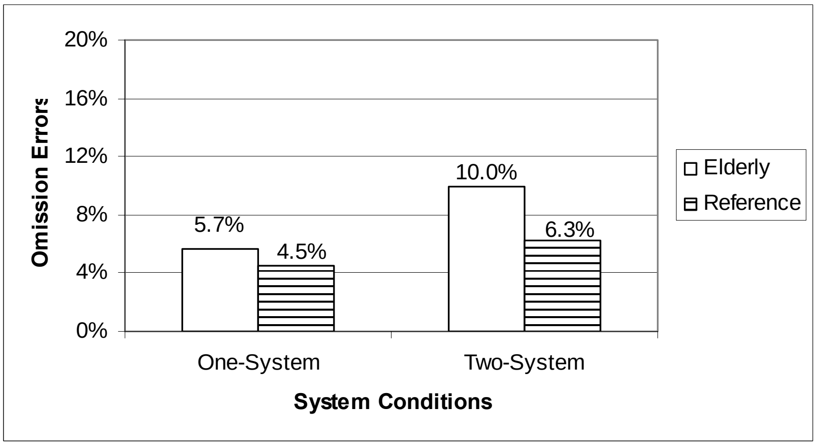

Figure 34. Omission errors in both system conditions and for each driver group

1.1.2 Timing Errors

In what concerns the moment in which drivers activated the turning indicator sign, data exposed a main effect between system conditions. This means that there was a significant difference between the number of drivers that turned on the turning indicator too late [χ^2 (1)=8.77; p=0.003]. This latter activation was more frequently observed while drivers were conducting simultaneously the mobile phone task meaning that, interacting with both systems led drivers to latter indicate their intentions to turn. When driver groups were considered no main effect of age was registered. As expressed by the following figure, for the one-system condition reference drivers made more late activations. However, for the two-system condition this situation was inverted, having elderly drivers a higher percentage of timing errors. For both age groups, the two-system condition led to an augmentation of the number of latter turning indicator activations, however elderly drivers were the only ones significantly affected by it [$\chi^2(1)=10.89$; $p=0.001$]. This means that older participants were the ones behaving significantly different with the inclusion of the phone conversation, being this behaviour characterized by a higher percentage of late activation of the turning indicator.

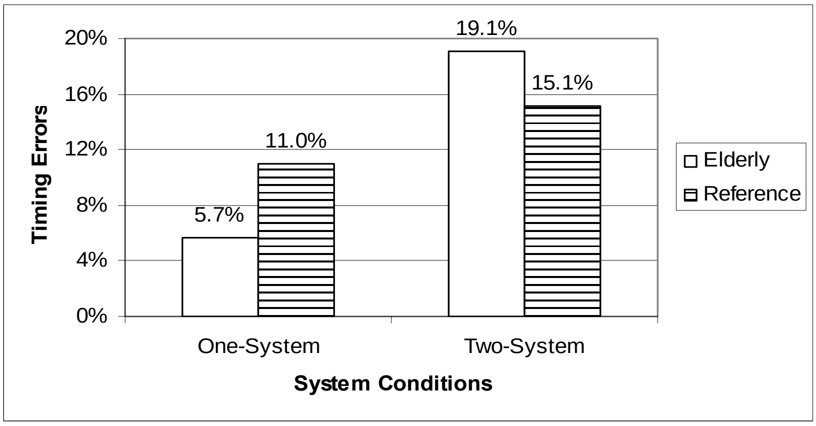

Figure 35. Timing errors in both system conditions and for each driver group

1.2 Braking Behaviour

Data analysis from abrupt braking revealed that significant differences were observed between system conditions: a higher percentage of abrupt brakes were registered for the two-system condition [$\chi2(1)=13.83$; $p=0.000$]. This difference was manly due to reference participants that had a much higher percentage of such braking behaviour when interacting with both devices [$\chi2(1)=20.30$; $p=0.000$]. In the one-system condition reference participants exposed a very small percentage of sudden braking (0.7%) while elderly drivers almost reached the 8%. This difference between age groups was statistically significant when drivers interacted only with the guidance system [$\chi2(1)=9.35$; $p=0.002$], and vanished for the two-system condition once both driver groups increase their abrupt braking to a similar value.

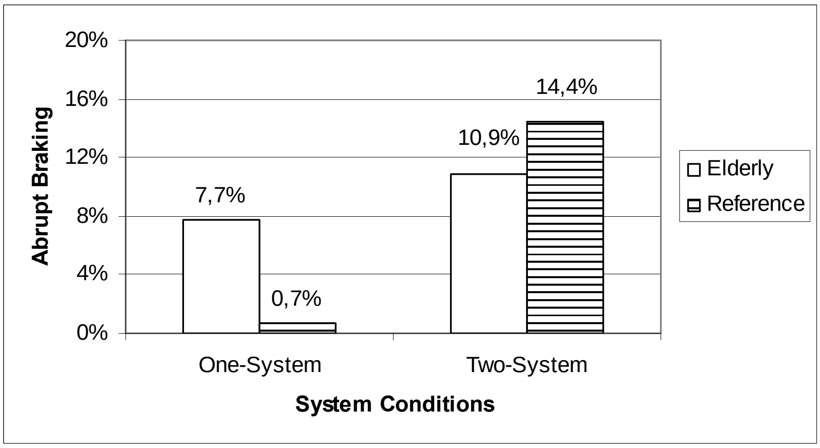

Figure 36. Percentage of sudden braking in both system conditions and each driver group

1.3 Moment to Turn

1.3.1 Hesitations

Hesitations were marked down at the observational table whenever there was an interruption of the turn manoeuvre. Results revealed that no main effect of system condition occurred, meaning that there were no significant differences for the entire group of participants between both situations. In what concerns the age differences, in spite of the higher values for elderly drivers, no main effect of age was exposed. The only significant difference was obtained for the one-system condition: while interacting just with the guidance systems elderly participants made significantly higher percentage of hesitations while performing a turn manoeuvre [$\chi^2(1)=4.78$; $p=0.040$]. However, for the two-system condition this difference between driver groups vanishes once reference participants increased their number of hesitations to a similar value than their older counterparts.

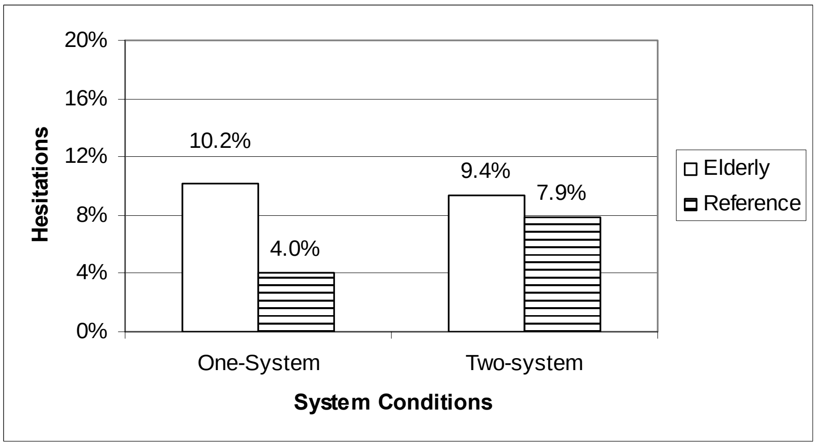

Figure 37. Percentage of hesitations in both system conditions and each driver group

1.3.2 Abrupt Turn

Results from *abrupt turns* showed a main effect of system condition. This means that there was a significant difference between the percentage of abrupt turns between the one-system and the two-system situations. It reveals also that when interacting with both in-vehicle systems, participants made more sudden and too fast turns [$\chi^2(1)=5.11$; $p=0.024$]. As it can be seen in the following figure, this result is mainly due to the reference group that expressed a significantly increase of such behaviour while interacting with both devices [$\chi^2(1)=5.87$; $p=0.015$]. In what concerns age differences, elderly drivers showed always higher percentages of abrupt turns, however data only reveals a slight tendency once no effect of age was expressed in both conditions.

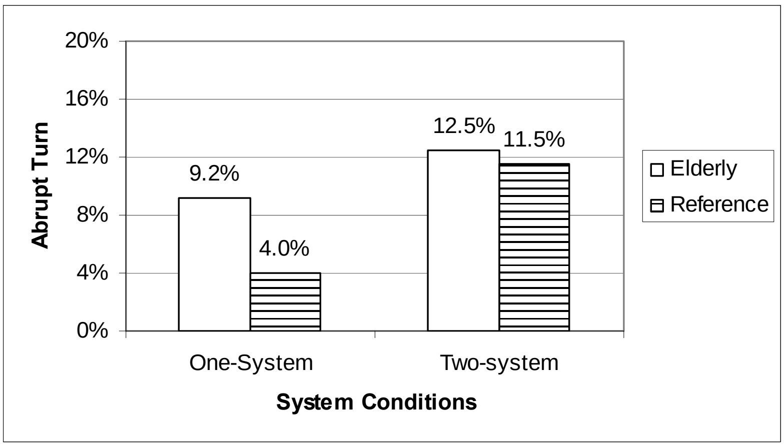

Figure 38. Percentage of abrupt turns in both system conditions and for each driver group

1.3.3 Turn with Vehicle Near

In what concerns performing the turn with another vehicle close to the intersection, data showed no main effect of system condition. Besides the higher values observed for the two-system condition, the difference is not statistically significant (one-system=4.4%; two-system=6.0%). Moreover, important dissimilarities are observed between both driver groups. In a general way, elderly drivers made frequently more turns with another vehicle dangerously close to the intersection [$\chi^2(1)=9.36$; $p=0.002$]. This was highly evident when participants were instructed to interact with both systems [$\chi^2(1)=10.67$; $p=0.001$]. This more expressed difference between driver groups in the two-system condition was not only due to the higher percentage for the elderly but also due to the decrement observed for the reference participants.

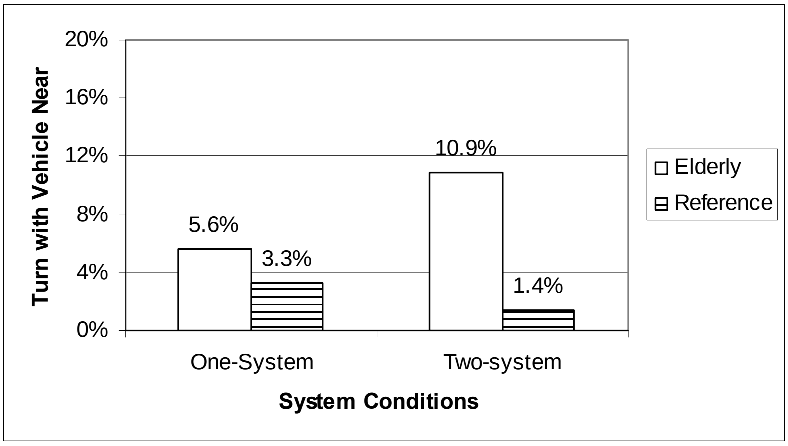

Figure 39. Percentage of turns with vehicle near in both system conditions and for each driver group

1.4 Dangerous Situations

During the experiment some traffic conflicts occurred and in spite of not being very frequent they were object of analysis due to its importance. The register of those critical situations were confirmed throughout the videos of the experiments and this analysis showed that for five times the driving instructor had to intervene in order to avoid an accident. When system conditions was taken into account, it revealed that the great majority of those situations happened while participants were interacting with both in-vehicle devices at the same time (one-system condition=1; two-system condition=4). In what concerns the driver groups' differences, it is important to refer that all critical situations were performed by elderly drivers. When proportions were considered, the near crash situations for the one-system situation represented for the elderly drivers less than 1% (0.7%), while in the two-system condition corresponded to 3.13% of the intersections performed.

1.5 Navigation Errors

During tests, several navigation errors were observed for both driver groups. The analysis of this data exposed that, when comparing both system conditions, the two-system situation was the one with higher percentage of error. However this dissimilarity only revealed a slight tendency because no statistically significant difference was observed. This result was verified when all the participants were taken into account and also for each of the drivers group. For elderly and also reference participants no significant differences were seen between system conditions, even knowing that the two-system situation had induced to higher percentages of error. Regarding the driver group differences, as can be seen by the following figure, elderly were the ones with higher navigation errors. This result was observed for the overall data as well as for each system situation. Once again, this reveals only a slight tendency because no statistically significant differences were observed between driver groups.

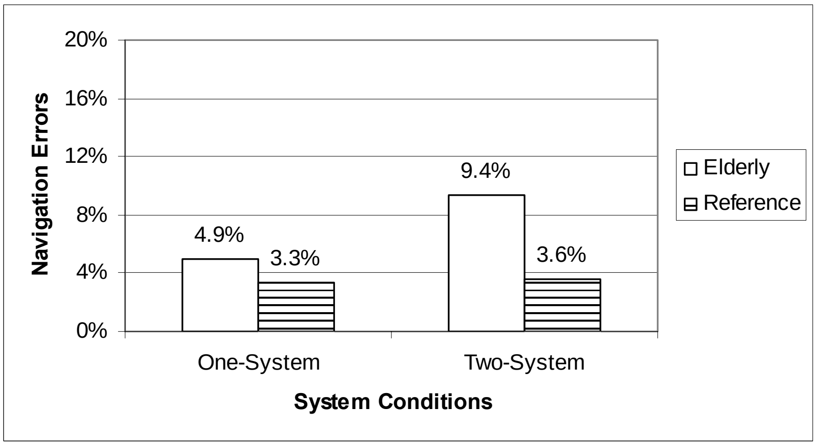

Figure 40. Navigation errors in both system conditions and for each driver group

1.6 Navigation Behaviour

Regarding the comparisons between both system conditions, it could be seen that the frequency of times participants demanded for "*help*" was very small in both cases (one-system condition=1.02%; two-system conditions=1.15%). For the category of "*hesitations*" this frequency showed a difference between system conditions because when drivers were interacting with both in-vehicle systems the percentage of hesitations was almost the double (one-system condition=4.44%; two-system conditions=8.02%). In what concerns the "*difficulties*" expressed verbally, they occurred some times during both system condition, however the frequency was higher during the one-system moment, meaning that while at the phone they expressed less frequently their difficulties (one-system condition=4.44%; two-system conditions=2.29%). In spite of the higher differences between system conditions for the "*hesitation*" and "*difficulty*" categories, only slight tendencies were revealed once no statistically significant differences were expressed.

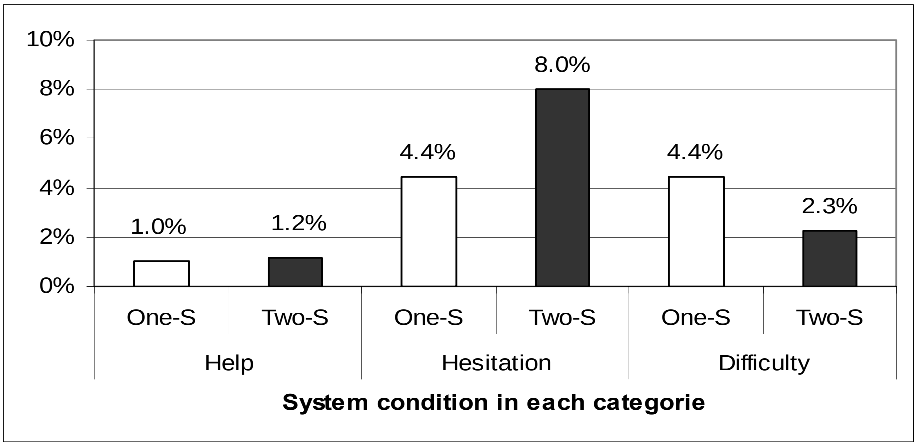

Figure 41. Percentage of observed behaviour in both system conditions and for each driver group

Comparisons between both driver groups were also made. It was revealed that in all the three categories, elderly drivers were the ones that obtained higher percentages. This was even more evident for the "hesitation" and the "difficulty" categories. For these two variables the difference between elderly and reference participants revealed that elderly drivers were the ones that made significantly higher percentage of hesitations [χ2(1)=3.30; p=0.050] and also significantly more expressions of difficulty [χ2(1)=4.60; p=0.027].

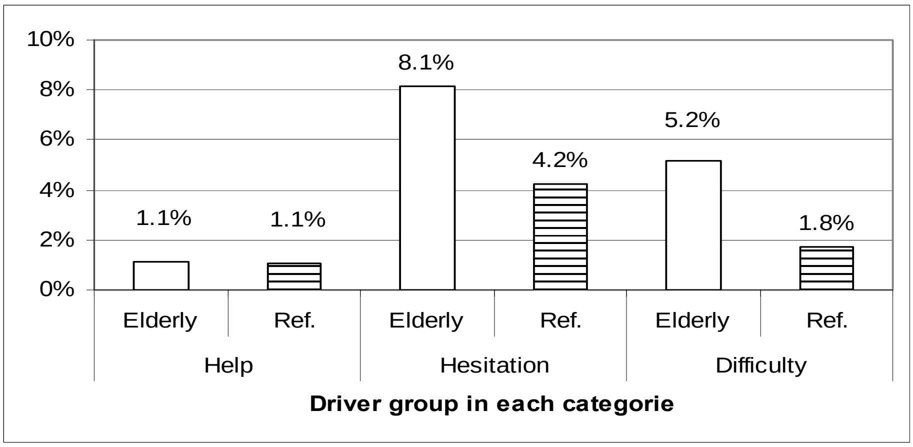

Figure 42. Percentage of observed behaviour in both drivers group and for each driver group

1.7 Secondary-Task Performance

The next figure shows the mean number of times participants didn't repeat the sentences, didn't answer if the sentence was sensible and/or gave incorrect answers.

A general analysis revealed that elderly drivers were the ones that had higher mean values for inadequate performance on the secondary task. However, the "*absence of answer*" and the "*incorrect answer*" variables were the ones that showed statistically significant differences. During the experimental tests, elderly drivers were the ones that didn't accomplish the mobile phone task more frequently, not evaluating the meaning of the sentence (U=51.50; p=0.002). This means that after repeating the sentence sent by the interlocutor they didn't produce an answer. They also had higher mean values in what concerns incorrect answers (U=76.50; p=0.045), meaning that while conducting a mobile phone conversation, elderly drivers had significantly worse performance.

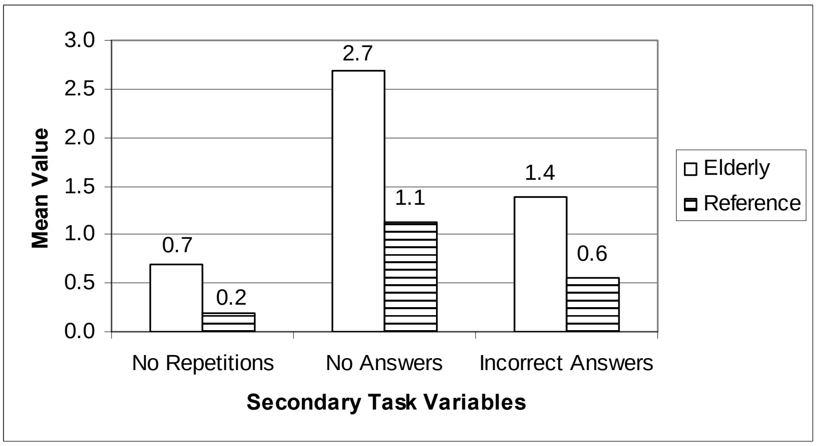

Figure 43. Mean number of "*no repetitions*", "*no answers*" and "*incorrect answers*" in the mobile phone task per intersection performed

1.8 Visual Behaviour

1.8.1 Visual Behaviour Errors

Glances towards the intersection

The comparison of the results between the one-system and the two-system situations revealed that a main effect of system condition was observed for the errors when looking at the intersection. This means that when interacting with both in-vehicle systems participants missed to check the intersection area more frequently [$\chi^2(1)=12.60$; $p=0.000$].

This result was also verified in each driver group. Elderly and reference participants made significantly more errors for the two-system condition [Elderly: $\chi^2(1)=5.26$; $p=0.018$ / Reference: $\chi^2(1)=6.99$; $p=0.008$]. This means that, the simultaneous interaction with both devices led participants to check significantly less the intersection area before turning. When driver groups were compared, no statistically significant differences were observed.

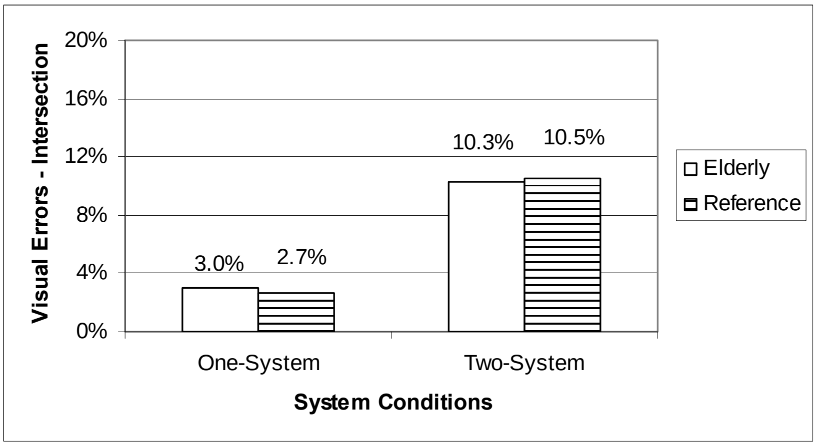

Figure 44. Visual checking errors towards the intersection area in both system conditions and for each of the driver group

Glances towards the mirrors

Results revealed a main effect of system condition for checking errors towards the mirrors. This means that in the two-system condition participants missed more frequently to check the rear mirrors [$\chi^2(1)=5.43$; $p=0.020$].

A main effect of age was also registered. Elderly drivers were the ones that missed to check the rear mirrors more often, being this difference statistically significant [$\chi^2(1)=7.11$; $p=0.008$]. This driver group difference is mainly due to the results of the one-system condition because in this situation both groups of participants behaved significantly different. Elderly drivers missed to look the rear mirrors more frequently than reference participants when interacting just with the guidance system [$\chi^2(1)=5.29$; $p=0.021$]. However, when interacting with both devices this considerable difference vanished since reference subjects increase significantly their checking errors [$\chi^2(1)=4.35$; $p=0.037$].

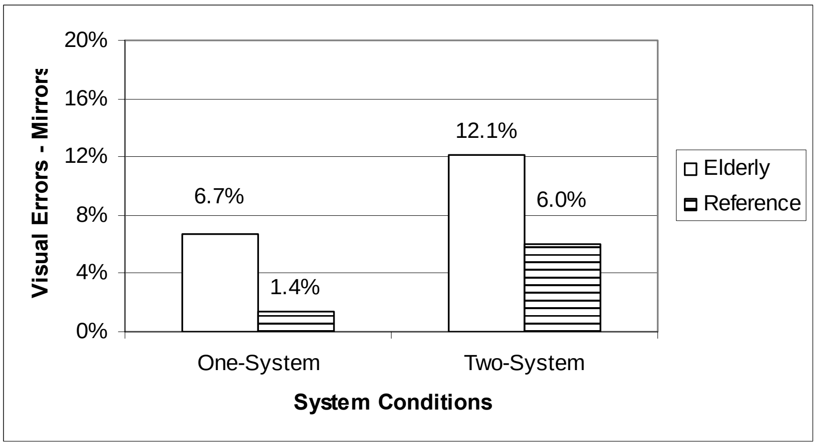

Figure 45. Visual checking errors towards the rear mirrors in both system conditions and for each driver group

1.8.2 Visual Behaviour Towards the Guidance System

Average number of glances

Results obtained from the average number of glances towards the guidance system revealed that no main effect of system condition was observed. This means that the mean number of glances per intersection was not dependent on the fact of interacting with the mobile phone device. However, the same result was not expressed when both driving groups were compared. There was a main age effect indicating that the mean number of glances per intersection was significantly different for both driver groups [F(1,30)=8.40; p=0.007].

In a general overview it was noticed that reference participants looked significantly more often to the guidance system per intersection. These main differences were also observed when both system conditions were considered separately. As it can be seen in the following figure, while the number of glances per intersection was reduced for the two-system condition by the elderly participants, reference drivers augmented it. Thus, this difference between age groups was statistically significantly for the one-system condition (U=66.50; p=0.009) and even more evident in the two-system situation (U=52.00; p=0.003). This leads to consider that elderly drivers glanced less frequently to the navigation display, specially in the presence of the mobile phone.

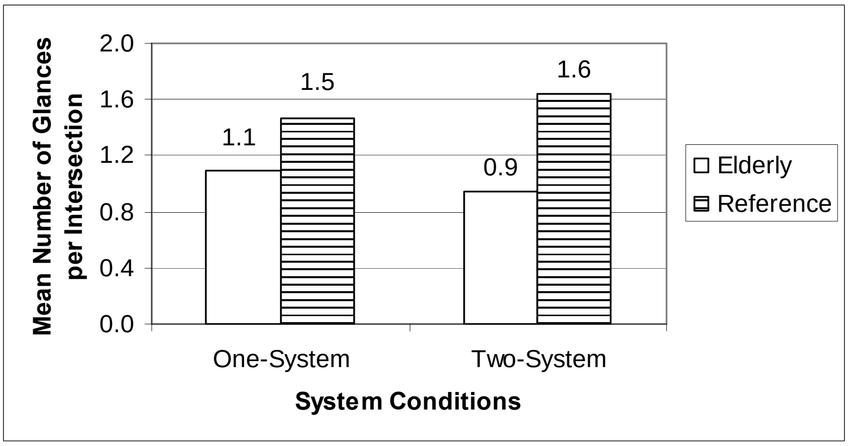

Figure 46. Average number of glances per intersection in both system condition and for each driver group

Mean glance duration

After analysing the glance duration towards the navigation system, it could be observed that no main effect of system condition was revealed. No statistically significant differences were registered between the interaction with one and two systems. Similarly, there was also no main effect of age. When results of each driver group were compared in each of the system conditions, it could be seen that elderly drivers made longer mean glances towards the guidance system. This difference was statistically significant for the one-system condition (U=75.00, p=0.047) but not for the two-system situation. This indicates that the mobile phone presence led elderly drivers to make shorter glances reducing the difference seen when the mobile phone was not present.

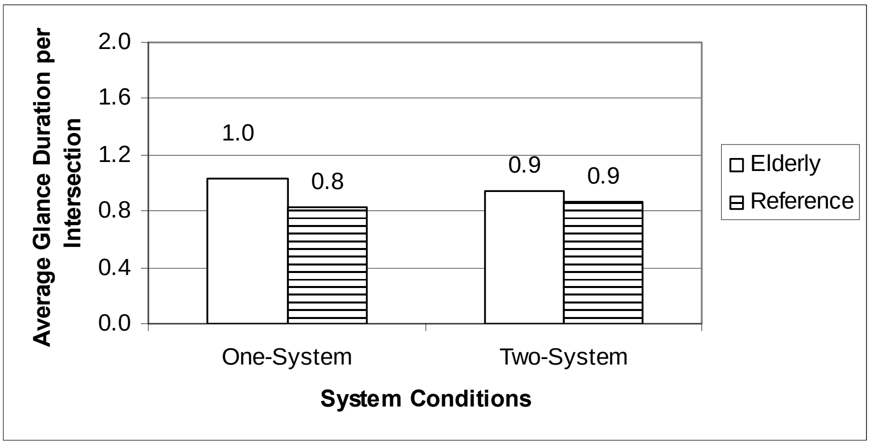

Figure 47. Mean glance duration (seconds) in both system condition and for each driver group

1.9 Self-Reports

A part of the questionnaire applied after the driving test concerned uniquely intersections performed with one in-vehicle system. Participants were asked about the level of difficulty to understand the visual and voice messages from the guidance device. In what concerned the difficulty to apprehend the visual messages it could be seen that the majority of the respondents considered it as “without difficulty”. Nevertheless, a higher percentage of elderly participants expressed understanding the visual information from the guidance system as being “a bit difficult” or “difficult”.

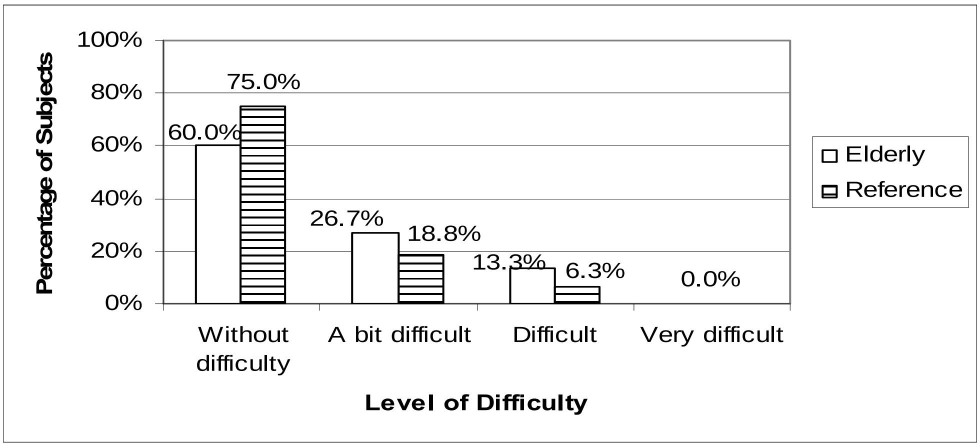

Figure 48. Level of difficulty to understand the visual messages from the guidance system

Regarding the level of difficulty to understand the voice messages of the guidance system without the interference of the mobile phone additional task, it was observed that almost all reference drivers consider it as “without difficulty” while a lower percentage of elderly participants place that action in the same category. Comparatively, a slightly higher number of older subjects felt that understanding the voice messages from the guidance device was at least “a bit difficult”.

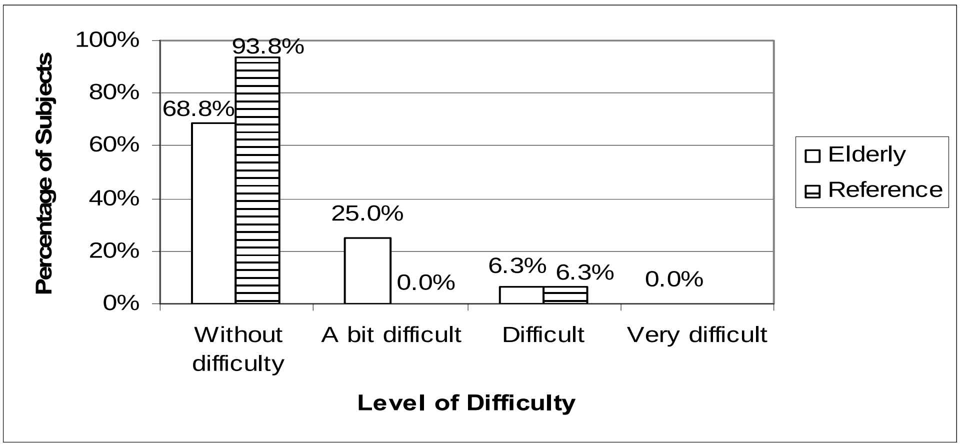

Figure 49. Level of difficulty to understand the voice messages from the guidance system

In order to know if participants felt that the guidance systems had helped them in their driving task, they were questioned about the importance of the help brought by such device. As it can be further observed in the figure, a very low percentage of subjects considered that the guidance systems didn't bring any help. In what concerns the comparison between driver groups it is revealed that percentages are not very dissimilar. The great majority of reference and elderly respondents believed that the system brought at least, an "important help" for accomplishing the task.

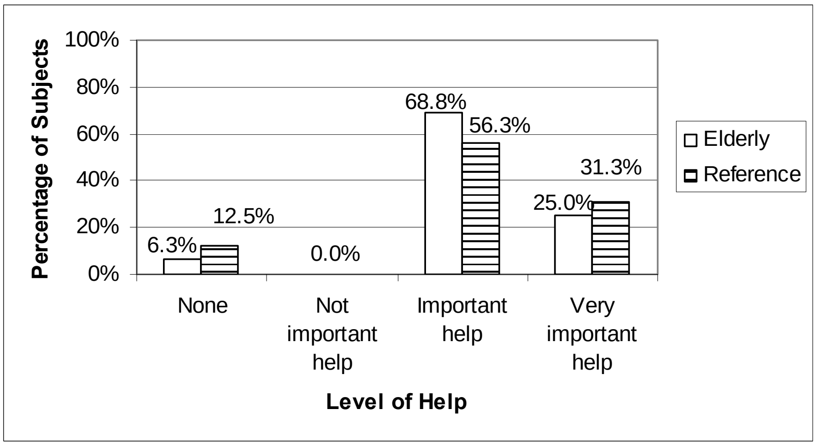

Figure 50. Level of help given by the guidance system

In an opposite evaluation, participants were asked to classify the level of disturbance that the interaction with such device imposed to the driving task. As it can be testified by the graphic the majority of respondents believed that the guidance system didn't led to any disturbance on the driving task. Nevertheless, a percentage of reference respondents considered that the device had disturbed them a bit, and some elderly subjects stated that level as “disturbing” or “very disturbing”.

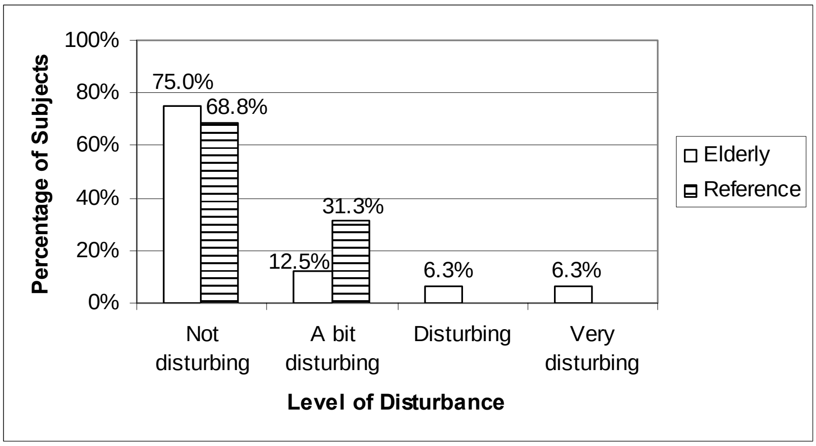

Figure 51. Level of disturbance induced by the guidance system

Following to these questions, participants were asked about the moments they had to interact with both in-vehicle systems simultaneously. The majority of subjects indicated that, while receiving guidance instructions and conducting the mobile phone conversation they didn’t felt any difficulty in the driving task. When responses of both driver groups were compared it could be verified that the answers percentage was the same (Yes= 18.75%; No= 81.25%). Nevertheless, more than half of the respondents believed that they had changed their driving behaviour with the interaction with both in-systems. Analysing the driver groups separately, it was revealed that a higher percentage of reference drivers believed to have changed the behaviour while the majority of the elderly respondents considered that their behaviour maintained the same while receiving guidance instructions and conducting the mobile phone conversation. Contrarily to the variables from the questionnaire analysed so far, this comparison between driver groups is statistically significantly ($U=52.00$; $p=0.003$).

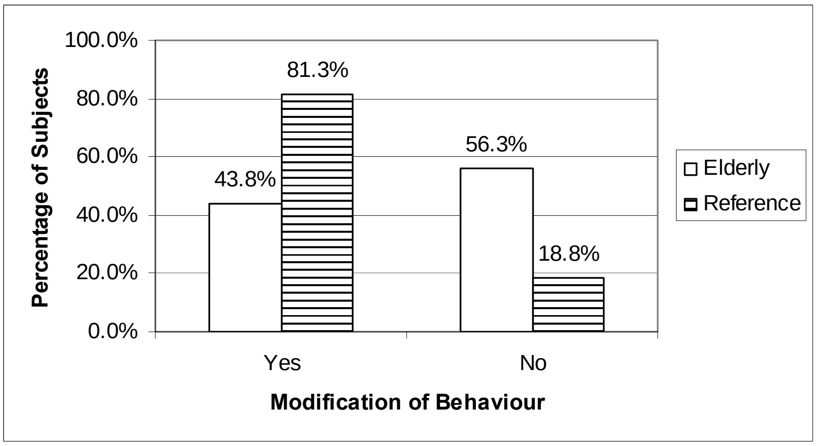

Figure 52. Modification of the driving behaviour in the two-system condition

In this two-system condition, participants were also asked if they felt to have had the time to manage all the road environment information. The vast majority of drivers considered having managed adequately this type of information at least "frequently". A lower percentage of subjects believed that they rarely managed adequately the road environment information and none considered has never doing it.

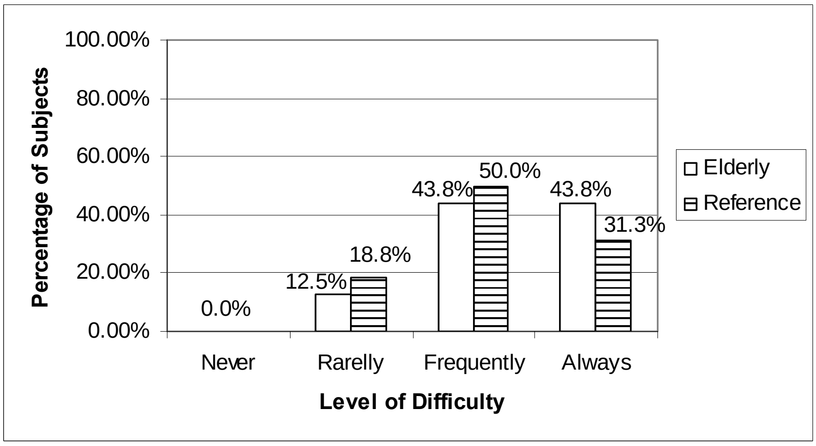

Figure 53. Adequate management of the road environment information

Regarding the several sources of information that drivers had to manage (from the mobile phone, the guidance system, and also from the road environment) when asked if they considered as having neglect some source of information, the majority of the reference and elderly drivers believed to have done it. The source of information that the vast majority of the participants considered as having neglected during the two-system condition was the mobile phone. Furthermore, 87.50% of the respondents affirmed to have given priority to the information from the road environment over the other two available.

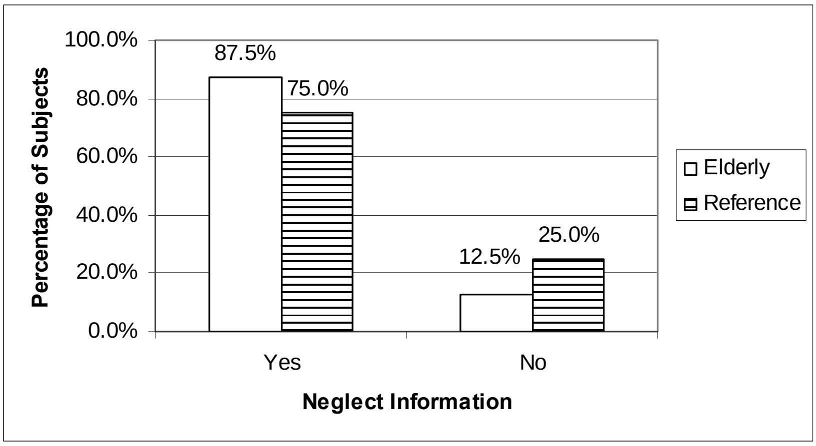

Figure 54. Neglect a source of information

2. Simulator Experiment Results

In the following paragraphs the results of the simulator experiment will be presented. Their order of appearance will be the same as for their description in the methodology.

2.1 Lane Exceedences

The results on the lane exceedences revealed that there was a decrease in the mean number of lane exceedences per kilometre driven from the baseline to the two-system condition. In fact, statistical analysis exposed a main effect of system condition expressing that there was a significant difference between courses [F (1,60)=3.81, p=0.028]. This main effect was the result of the difference between the one-system and the two-system conditions [F (1,30) =9.24, p=0.005], because between the baseline and the one-system situation no statistical significance was observed. Thus, these outputs indicated that while interacting simultaneously with the guidance system and the mobile phone participants made a significantly less number of lane exceedences per kilometre driven. In what concerns driver group differences, it was observed that reference drivers were the ones with more lane exceedences per kilometre. The baseline and the two-system condition contributed highly for this result. However, the dissimilarity of results between driver groups showed only a slight tendency as results were not significant.

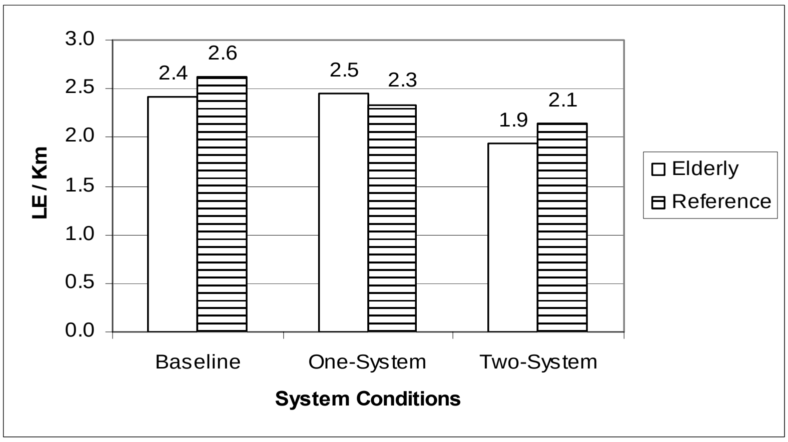

Figure 55. Average number of lane exceedences per kilometre travelled in each test condition

The time spent in each lane exceedence was also an important variable to consider. Whenever a lane deviation occurred, the time spent outside the lane margins was registered in seconds. The analysis of these data revealed that, the navigation system condition was the one where participants made longer lane exceedences. Nevertheless no main effect of system condition was observed. Regarding driver groups comparison, elderly drivers spent more time outside the lane margins for all conditions. This means that every time a lane deviation was made elderly drivers took more time to return to the lane limits. In spite of the dissimilarities, no main effects were observed between driver groups.

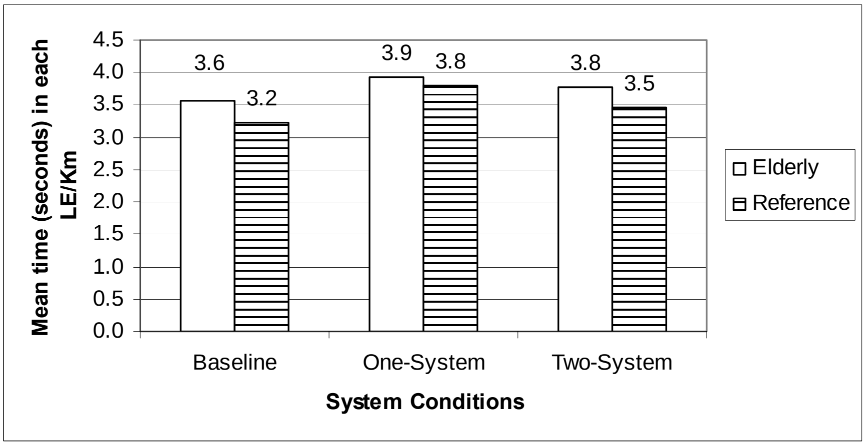

Figure 56. Average time (seconds) in each lane exceedence for all systems condition

2.2 Mean Speed

The analysis between system conditions revealed that, besides the slightly higher mean speed in the baseline course, no statistically significant differences occurred. This revealed that, when all participants were taken into consideration, there was no important difference in the average speed between courses. When ages were taken into account, it was observed that elderly drivers had lower mean speeds. A main effect of age was expressed because elderly participants obtained a significantly lower mean value compared with their younger counterparts [$F(1,30)=10.47$, $p=0.003$]. This significant scenario was also exposed when each condition was considered separately. Elderly drivers drove significantly slower than reference subjects in all system conditions [baseline: $U=53.5$, $p=0.003$; one-system: $t(30)=-3.03$, $p=0.005$; two-system:

t(30)=-3.15, p=0.004]. Nevertheless the greatest difference registered between drivers groups was for the two-system situation, once the mean values of speed were the most dissimilar. The analysis didn't expose an interaction effect between both variables (system condition and drivers group). This means that, mean speed values were significantly different as a consequence of the participants' age, not being dependent on the system conditions.

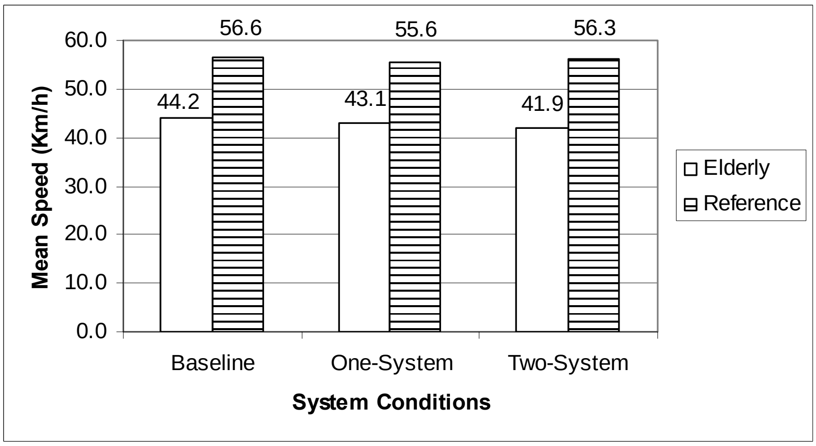

Figure 57. Mean speed for both drivers group in different system conditions

2.3 Violation of the Speed Limit

Results revealed no main effect of system conditions, i.e. there were no statistical significant differences between the three system situations (baseline, one-system; two-system condition). This means that, the frequency of times participants exceeded the speed limits was not dependent on the presence or absence of in-vehicle technologies. As it can be seen in the following figure, comparisons between age groups indicate some differences. In a general way, reference drivers were the ones that exceed the speed limits more frequently. This was also seen when each system condition was observed separately. However, in spite of the visible dissimilarity, the only significant difference was registered for the baseline and the one-system condition. In the baseline reference drivers crossed the speed limit approximately 2.9 times more than elderly [U(79.00); p=0.041] and in the one-system situation 3.5 times more [U(73.50); p=0.027]. It is also worth to notice that in the two-system situation elderly drivers crossed the speed limit more often than for the previous courses. However this value only showed a slight tendency for higher speed violations while interacting with both in-vehicle systems because no statistically significant differences were recorded between conditions.

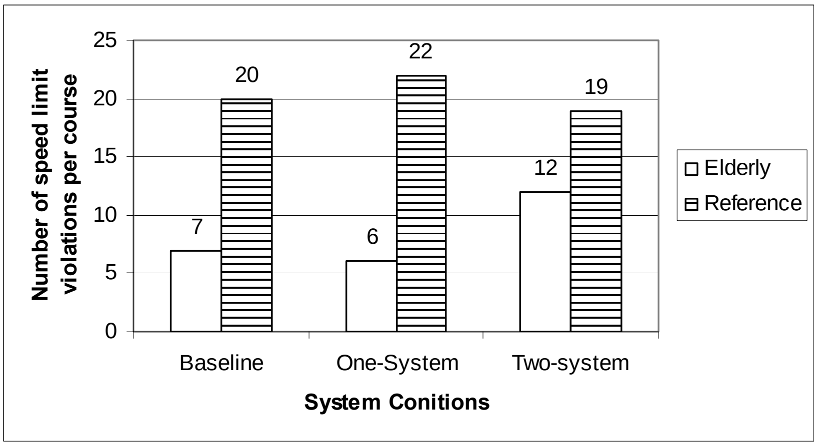

Figure 58. Total frequency of speed limit violation for both drivers group in each system condition

2.4 Turning Indicators

2.4.1 Omission Errors

Regarding the omission errors for the turning indicator sign, data revealed that there were no statistically significant differences between the system conditions, neither for the overall of the participants nor within each driver group. However, the analysis between both driver groups revealed a significant difference of "omission" errors for the activation of the turning indicator. As it can be observed in the following figure, elderly drivers had higher values for the baseline and also for the one-system and two-system situations. Statistical analysis exposed that the difference of such errors was not significant for the baseline but for the other two conditions. When systems were present in the vehicle elderly subjects forgot significantly more often to activate the turning indicator sign [one-system condition χ^2 (1)=4.76; p=0.029; two-system condition χ^2 (1)=4.41; p=0.036].

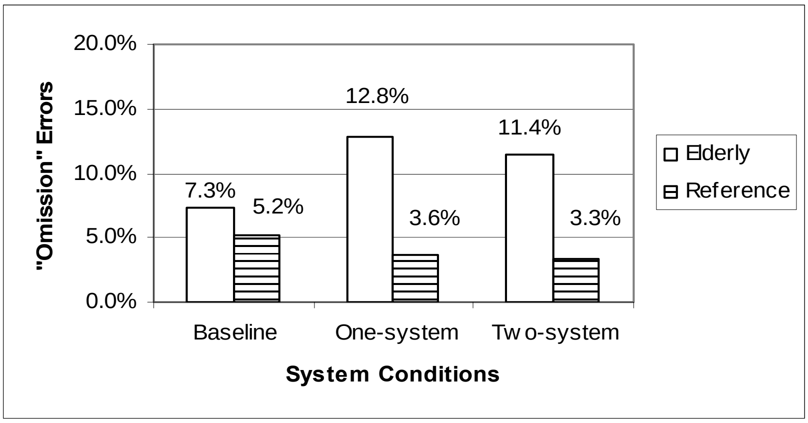

Figure 59. Percentage of "omission" errors in all system conditions for each drivers groups

2.4.2 Moment of Activation

The analysis of the moment for the turning indicator activation revealed that the comparison between one-system and two-system conditions was statistically significant. In average, the moment for this activation was made 11.37 meters sooner for the two-system situation [F (1,27)=4.59, p=0.041]. However, this significance vanishes when both driver groups were considered separately. Despite the higher values for the two-system condition, meaning that both driver groups activated the turning indicator sooner, no significant differences can be seen within each group. Furthermore, when the comparison between groups was made it was revealed that values were very similar for the one-system condition and slightly different for the two-system situation. No main effect of age was expressed as no statistically significant differences were observed.

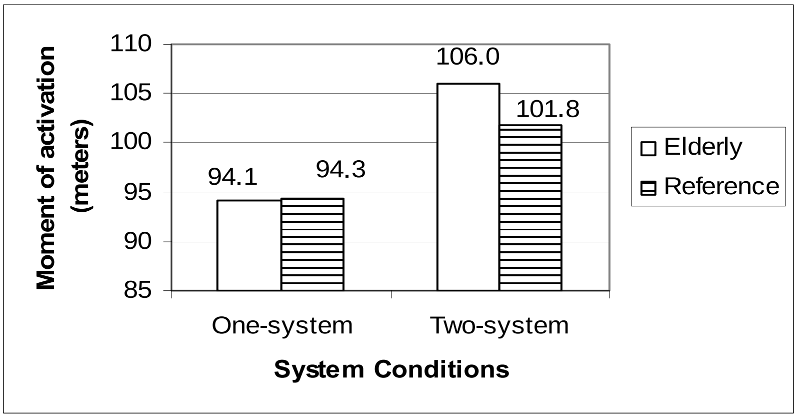

Figure 60. Distance for activation of the turning indicator

2.5 Navigation Errors

Only one navigation error occurred during the tests. It was performed by a subject that belonged to the elderly driver group and happened while the driver was accomplishing both in-vehicle tasks at the same time. At the intersection and while the phone conversation was being conducted, the guidance system informed the driver to turn left and the referred subject continued in front. After passing the intersection, the navigation error was detected by the participant. No other guidance errors were performed in the one-system conditions or in the baseline course.

2.6 Mobile Phone Task Performance

2.6.1 Hesitations

Results from the mobile phone task performance revealed that several hesitations were made during the tests. The examination of the “hesitation” category revealed that, when both zones were compared (“intersection zone” and “out of intersection zone”), no statistical significant differences were observed. Comparison between driver groups also didn’t show a main effect of age.

However, it could be seen some important differences when the interaction effect of both zone and age variables were considered. Elderly drivers had a higher percentage of hesitations in both course zones, however only for the “outside of intersection” area a statistical significant difference was expressed between elderly and reference participants [χ^2 (1)=7.23; p =0.007]. This means that, outside the intersection zone, elderly were the ones that had a significant higher percentage of hesitations. However this scenario was not the same for the intersection zones due to the important increase of hesitations for the reference participants. While conducting these simultaneous in-vehicle activities elderly drivers hesitate in the same manner during the entire course but not the reference drivers, which took frequently longer time to answer closer to intersections.

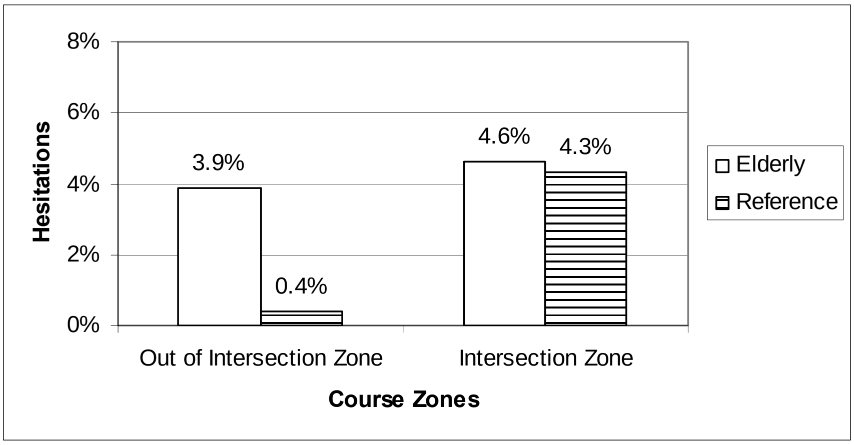

Figure 61. Percentage of "hesitations" in both areas of the course for each driver group

2.6.2 Incorrect Answers

In what concerns the number of incorrect answers given by participants, a similar analysis to the hesitation behaviour was made. Results revealed neither main nor interaction effect between independent variables. This means that the performance of multiple tasks had a similar effect on the accuracy of the answers given independently of the course zone or driver group.

2.6.3 Absence of Answer

The analysis regarding the absence of answers exposed some important and noteworthy results. The comparison between the two main areas of the course revealed that the intersection zone lead to a significantly higher percentage of non responses [$\chi^2(1)=17.09$; $p=0.000$]. Moreover, both drivers groups had higher percentages of non answers for the intersection zone [Elderly: $\chi^2(1)=12.54$; $p=0.000$; Reference: $\chi^2(1)=4.56$; $p=0.031$]. This means that was in the intersection area that drivers didn't answer more frequently to the request of the mobile phone speaker.

There was also a main effect of age revealing that elderly drivers where the ones that had higher missing answers [$\chi^2(1)=8.02$; $p=0.005$]. Elderly drivers were the ones that didn't accomplish the second part of the mobile phone task more frequently and this difference between age groups was even more pronounced inside the intersection area.

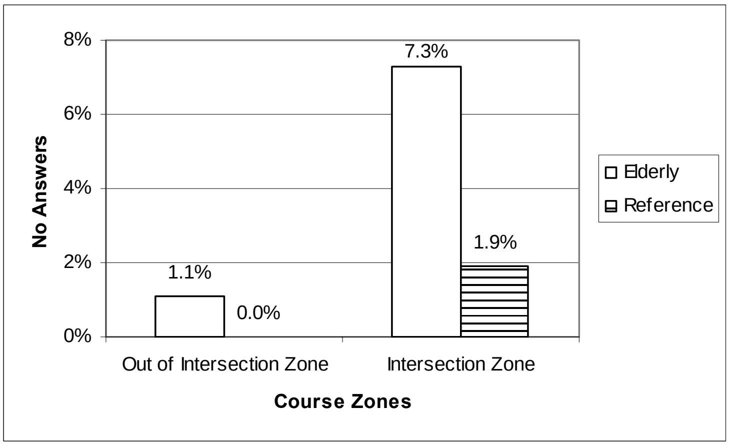

Figure 62. Percentage of "absence of answer" in both areas of the course for each driver group

2.7 Visual Behaviour

2.7.1 Gazes Towards the Control Panel

The mean number of gazes towards the control panel was counted and compared for each road section in each of the three system condition (baseline, one-system, and two-system). Considering the area outside the intersection, it was seen that when both in-vehicle systems were activated, participants made significantly less gazes towards the control panel of the vehicle. This glance decrement was not statistically significant between the baseline and the one-system conditions. However, when the two-system condition was compared with the other two situations significant differences were observed [baseline and two-system condition: $F(1,30)=10.30$, $p=0.001$; one-system and two-system condition: $F(1,30)=4.17$, $p=0.000$]. This means that, when interacting with both in-vehicle systems outside the intersections area, participants checked significantly less frequently the control panel of the car.

In what concerns driver groups, reference subjects showed a tendency to make higher number of gazes, specially for the one-system condition. However, no significant differences were registered. There wasn't also any interaction effect between the systems condition and the driver groups

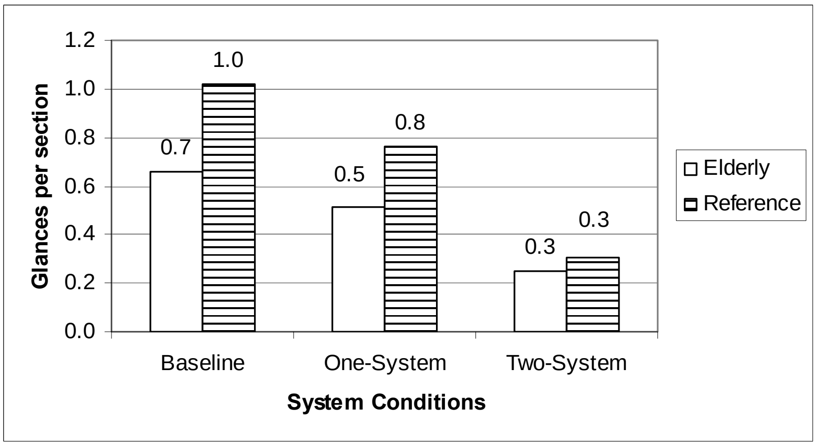

Figure 63. Glances per section towards the control panel at the “out of intersection” area

Different results were observed when the “intersection area” was taken into consideration. The comparison between system conditions was statistically significant, revealing a different number of gazes per section for all the situations [baseline and one-system condition: $F(1,30)=2.59$, $p=0.001$; one-system and two-system condition: $F(1,30)=0.25$, $p=0.029$; baseline and two-system condition: $F(1,30)=4.45$, $p=0.000$]. This means that closer to the intersection, participants looked significantly less to the control panel in the presence of the guidance system and even less when conducting the mobile phone task simultaneously. Again reference participants were the ones that made more glances per section to the control panel in both conditions. However this difference between age groups showed only a slight tendency once no statistically significant results were obtained.

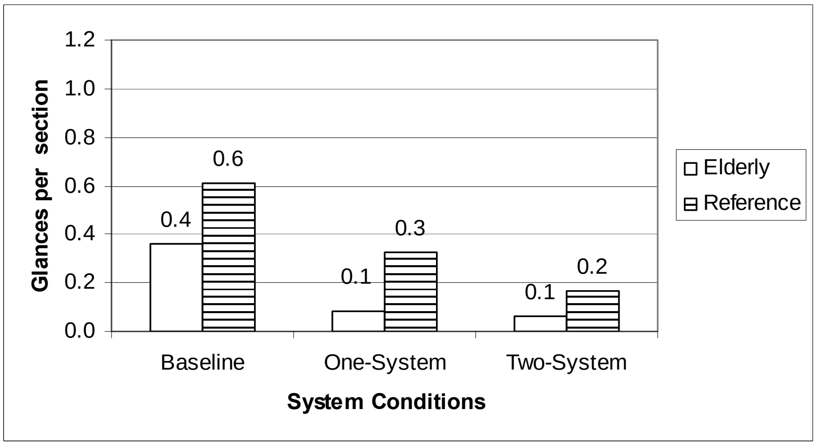

Figure 64. Glances per section towards the control panel in the “intersection” area

2.7.2 Gazes Towards the Guidance System

The number of gazes towards the guidance system display was analysed for both section areas. As it can be seen in the following figures, the two-system condition induced always to a lower number of glances per section. However, in spite of this tendency, no statistically significant differences were observed for none of the areas. In what concerns driver groups, elderly drivers were the ones that made higher number of glances per section and this tendency was observed for all the areas. However, no statistically significant differences were revealed.

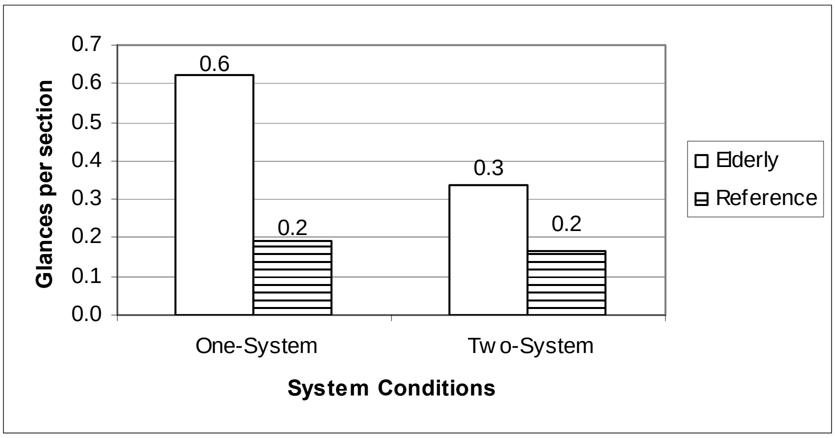

Figure 65. Glances per section towards the guidance display while "out of intersection" area

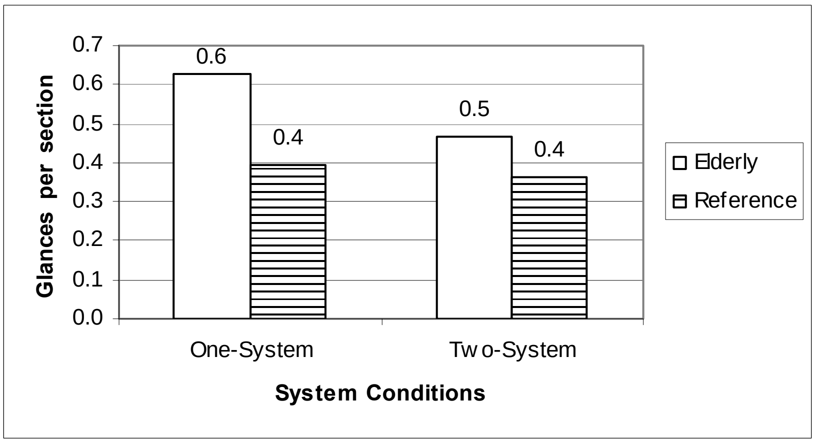

Figure 66. Glances per section towards the guidance display while at the "intersection" area

2.8 Self-Report

Concerning the guidance method used for accomplish the course and reach the destination, a question was made in order to find out the difficulty to get instructions from the direction signs and the navigation system. Participants had to choose one of the four levels of difficulty: “without difficulty”, “a bit difficult”, “difficult”, and “very difficult”. Regarding the baseline condition where drivers got instructions from the road signs, the majority of participants revealed that reading the plaques was “not difficult”. Even thought, 37.50% of elderly participants and 6.25% of reference drivers answered that it was “a bit difficult” to do it. On the other hand, when asked about the difficulty to understand the written and the audio instructions sent by the guidance system, all but one subject (a reference one) considered that this was done without difficulty. This reveals that, in spite of the majority of participants had answered that receiving instructions from both guidance methods had no difficulty, the baseline condition method was considered by a higher number of subjects as a bit more difficult than receiving instructions from the guidance system. Nevertheless, no significant differences were observed between system conditions or age groups.

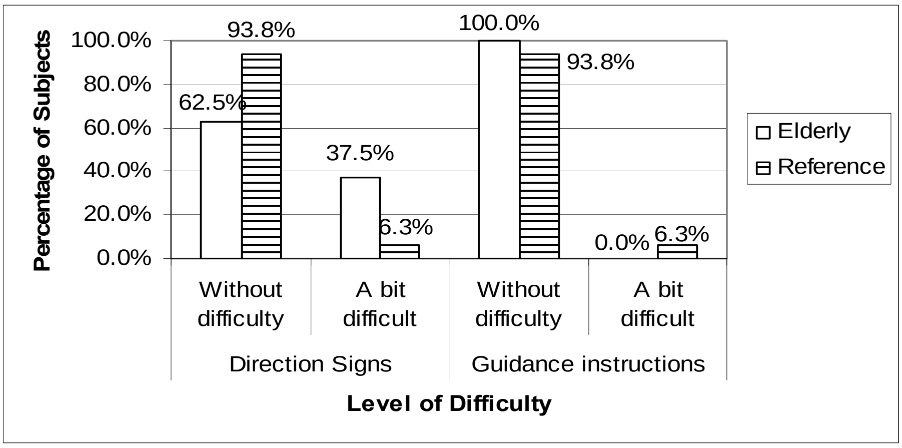

Figure 67. Level of difficulty to understand direction signs (baseline condition) and guidance instructions (one-system condition)

Participants were also asked about the level of disturbance that the vertical signs, the guidance instructions and the simultaneous inputs from the guidance and the mobile phone device induced on the driving task. This level of disturbance felt on the driving task was evaluated through a four level scale: “not disturbing”; “a bit disturbing”; “disturbing” and “very disturbing”. The guidance system itself (one-system condition) was the one that received more “not disturbing” responses from both age groups (75.0% from the elderly and 68.75 % from the reference). In fact, a higher number of subjects referred the situation with both in-vehicle systems as more disturbing, once 31.35% considered it “a bit disturbing” (for both driver groups) and 37.5% of the elderly and 62.50% of the reference respondents found it as a “disturbing” situation. These results indicate that there was a statistically significant main effect of system condition for the level of disturbance felt by drivers. The disturbance induced by the interaction with both systems simultaneously was considered superior by a higher number of subjects [compared with baseline: $\chi^2(1)=16.20$; p =0.000; compared with one-system condition: $\chi^2(1)=20.17$; p =0.000]. Furthermore, no statistically significant differences were observed between driver groups.

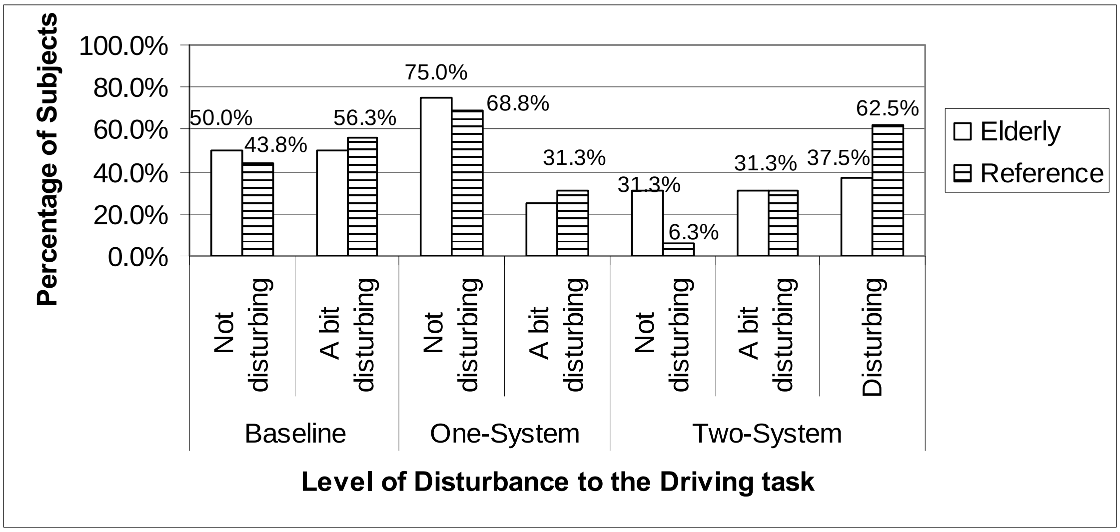

Figure 68. Level of disturbance felt to the driving task in each course condition

With the aim of knowing with more detail the effect of the mobile phone, participants were asked about the disturbance that this system induced in the driving task and in the guidance task separately. As it can be seen in the following figure, a higher number of “not disturbing” evaluations were made for the guidance task. This can suggest that the mobile phone conversation might have interfered more in the driving task than in the guidance task. However, this difference was not statistically significant and indicated only a slight tendency for participant to feel that the mobile phone was more disturbing in the driving rather than on the guidance. When both driver groups were compared some significant differences could be drawn. There was a higher number of elderly drivers reporting that the mobile phone did not disturb the driving neither the guidance task. This means that reference participants were the ones that felt the influence of the mobile phone conversation as more disturbing for the driving task [U=75.00, p=0.041] and also for the guidance task [U=60.00, p=0.007].

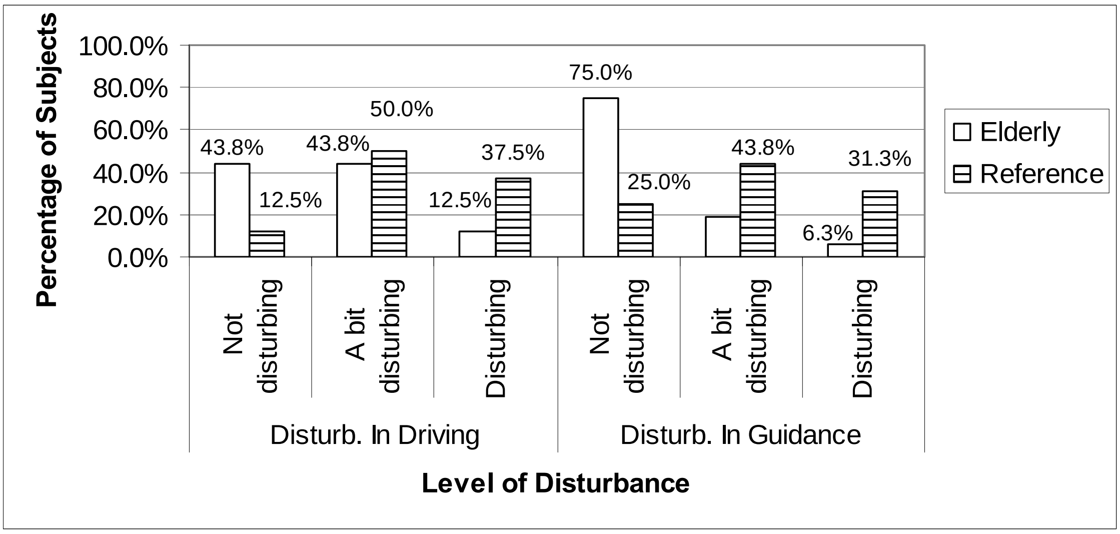

Figure 69. Level of disturbance induced by the mobile phone task on the driving and on the guidance task performance

The modification of the driving behaviour while interacting with in-vehicle systems was also questioned. Participants had to express if they felt some change in their driving behaviour while interacting with one and with two in-vehicle systems. The majority of participants answered that their driving behaviour was the same when interacting just with the simulated guidance system. However this percentage altered when they reported the interaction with the guidance and the mobile phone at the same time. When asked about the reasons that induced to these modifications (in the two-system situation), the majority of drivers answered that it was a problem of concentration. As it was very difficult to concentrate in all tasks at the same time they had to do things with double attention and careful. Some participants indicated also that due to the additional mobile phone task they devoted less attention to driving and even forgot to do some important things like activating the turning indicator signs. Three subjects felt that they drove slowly in this condition. The comparison between both drivers groups showed higher percentage of reference participants reporting a modification of behaviour; however this difference is not statistically significant.

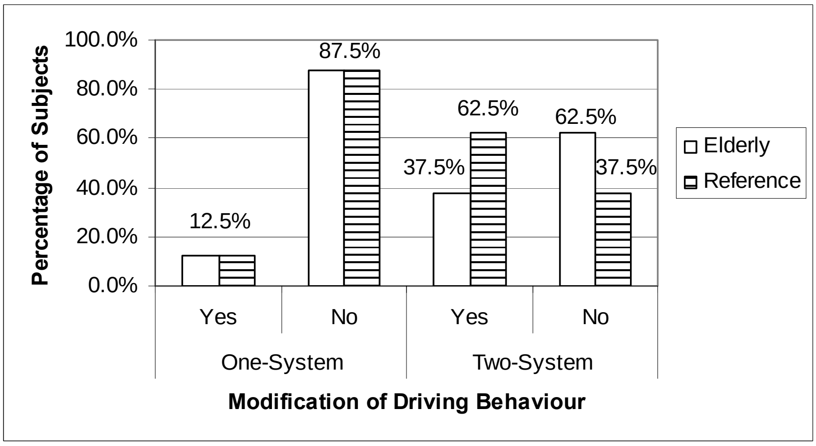

Figure 70. Modification of the driving behaviour while interacting with one or two in-vehicle systems

At the end of each questionnaire two final questions were made. The first one was to evaluate, in a scale from 1 to 10 (being 1 the lowest value and 10 the highest), the general difficulty of the course. The second question was to rate their effort while performing that specific condition.

Results revealed that the two-system condition was the one where a higher number of participants scored superior values. Comparing with the other system situations, significant differences were exposed. Scores from the two-system situation were significantly higher than the ones obtained in the baseline (z=-2.76, p=0.005) and in the one-system condition (z=-4.13, p=0.000). It is also important to report that, in spite of the slight dissimilarities between the baseline and the one-system situation, no significant differences were observed for the global difficulty level. No significant differences were revealed for the comparison between age groups.

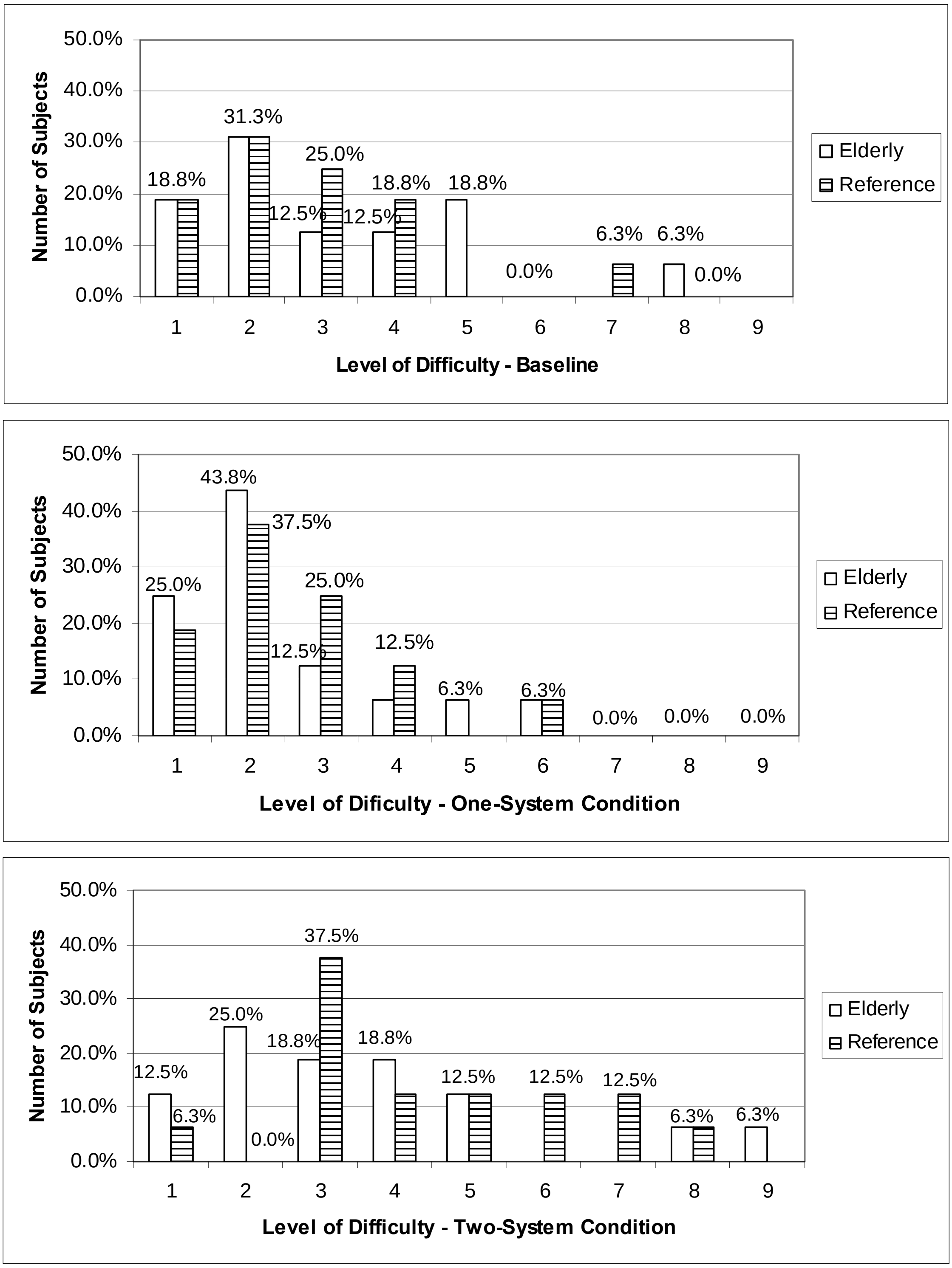

Figure 71. Level of difficulty for the baseline, one-system and two-system conditions

When the level of effort was evaluated, similar results were obtained. The two-system condition was the one with higher levels of effort, while the navigation system condition was the lowest. When results were compared significant differences were observed between the baseline and the one-system condition (z=-2.24, p=0.027) and also between the one-system and the two-system condition (z=-4.17, p=0.000). This means that the two-system condition induced to higher levels of effort while the one-system situation led to less effort. No significant differences between driver groups.

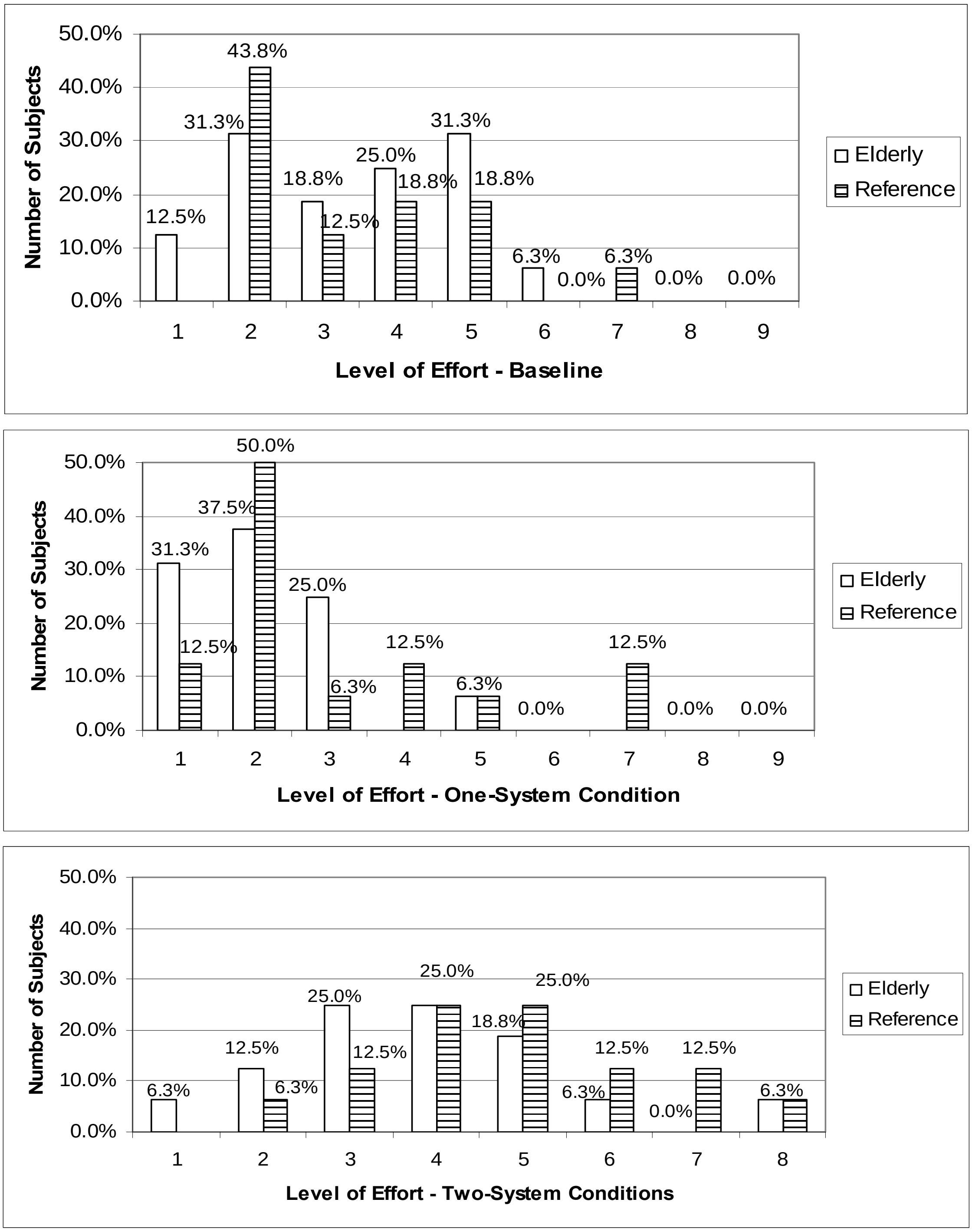

Figure 72. Level of effort for the baseline, one-system and two-system conditions

CHAPTER 2. DISCUSSION

As it was already stated, the objective of the present research was to study the impact of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour. It was intended to investigate the interaction with more than one in-vehicle system and examine the consequences of this simultaneous interaction on the activity of the driver. In order to verify if the general aim of the research was reached and also to sum up the outputs of the experiments, the discussion will be organized in accordance with the specific objectives established to this work.

Objective 1*: To determine the consequences produced by the simultaneous interaction with a guidance system and a mobile phone device on the driving task.*

The comparison between both system conditions (interaction with one in-vehicle systems vs interaction with two in-vehicle systems) showed considerable changes. As it could be verified in both on-road and simulator experiments several were the variables that showed the adoption of different behaviours by participants. When analysing this dissimilar behaviour registered on the multiple-task scenario (interaction with both in-vehicle systems) it could be observed that subjects assumed more frequently unsafe actions that could potentially interfere with the communication between them and the other road users. This interference could be done by means of indicating inadequately their actions; by the abrupt and unexpected adoption of determined behaviour; and also by neglecting some road information from the environment.

The on-road experiment showed that while interacting with both in-vehicle systems participants activated the turning indicator more often in an inadequate moment. In this situation the percentage of late activations of this sign (activations done less than two meters from the intersection or even after having stopped to perform the manoeuvre) was significantly higher. Nevertheless, this result was not confirmed by the simulator experiment because in this multiple-task scenario subjects activated the turning indicator approximately 11 meters sooner than for the situation where just interacting with one system (statistically significant result). These results going in opposite directions can be justified by the different natures of each experiment: the simulator environment was much simpler, with fewer cars, pedestrians and fewer elements in the landscape. The higher complexity of the on-road experiment environment could have led subjects to split their atencional resources through a higher number of elements, impeding them to activate the turning indicator in an adequate moment. The higher validity of this on-road experiment induced to consider that in a real traffic situation this can be the scenario, and in the presence of a guidance system and a mobile phone drivers can be delayed of indicating to other road users their intentions to turn.

Another situation worth to notice, despite the non significant results, was the verified tendency to forget to activate the turning indicator sign in the presence of both in-vehicle devices. This tendency, expressed in a more evident way in the on-road experiment, must also be taken into account once it can be a potential consequence while receiving instructions from a guidance system and also conducting a mobile phone conversation.

The changing in drivers' behaviour was also expressed on breaking and on the moment to turn. While interacting with both systems at the same time, significantly higher percentage of abrupt breaks were registered. This mean that when arriving to an intersection where a manoeuvre was needed participants changed more frequently their driving speed in an abrupt and sudden way. Abrupt breaks can be performed in emergency situations in order to compensate for inadequate actions like improper speed, unobserved events or lack of anticipation to some situations. Receiving guidance instructions and conducting a mobile phone conversation could have led to a higher number of inappropriate speed or unobserved events as a result of an inadequate allocation of the attentional resources to the driving task. This insufficient attention given to the driving task could induced drivers not to anticipate and prepare in a proper way to the next manoeuvre, forcing them to take a latter and more abrupt action to adjust the speed to perform the intersection.

While interacting with both systems participants also showed a significantly higher number of abrupt turn manoeuvres. This means that for the multiple-task scenario there were more situations where subjects accelerated inappropriately to perform the turn manoeuvres. This action can be justified in two ways: as an unintentional consequence of the inappropriate control of the car due to the not sufficient attentional resources allocated to the driving task or an intentional way to pass rapidly through the most critical places of the course (the intersection itself) where the probability of other cars to collide with the subject's vehicle was higher. Nevertheless, in both explanations the underlying cause could be attributed to the excessive mental workload: the attention given to the guidance instructions and to the mobile phone conversation could have induced the driver to divert the attention from driving; or participants tried to shorten the moments where the situation could be more critical and more difficult to manage.

The visual behaviour of participants also changed while interacting with both in-vehicle systems at the same time. It could be observed that for the multiple-task scenario participants missed more frequently to check the intersections and also the mirrors before performing the turn manoeuvre. This difference was significant and revealed that while interacting with both in-vehicle systems drivers looked less to the road environment, reducing the amount of important information captured from the surroundings.

The results obtained in the on-road experiment were coincident with the ones from the simulator tests. In spite of the dependent variable had not been exactly the same, the findings obtained go in the same direction. It was verified that in the simulated environment, significantly less glances were made to the control panel of the car when the simultaneous in-vehicle tasks were performed. This was true for the moments before the voice guidance system instructions to the manoeuvre and also for the moments after this message was transmitted. As it was a based-fixed simulator, in order to control the speed drivers had to look to the control panel of the car. The reduced number of gazes performed in the multiple-task condition indicated that they searched less frequently for that type of information. Thus, results from both experiments were consistent and indicated that while interacting simultaneously with a guidance and a mobile phone system subjects looked less to important areas of their surroundings. This behaviour can indicate that, for this type of situations, drivers can extract less information from the environment and miss some important signs that can compromise their safety.

These results from the visual behaviour are in accordance with the ones obtained by Nunes and Recarte (2002) when they compared driving without additional tasks and while talking just with a hands-free mobile phone. They verified that while performing the secondary task there was a spatial concentration, meaning that the percentage of time spent looking to the centre of the visual field (road immediately ahead) was higher. This higher spatial gaze concentration was confirmed by the data from the mirrors and speedometer inspection that suffered a considerable reduction. Authors suggested that those results showed that a higher mental workload can induce drivers to fail to detect visual information from the surroundings.

An effect that could also have been a consequence of this visual spatial concentration was the results of the lane exceedences on the simulator experiment. A lower number of excursions from the lane were expressed when interacting with both in-vehicle systems. This difference was statistically significant leading this condition to have been the one with lower lane exceedences. The reasons for this result may be related with the ones obtained in the visual behaviour variable. While interacting with both systems driver's mental workload could have increased in a way that led them to focus their attention on the road ahead, deviating less frequently their gazes to the periphery of their visual field. This visual concentration could have been accompanied by a more "freeze" behaviour, induceing to a lower number of lane excursions.

Furthermore, the higher number of exceedences observed in the other conditions could also have been a result of the high sensitivity of the simulated vehicle. As some subjects have referred at the end of the experiment, the sensitivity of the wheel was higher than in real cars and a small deviation on the steering wheel angle produced a much higher variation on the road scenario than it should be expected. As subjects looked more to the control panel of the car when just performing the guidance task, they could have made some lane exceedences while glancing away from the road environment. For that reason the results obtained on the visual behaviour could be linked with the ones achieved for the lane exceedences.

Contrarily to the outputs obtained in the previous variables, the mean speed values and also the violations of the speed limit did not showed statistically significant differences among the system conditions. This means that independently of interacting with one or two in-vehicle systems, the mean speed with which participants performed the courses was not significantly different. As this was a variable measured in the simulator experiment, the reason that can justify this result can rely on the type of course developed. The course had seven intersections (in which 6 should be made turn manoeuvres) and almost all intersections had a distance from each other of 600 meters. The road between intersections was not very long, and because a speed limit was imposed, participants may not have performed the course with high speeds. This could have led to similar results observed between the mean speed values among system conditions and to the non significant results. The same is valid for the violations of the speed limit, where no major differences were observed between system conditions.

In order to examine the consequences produced by the simultaneous interaction with a guidance system and a mobile phone device, the opinion of participants was also registered. The applied questionnaires tried to verify if the impacts on the driving task induced by interacting with both in-vehicle systems was assumed by drivers. Results from the simulator experiment revealed that participants considered the situation with both in-vehicle systems as the most disturbing. The majority believed also that their driving behaviour changed in that multiple task condition specially due to the difficulty in concentrating in all tasks at the same time. Some participants considered also to have devoted less attention to driving, rating the simultaneous interaction with both systems with higher levels of difficulty and effort.

In what concerns the opinions registered at the on-road experiment, additional findings could be drawn. More than half of the respondents believed that they have changed their driving behaviour when interacting with both in-systems. However, a great number of respondents (more than 35%) have indicated that while receiving instructions from the guidance system and also conducting the mobile phone conversation their driving behaviour had not been changed. Additionally, the great majority of subjects indicated that, while at the multiple-task condition, they didn't feel any difficulty in performing the driving task. This majority also considered to have managed all sources of information adequately in the most part of situations. When this management was not possible to be done appropriately, participants considered to have neglected more frequently the mobile phone conversation, giving priority to the information from the road environment.

By comparing the answers from the questionnaires with the driving behaviour variables it can be suggested that, despite the general idea that the interaction with more than one in-vehicle system could be more difficult and induce to changes in the driving task, some respondents considered to have succeeded without major decrements in their driving performance. Nevertheless, the determination that the interaction with both in-vehicle information systems can produce considerable changes in the driving task was confirmed. This verification was given by the inadequate activation of the turning indicator signs, the unadjusted breaking behaviour and manoeuvre performance, and also by the lower visual verifications of the environment. Finally, the impact on the driving task and specially on the road safety was confirmed by the higher number of traffic conflicts that occurred during the on-road experiment.

Additionally and to satisfy the objectives of the simulator experiment, the consequences on the driving task induced by the interaction with one in-vehicle device were verified. For that purpose the results obtained for the baseline conditions were compared with the ones acquired while interacting just with the guidance system. The variables indicated not existing major differences while interacting just with the simulated guidance system. No statistical dissimilarities were observed for the number of lane exceedences, for the mean speed and also for the violation of the speed limits. The self-reports given by subjects were in accordance with these findings and revealed that between the vertical signs and the guidance messages from the electronic device no significant differences were seen for the level of difficulty to understand the messages and the level of disturbance felt. The majority of respondents considered also that their driving behaviour was the same when interacting just with the simulated guidance system.

When rating the global level of difficulty to perform the courses, in spite of the slight dissimilarities between the baseline and the one-system situation, no significant differences were observed. However, when rating the level of effort felt during the course participants considered that interacting just with the guidance system led to less levels of effort than reading the vertical signs on the simulated road.

Despite the very good results for the interaction with the simulated guidance system, it should not be forget that these results could have been influenced by the low level of complexity of the course and consequently by the simplicity of the messages sent to the drivers. Going deeper on detail to the on-road experiment, despite the lack of comparison with a condition where no in-vehicle systems were activated, some errors were also observed in the one-system situation. This guidance interaction was not free of driving errors and induced to one critical situation (traffic conflict). Even though the examination of the consequences induced by the guidance system on the driving task was not the main aim of this experiment, the results obtained must not be extracted from their context. It can be suggested that the complexity of the environment and also the adequacy of the system to the specificities of the situations determine the success of the interactions performed.

To conclude, it can be stated that the first objective of the research was fulfilled and the first hypothesis was confirmed: the simultaneous interaction with a guidance and a mobile phone device while driving had an impact on the driving task performance. As this objective was reached by the comparison of a condition where drivers had to interact uniquely with a guidance system and another where drivers had to receive guidance instructions and conduct a mobile phone task, it is believed that the results obtained were not just due to the influence of the mobile phone device. The changes registered on the driving task performance could have been the result of the joint interaction with both on-board devices revealing that the whole could be more than the sum of the parts.

Objective 2: *To identify changes on the driver mental workload while receiving information from both in-vehicle information systems*

In order to answer to the second objective, a variety of assessment techniques was utilized. As it was mentioned on the literature review concerning the mental workload topic, the existence of such variety of assessment techniques is important once it was already proven as more appropriate than one unique single approach (Stanton et al., 2005; Zhang, & Luximon, 2005; de Waard, 1996). Distinct workload measures were defined to assess the driver mental workload in both system conditions (interacting with one and with two in-vehicle systems). The workload is one important factor that can determine the occurrence of human errors. When the level of workload is not adequate to the capabilities of the driver (very high level or even very low) it can contribute to a higher percentage of driver errors (Kantowitz, & Sorkin as cited in Schlegel, 1993).

As the results from both experiments could confirm, higher workload levels were obtained when drivers were interacting with both in-vehicle systems. This statement is confirmed by the outputs achieved in the distinct workload measurement groups. In what concerns the results from the primary task performance measures, the variables utilized on both experiments revealed a decrement of the driving task performance of participants. This decrement was expressed by the augmentation of the number of errors made and, as it is confirmed by the theory, it can be seen as an expression of the augmented mental workload. Additionally, secondary-task performance variables also confirmed this result. Once during both on-road and simulated experiments it was given the instruction to maintain the primary task performance, the observed variations in the secondary task could be seen as a consequence of the variation in difficulty. The inaccurate accomplishment of the additional task may have indicated that the operator workload was high as a consequence of the reduction in the spare capacity. The measurement of the visual behaviour of participants (considered as a physiological measure) registered also some decrements in the efficiency of looking for information. This also revealed that while receiving guidance instructions and conducting a mobile phone conversation an increase on the driver’s mental workload could have occured.

If the six region model presented in the work of de Waard (1996) is taken into account, it can be suggested that the interaction with both in-vehicle systems analysed in this research induced, in general terms, participants to experience a level of workload that could be placed in region A3 and B. This means that the increased demand imposed by the presence of both on-board devices, led to a lowering of the driver's performance expressed by the higher number of errors verified during the tests. Nevertheless, it is important to express that this is a general deliberation as all the situations are considered together, as well as the performance of all drivers. If a more detailed look is given to determine moments of the experiment and also to certain participants, it could be verified that there were instants where no errors were evidenced. However, this can not mean that a low level of workload is experienced. As it was already described on the workload six region model description some tasks can induce to a high levels of demand without showing performance decline (region A3). This higher demand can be temporarily compensated by an exertion of the effort; nevertheless this situation can not be maintained for a long period of time.

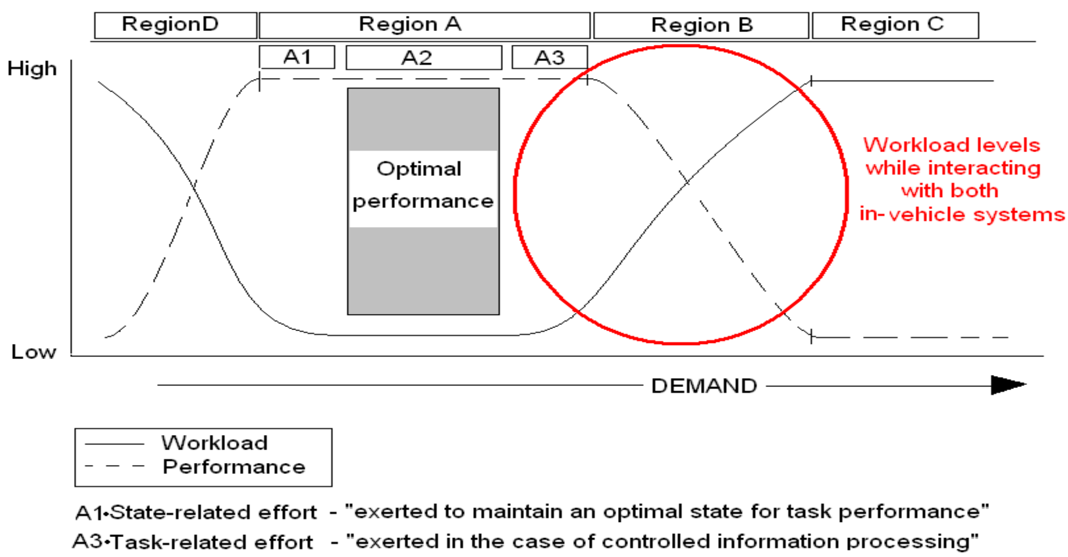

Figure 73. Representation of workload and performance in six regions (de Waard, 1996) with the levels of workload expressed by the participants in the present research

Due to the results obtained and also taking into consideration the theoretical framework presented on this research, it can be stated that the second hypothesis was confirmed: receiving information from a guidance system and conducting a mobile phone conversation induced to changes on the participants' mental workload.

Objective 3: *To verify the effects that the multiple tasks scenario induced on the guidance and mobile phone task performance.*

With the establishment of the third objective it was intended to verify some changes on the guidance task performance between the different system conditions, as well as examine the mobile phone task in order to discover any signs of poor performance.

Thus, the number of navigation errors was verified and the results obtained on both experiments were congruent. No statistically significant differences were observed between both system conditions revealing that the guidance performance did not suffer major declines from the introduction of another in-vehicle task: the mobile phone conversation. As it could be observed for the on-road experiment, while interacting with both in-vehicle systems subjects made a higher percentage of navigation errors, however that difference was not statistically significant. As a consequence, it can be suggested that performing the most complex multiple-task condition produced no significant decrement on the guidance task performance. This result was also confirmed by the simulator experiment where no major differences on the number of navigation errors were observed. Only one navigation error was registered during the tests and it was made while a subject was interacting with both on-board devices. The reason that can justify these results of confirmation with a minor expression (in terms of number of errors) could have been due to the simplicity of the simulated road environment. Once intersections had a simple orthogonal design and were placed apart from each other at least 600 metres, the complexity imposed to the guidance task was not very high. As a consequence, the number of errors was much lower when compared with the real experiment.

Furthermore, the variables related with the navigation behaviour collected for the on-road experiment also confirmed the results obtained for the navigation errors. The data from behaviours like “hesitations”, “express verbally the difficulties”, and “demanding for help” did not express a higher percentage of cases as it was expected on the beginning of the research. Additionally, the analysis of the guidance system performance expressed two important outcomes: the first one was related with the fact that participants did not change dramatically their guidance performance with the introduction on the additional mobile phone task; and the second outcome was linked with the poor diagnose capacity of two selected measurements (“express difficulties” and “demand for help”). In fact, the lower than expected verbalizations obtained while conducting the mobile phone conversation could have been imposed by the additional task. Once drivers had to respond verbally to the mobile phone task, it was less probable that they would express verbally their difficulties concerning the guidance performance. Furthermore, the number of verbalizations made was also much dependent on their comfortable or uncomfortable attitude towards the experiment and the other passengers present in the vehicle (driving instructor and researcher), meaning that a participant that did not express a difficulty verbally did not mean that he/she didn’t had it.

Another aspect confirming the fact that participants have not changed their guidance behaviour was the frequency of glances towards the display of the guidance system. In both experiments it was verified that while interacting with both on-board equipments, the visual behaviour to the guidance display in order to collect important information to the guidance task was not significantly different. This can mean that, independently of being interacting just with a navigation system or simultaneously with the mobile phone, drivers looked generally for the same amount of information from the guidance display.

In what concerns the effects that the multiple-task scenario induced on the mobile phone task performance, it could be observed that some errors were revealed. When the secondary task performance of participants was analysed it could be showed that several were the moments where participants gave inadequate answers to their interlocutor. However, the most frequent reaction was the absence of answer. After receiving and repeating the sentence from the researcher participants forgot, or decided, not to judge the sensitivity of the phrase. This result corroborate with the hypothesis indicating that the driver mental workload would increase with the interaction with both in-vehicle systems. The observed inaccuracies on the mobile phone task performance can be justified as a consequence of the increased difficulty and also increased level of mental workload experimented by the driver.

Hence, the third hypothesis proposed to this research regarding the assumption that the interaction with both in-vehicle devices at the wheel would have an impact on the performance of the guidance and of the mobile phone tasks, was only partially confirmed. The multiple-task scenario induced to a poor efficiency of the mobile phone conversation but did not impose significantly decrements on the guidance activity.

Attempting to explain why such results happened, a link could be made with one of the latest theories that tried to explain the multiple-task performance: the multiple-resource model of attention (Wickens, 1984). As it was previously mentioned, this model suggests that when two tasks are similar in terms of their sensory or motor requirements, it is likely to verify interference between both. Thus, two auditory signals are probable to interfere with each other, as well as two verbal processing tasks or two manual responses. On the other hand, tasks involving different modes of encoding, central processing and distinct form of response should get little interference from each other.

While coding the three specific tasks performed during the driving experiments, some difficulties emerged: its codification. When the driving task is taken into account it should be noted that its classification as a unitary activity is not adequate because this task is considered to be composed by several sub-tasks (McKnight, & Adams as cited in Groeger, 1999) or even divided by different task levels (Michon as cited in Bellet et al., 2003; Rasmussen as cited in Reason, & Hobbs, 2003). As a result each sub-task or level must be considered separately so that an adequate representation into the multiple-resource model can be performed (Hole, 2007). Moreover, the mobile phone task classification should also made cautiously as there are questions drivers might be asked that require more the use of visual imagery and others that require verbal resources. Thus, knowing that some errors can be made on the classification of these two tasks, the following simplification and justification were necessary to be made:

- Driving task: since the driving task can be composed by several sub-tasks, for these purpose it was only considered the activity of performing a turn manoeuvre. Thus, it can be classified as being perceived visually (encoding), processed spatially, and with a manual response.

- Mobile phone task: the sentences were transmitted orally to participants and in what concerns the encoding and the central process in which they were coded, the type of sentences did not endorse only one form of codification. In spite of certain phrases being coded verbally, many others were coded spatially because they deal with sizes to compare objects or objects' colours. Thus the majority of the mobile phone task could be processed spatially with sporadic verbally coded sentences. Responses to the mobile phone task were vocal.

- Guidance task: the messages from the guidance device were sent both visually and auditory, the central processing was assumed to be made spatially and no direct response was required to that specific task (the response was given by the manoeuvre made).

Table 24. Codification of each task

Tasks	Encoding	Central Processing	Response
Driving (performing a turn manoeuvre)	visual	spatial	manual
Mobile Phone	auditory	spatial	vocal
Guidance	Visual/auditory	spatial	(not required directly)

Supposing that participants coded the tasks as it was described in the previous table, it can be stated that:

- In the one-system condition (interaction just with the guidance device) it could be expected that both tasks interfered with each other, specially if the guidance task is encoded in a visual manner. If the central processing of the guidance task was done spatially, it could interfere with the driving task performance. In fact, what could be observed on the on-road experiment was that determined errors occurred while drivers were interacting just with the guidance system. In spite of the one-system condition had

had lower number of errors compared with the two-system condition, while interacting just with the navigation system some errors also occurred. Those errors showed interference between both tasks that could be visible on the driving and also on the guidance performance.

- In the two-system condition (interaction with the guidance system and the mobile phone device) it could be expected that all the tasks could have an interference with each other, once there was more than one task with the same encoding and also with an equal way to central process the information. In this respect, what could be observed in the experiments was that errors occurred in this multiple-task situation and the interference was expressed in all the three task performances: driving, conducting the mobile phone conversation and also guidance.

Moreover, an interesting result of this research that was not foreseen and not considered by the hypothesis was revealed in the comparison between both system conditions (one-system and two-system). Despite the performance decrements that were seen in both conditions and in all the tasks, the errors concerning the guidance activity did not suffered a significant increase with the inclusion of the mobile phone task. This could indicate that, despite the not 100% accuracy on the navigation, this task was the one that suffered less interference from the simultaneous interaction with other tasks.

A couple of explanations can be suggested to justify this result. The first one is related with the higher allocation of attention resources given to the guidance task by the participants of these experiments. Even knowing that the driving task was the most important and it should be considered as the priority task, driver also knew that a certain objective should be reached in order to complete the experiment. Having this objective in mind, drivers could have preferred to make some mistakes on the driving than on the guidance performance because it could compromise the success of the experiment. Another justification for the maintenance of the guidance performance could have been the way participants process the information from the guidance messages and the mobile phone task. Guidance instructions could not have been always processed spatially but in some moments in a verbal manner. Additionally, as it was already seen, the mobile phone task could have been coded verbally, specially in the moments when the guidance task had to be spatially processed. Thus, when the auditory messages were not overlapped by the ones from the mobile phone task, or the apprehension of the visual guidance information did not impair the collection of important cues from the road environment, the guidance task did not suffered considerable interference from the other tasks. The flexibility in which information from the guidance and the mobile phone tasks were coded and the supposed not synchronized ways to code the messages could have reduced or controlled the interference produced on the guidance task. Moreover, the errors observed on the mobile phone conversation could not have been due to the guidance task performance but due to the driving task.

Objective 4: *To determine age-related differences in the driving task performance among adult and elderly drivers, induced by the multiple-task scenario.*

The verification if the multiple-task scenario led to distinct consequences on the different driver groups was performed through the comparison of both groups' performance. In what concerns the consequences produced on the driving task, results showed that for some variables the performance of elderly drivers suffered higher decrements with the interaction with both in-vehicle systems. This was the case of the activation of the turning indicators. In spite of the on-road experiment showed only a slight tendency to elderly drivers forgot more frequently to activate the turning indicator in the presence of both systems, the simulator study revealed a significant difference between driver groups. Additionally, for the on-road study, elderly drivers performed a significantly higher number of late activations for the multiple task situations while the simulator test only revealed slight tendencies. Independently of the non exact same results in both experiments, a higher performance decrement could be observed for the elderly drivers when interacting with both in-vehicle systems in what concerns efficiency of the turning indicator sign activation. While receiving messages from the guidance system and performing the mobile phone conversation, elderly drivers also had higher percentage of turn manoeuvres performed with another vehicle dangerously near the intersection.

Additionally, and contrarily to what was expected, there were a number of variables showing a decrement on the elderly drivers performance accompanied by similar decrements for reference participants. In what concerned the errors committed while braking (abrupt braking), the number of hesitations to perform a manoeuvre, the abrupt turns, and also the inadequate checks to the mirrors before the intersection, results showed significant differences between age groups for the one-system condition but not for the two-system situations. This reveals that despite the generally higher values of errors for the elderly drivers in both situations, reference drivers worsen significantly their driving performance while simultaneously interacting with the devices. It can be suggested that elderly drivers performed a considerable number of errors while interacting with one system and even more errors while interacting with both on-board devices. On the other hand, the performance of reference drivers when interacting just with the guidance system had lower number of errors. However, in a surprising way, certain aspects of their driving performance were equally poor when compared with the elderly participants, specifically the breaking behaviours, the hesitations to perform a manoeuvre, the abrupt turns and the omissions on the rear mirror checking.

It was also be registered on the simulator experiment that the reference drivers made more violations of the speed limit. This value was significantly different from the value of elderly drivers while interacting with one system but similar for the two-system condition because this frequency was reduced. The values of mean speed are also important to refer as they expressed a distinction on the behaviour of both driver groups. Elderly drivers had always lower mean speeds being this difference from elderly participants even more pronounced while interacting with both in-vehicle systems. As some studies already mentioned, the lower speed values of elderly as well as the fewer number of violations of the speed limit is a behaviour that is generally observed for these age cluster. Their frequently more cautious behaviour was already reported and its higher expression is often verified in situations with increased difficulty.

Thus, the results obtained on the experiments revealed that the performance of elderly drivers decreased with the introduction of another in-vehicle task while driving, however some aspects of the driving task performance of reference drivers worsened to similar values. Nevertheless, there was a last variable that allowed suggesting that oldest participants had more difficulties managing the amount of information from the different sources: the dangerous situations. As it could be observed by the results, all the traffic conflicts occurred on the on-road experiment and were performed by elderly drivers.

Hence, in spite of similar frequencies of errors in determined aspects of the driving task, and on the majority of elderly drivers opinion revealing that the multiple-task scenario did not cause significant changes on driving, the consequences of the simultaneous interaction with a guidance and a mobile phone task produced more severe consequences to the driving task performance of elderly drivers.

The performance on the driving task was not the only one that expressed dissimilarities between driver groups. The guidance task also revealed some differences. Contrarily to what could be expected and also contradicting some results revealed by other researches, the percentage of navigation errors was not significantly different between age groups. Elderly drivers only showed a slightly higher tendency to make more navigation errors, tendency that was higher while interacting with both in-vehicle systems. The significant differences occurred for the guidance performance was registered for other variables like the hesitations and also expressions of difficulty. Elderly drivers had significantly higher values of hesitations before performing a turn manoeuvre and also expressed more frequently their difficulties towards the guidance messages sent by the device.

Moreover, the visual behaviour was also different from their younger counterparts. Older participants looked less frequently to the visual display of the guidance system and this difference was even more pronounced while interacting simultaneously with both systems. This lower frequency of glances was also confirmed by the simulator experiment when both systems were activated. Additionally, it was also registered that they made longer glances towards the display when interacting uniquely with the guidance device, but reduced when the mobile phone task was present. Thus, it was exposed that while interacting just with the guidance system elderly drivers made fewer but longer glances than their counterparts. When the mobile phone conversation was added they reduced their number of glances towards the display and the mean duration of each glace had similar values to the glances of reference participants. This can mean that the multiple-task scenario led elderly drivers to look frequently less to the guidance system, extracting a lower amount of visual information from the display. Regarding the navigation errors performed during this more difficult condition, it can be suggested that the fact of extracting less amounts of visual information could had been the cause of the slightly higher tendency for making navigation errors. However, the non significant difference in such errors between systems condition could reveal that in the multiple-task scenario elderly participants relied more in the voice instructions and that information was sufficient for the satisfactory completion of the guidance task.

Lastly, elderly drivers also showed differences in the performance of the mobile phone task. The number of incorrect answers and also the percentage of lack of answer were significantly higher for the elderly participants and proved that the performance on the mobile phone task was worse than their younger counterparts. Additionally, in the simulator experiment elderly drivers made more hesitations before answering to the sentence of the interlocutor and also had more percentage of absence of answer. However, results showed some differences before and after the guidance system instruction. Elderly drivers made significantly more hesitations than reference before the guidance instruction and this value increased after this message for similar values to the ones obtained by the reference subjects. Furthermore, the number of non judged sentences (absence of answers) was significantly higher for elderly before the guidance instruction, being this difference even more pronounced after this navigation message.

As a conclusion and in accordance with researches that investigated the influence of one in-vehicle system on the driving performance (e.g. mobile phone devices) higher effects were observed on the performance of elderly drivers. Despite some of the consequences to the driving activity of reference drivers have been expressed in similarly values, major costs were revealed by elderly participants. The management of all the sources of information and the supposed higher difficulty for elderly to cope with all the tasks demands induced them to compromise their safety and be involved in dangerous situations. Additionally, their worse performance on the mobile phone task helped to reveal that higher levels of workload could have been present for the older participants, demonstrating lower spare capacity to the completion of the additional mobile phone task. Results from self-reports have indicated that a higher percentage of elderly drivers have considered that the multiple-task scenario did not alter their driving task. However, this does not mean that participants do not have the conscience that the multiple-task was the most difficult scenario. In fact, the simultaneous interaction with more than one in-vehicle system was recognized as having the higher values of difficulty, but the notion that this higher difficulty could have interfered with their driving task was not expressed by the majority of elderly participants.

The hypothesis created at the beginning of the research was confirmed. The multiple-task scenario induced to distinct consequences on the performance of the groups of participants. While interacting with both in-vehicle systems elderly drivers showed a generally worse performance. It can be suggested that they can be more at risk due to their higher number of traffic errors, traffic conflicts and higher mental workload. Nevertheless, the comparison of their performance with their younger counterparts was not as distinct as expected for the most difficult condition. The performance of reference drivers when interacting just with the guidance system had lower values of errors and those values increased considerably for the two-system situation.

FINAL CONSIDERATIONS

1. Conclusions

The introduction of new technologies into the transportation sector has been changing gradually the driving task. Nevertheless, the existence of such technology is justified by the advantages that it could bring to the road system as well as to the driver itself. Once several related systems can be part of the road environment but also be present inside vehicles, it is essential to identify the exact consequences of the use of intelligent transportation systems, more specifically the interaction with in-vehicle information systems.

To contribute to increasing the knowledge and to search for explanations of drivers' behaviour towards the novel on-board technologies, the present research analysed the interaction with two of the most popular in-vehicle systems: a mobile phone and a road guidance system. Knowing that nowadays the number of electronic equipments inside cars is increasing much due to their new appealing features and functionalities, it was intended to investigate the consequences of a simultaneous interaction with more than one in-vehicle system. Thus, the aim of the present research was to study the impact of multiple visual and auditory inputs from in-vehicle information systems on the driver behaviour.

Throughout the literature review it was possible to characterize the driving task and to expose some of the most important theories that tried to explain the driving activity and the way drivers' process information. Human beings are not capable of attending to all the stimuli at once, and only specific parts of the information are detected. This selection defines the events to which subjects are aware of and give effective allocation of attentional resources. While driving this selection is extremely important, because a correct and appropriate collection of information from the road environment is crucial for an effective driving performance (Egeth & Yantis, 1997). Along decades several theories tried to explain the processes in which subjects selected the attention and divided it thought more than one task. A central idea for most models is that a subject has limited resources to allocate to a specific task or set of tasks (see Solso, 1998; Fortin, & Rousseau, 1992; Lucas, 1992). When the task demands exceed the individual's limited capacity, performance may deteriorate in a visible manner. This scenario can be even more likely when performance of two tasks happen at the same time.

The first theories believed that due to the individuals' unique resource of attention, subjects had a limited cognitive capacity for performing a task and this was the reason that justified the lower capacity to perform more than one task simultaneously. If two tasks demand more attention than a single one, simultaneous task execution could lead to a situation is which one ore both tasks have fewer resources than required (Wickens, 1991). However, in spite of this factual scenario, several experiments showed that in particular occasions participants were able to perform more or less efficiently two different tasks, and that the performance degradation of one or both tasks was not always evident. These results gave rise to a different theory, suggesting that rather than a single attentional resource subjects possess a number of different resources, each dedicated to a particular type of processing job. If two different tasks do not require the allocation of the same resources, it is possible that they can be performed simultaneously with low or none performance deterioration (Wickens, 1984, 1992).

When multiple-task performance is an issue, distraction can be the focus of discussion. If an in-vehicle information system is present in the car and captures the attention of the driver, the attentional resources that should be entirely given to driving can be diverted to the additional task. Nevertheless, preoccupation with the multiple-task performance in the road context is based also on the driver overload as the consequence of performing more than one task at the same time. This mental workload can be an expression of the interaction between task requirements and the subject's capabilities and resources. A level of workload that is not adequate to the capabilities of the driver can contribute to higher percentage of driver error and may be critical for road safety (de Waard, 1996).

To confirm that distraction can be an important issue and that mental workload can be an expression of the interaction with certain in-vehicle equipments, several studies demonstrated that particular on-board information system have an impact on the driving performance (Alm & Nilsson, 1995). One example are the researches made to the interaction with a mobile phone device. In spite of results could be slightly different depending on the nature of the conversation, the level of involvement and also the degree of active contribution from drivers, the majority of experiments showed that accident risk can increase when drivers are interacting with such equipment. Higher reaction times were noticed; undetected points on the peripheral field of view were verified; and also higher mental workload levels were distinguished (see Strayer, & Johnston , 2001; Consiglio et al., 2003; Patten, Kircher, Ostlund, & Nilsson, 2004; Parkes, & Hooijmeijer, 2001; Graham, & Carter, 2001). Additionally, researches that focused the interaction with a guidance system also expressed some concerns. Due to their potential distracting effects, the design of such systems is of major importance, leading a proper design to an effective guidance help, not inducing drivers to adopt risky behaviours that can endanger them and the other users of the road network (ESop, 2005).

After collecting information that allowed knowing specifically the consequences from the interaction with a single in-vehicle information system, the present research intended to investigate the interaction with more than one in-vehicle system and verify the consequences of this simultaneous scenario on the activity of the driver. The consequences produced by the simultaneous interaction with a guidance system and a mobile phone device on the driving task were expressed throughout the comparison between two system conditions: interaction with one in-vehicle systems vs interaction with two in-vehicle systems. This comparison showed considerable changes on the drivers' behaviour once the interaction with both in-vehicle systems induced subjects to assume more frequently unsafe actions that could potentially interfere on the communication between them and the other road users.

An example of that was the activation of the turning indicator performed significantly more often in inadequate moments and also a slight tendency to forget to activate it before performing a turn manoeuvre. Drivers' behaviour changing was also expressed on the braking and on the moment to turn. While interacting with both systems significantly higher percentage of abrupt brakes were registered and a significantly higher number of abrupt manoeuvres were verified. This means that when arriving to an intersection where a manoeuvre was needed, participants changed more frequently their driving speed in an abrupt and sudden way and also accelerated inappropriately to perform the turn manoeuvre.

The visual behaviour of participants also changed while interacting with both in-vehicle systems at the same time. It could be observed that for the multiple-task scenario participants missed significantly more to verify previously the intersections and also the mirrors (rear view mirrors and inner view mirrors). It was also verified in the simulated environment that significantly less glances were made to the control panel of the car. Another behaviour that changed in the multiple-task scenario and could have been a consequence of the lower glance deviation to the control panel was the results of the lane exceedences on the simulator experiment. A lower number of excursions from the road lane were expressed when interacting with both in-vehicle systems.

Contrarily to the outputs obtained in the previous variables, the mean speed values and also the violations of the speed limit obtained from the simulator experiment did not showed statistically significant differences among system conditions. This means that independently of interacting with one or two in-vehicle systems, the mean speed with which participants performed the courses was not significantly different.

The comparison of the answers from the questionnaires with the driving behaviour variables revealed that, despite the general idea that the interaction with more than one in-vehicle system could be more difficult and induce to changes in the driving task, some respondents considered to have succeeded without major decrements in their driving performance. Nevertheless, the determination that the interaction with both in-vehicle information systems can produce considerable changes in the driving task was confirmed. This verification was unequivocally showed by the inadequate activation of the turning indicator signs, the unadjusted breaking behaviour and manoeuvre performance, and also by the lower visual verifications of the environment. Finally, the impact on the driving task and specially on the road safety was confirmed by the higher number of traffic conflicts that occurred during the on-road experiment.

The verification of the effect from the multiple-task scenario on the guidance and the mobile phone task was also done. However, the hypothesis proposed to this research regarding the assumption that the interaction with both in-vehicle devices at the wheel would have an impact on the performance of the guidance and of the mobile phone tasks, was only partially confirmed. The multiple-task scenario induced to a poor efficiency of the mobile phone conversation but did not impose significantly decrements on the guidance activity. Some inacuracies were verified on the mobile phone task performance, being expressed by the inadequate responses or by the absence of answer. However, the guidance performance was not considerably deteriorated because the number of navigation errors was not significantly different, or the behaviour towards this in-vehicle system was visibly different.

Based on these results, it was possible to confirm the changes on the driver mental workload from the interaction with both in-vehicle systems, as expected in the beginning of the research. Higher workload levels were obtained when drivers were interacting with both in-vehicle systems and this was expressed by the performance measurements and by the unique physiological variable analysed. Furthermore, self-reports also confirmed the higher difficulty felt during the multiple-task scenario.

Finally, this study had the objective of determine age-related differences in the driving task performance among adult and elderly drivers. Results revealed that for some variables, the performance of elderly drivers suffered higher decrements with the interaction with both in-vehicle systems. This was the case of the activation of the turning indicators since a higher performance decrement could be observed for the elderly drivers when interacting with both in-vehicle systems in what concerns efficiency of the turning indicator sign activation. While receiving messages from the guidance system and performing the mobile phone conversation, elderly drivers also had higher percentage of turn manoeuvres performed with another vehicle dangerously near the intersection.

Additionally, and contrarily to what was expected, there was a number of variables showing a decrement on the elderly drivers performance, accompanied by decrements to similar values of reference participants. For determined variables, results showed significant differences between age groups while interacting just with one system but not when interacting with both. This reveals that despite elderly drivers performed a considerable number of errors while interacting with one system and even more errors while interacting with both on-board devices, reference drivers' performance was better when for one system condition considerably equally poor when interacting with both in-vehicle systems. This was evident for some variables like the braking behaviours, the hesitations to perform a manoeuvre, the abrupt turns and the omissions on the rear mirror checking.

The consequences of the simultaneous interaction with a guidance and a mobile phone task produced severe consequences to the driving task performance of elderly drivers and also decreased considerably the performance of reference drivers. In spite of the reference's performance have suffered significant changes in some variables for the one-system condition, elderly drivers are still considered as more at risk when interacting with both systems. The management of all sources of information and the supposed higher difficulty of elderly to cope with all the tasks demands induced them to compromise their safety and be involved in dangerous situations. Additionally, their worse performance on the mobile phone task helped to reveal that higher levels of workload could have been present for the older participants, showing lower spare capacity to the completion of the additional mobile phone task. The hypothesis created at the beginning of the research was confirmed. The multiple-task scenario induced to distinct consequences on the performance of the groups of participants. While interacting with one system, both age groups had considerable dissimilarities in behaviour; however those dissimilarities were much less pronounced for the two-system situation. Nevertheless, it is considered that elderly showed being more at risk in both system conditions.

2. Methodological Considerations

Some aspects of the methodology merit a special attention in order to allow a brief reflection regarding the limitations of the present research. While conducting the study and specially at the end of the project, some aspects were pointed out as being topics that could be improved.

One of these aspects was the sample on both experiments. Its enlargement can be consider as an advantage in what concerns the production of significant results and their extrapolation to a broader population. Furthermore, a higher number of subjects with experience in navigation/guidance systems could have made possible a comparison between subjects with and without such experience, and could enriched the results. The existence or absence of experience on these types of systems is very important once it can determine the drivers' automatisms and consequently their level of mental workload while driving. As a consequence reactions and behaviours can be different from the subjects that had no experience.

Another aspect that could have been a limitation to the study was the nature of the mobile phone task. Sentences could have belonged all to the same codification group, i.e. phrases should have been elaborated to be coded by subjects in the same manner (spatially or verbally). Without a homogenised codification it was difficult to determine in which extent the mobile phone task contributed to the degradation of the driving and the guidance tasks, according to Wickens' multiple-task theory (Wickens, 1984, 1992).

Regarding the simulator study, as it was mentioned in the methodology, the courses used during the tests could have been very simplistic. A higher degree of difficulty and complexity in the road environment, like the configuration and number of intersections, could have contributed to a more realistic guidance task and to different driving behaviours. Nevertheless, a more complex simulator environment had also to take into account the possibility of simulator sickness, and some strategies had to be considered to cope with that situation. Furthermore, the number of variables analysed for the simulator experiment could have been distended. A higher number of different measures could have enriched the results given by the simulator tests and also help to know more about the consequences of the simultaneous interaction with in-vehicle systems.

To conclude the methodological considerations it is important to inform that subjective analysis of participants could have been collected in a different way. The application of a simple and unidimensional subjective workload method to collect the opinion of drivers could have helped to homogenise the analysis of results between both experiments.

3. Future Perspectives

Based on the present research some perspectives for further investigations can be consider for improving this line of investigation.

The simultaneous interaction with the studied systems (guidance system and a mobile phone) could be analysed with a system that manages the voice messages sent to the driver or, as certain nomadic equipments already allow, to connect the mobile phone to the guidance system so that both messages are not sent at the same time. Studying the interaction with both in-vehicle systems without the overlapping messages could be important to determine in which extent the management of voice messages can benefit and reduce the impact on the driving performance decrements. Additionally, it is also important to discover the most adequate type of message management and also to verify if this situation does not create new problems that can endanger the road safety.

Additionally, further researches should focus more on real road environments in order to know better the real characteristics of the interaction with such in-vehicle systems. In this sense, naturalistic investigations should also be conducted with subjects that already know the studied system and have some experience with it.

An interesting aspect that can contribute to augment the knowledge regarding the behaviour of determined groups of drivers is the analysis of the interacting of male and female participants. As different gender subjects can have distinct attitudes towards the new technologies, opinions regarding its utilization can be different as well as their behaviour while interacting with such products.

Another aspect regarding the analysis of the data can also be considered in further investigations: self-confrontations. This method that allows each subjects to visualize part of the own performance throughout the video recording of the experiment is important once permit drivers to explain and justify their own actions.

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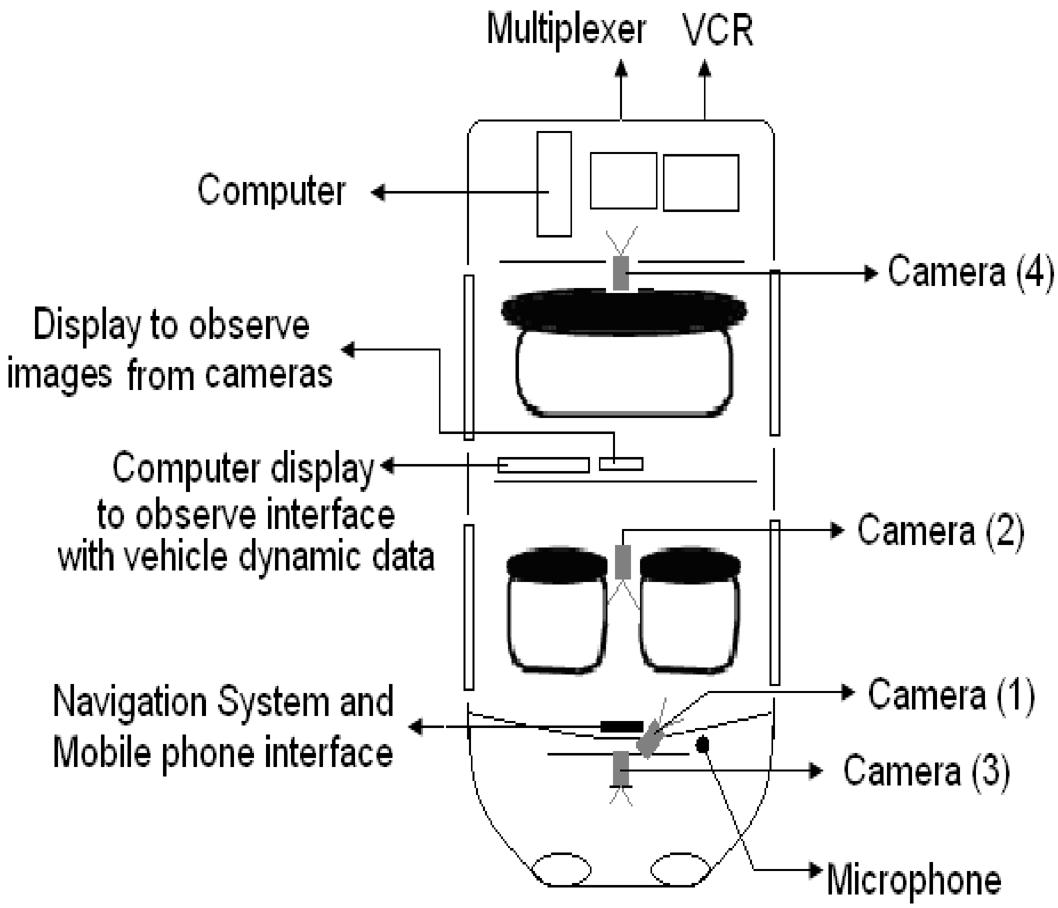
APPENDICES

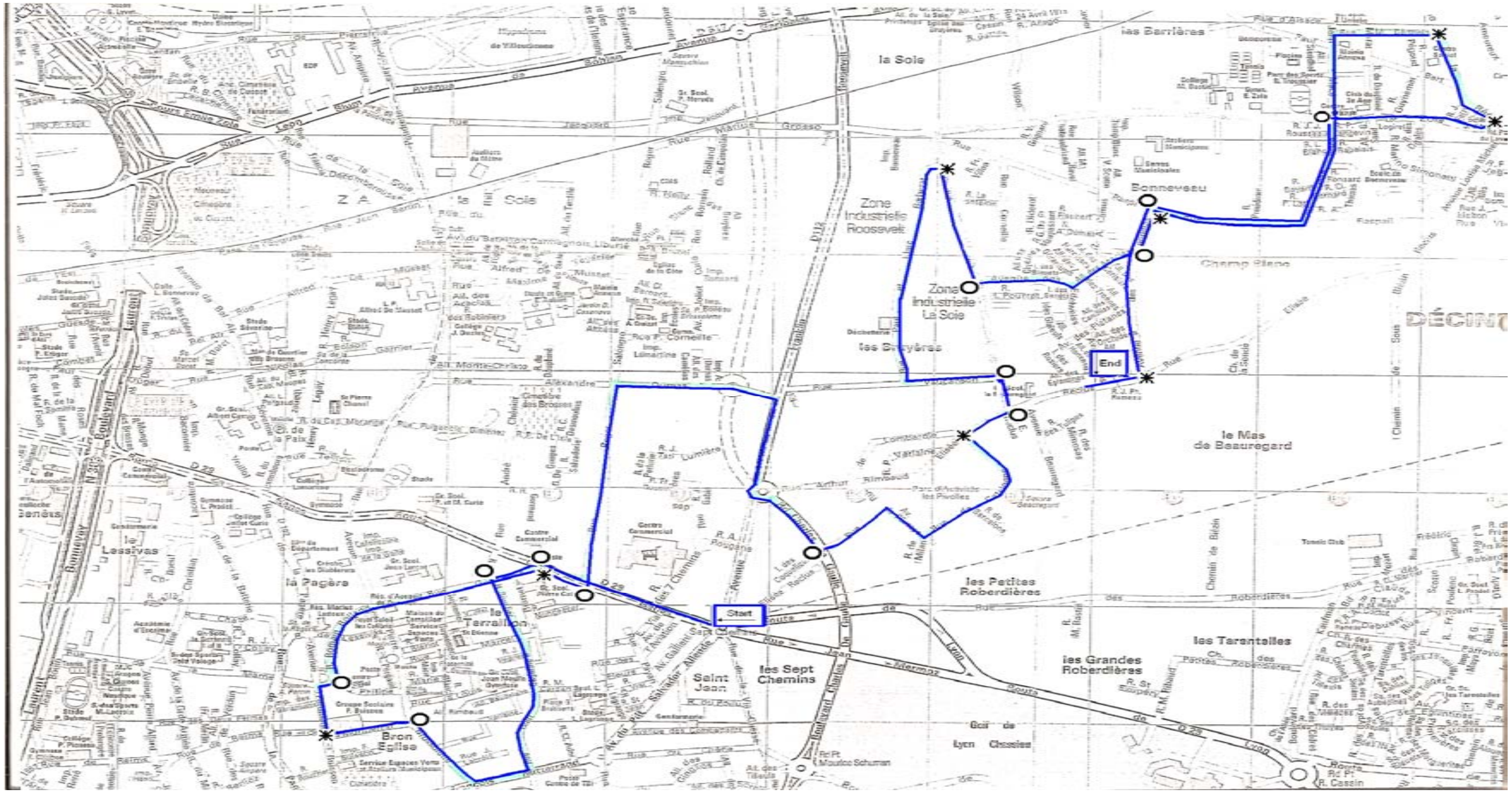
Appendix I

Sketch of the instrumented car with the equipments (on-road experiment)



Appendix II

Image of the completed course (on-road experiment)



Dots (12): intersections with manoeuvres to the left / Asterisks (8): intersections with manoeuvres to the right

Appendix III

Sentences list for the mobile phone task.

	Sentences (original version)	Translation	
1	O Z é a última letra do alfabeto	Z is the last letter of the alphabet	True
2	Para ir à praia usamos um elefante	To go to the beach we use an elephant	False
3	As semanas têm geralmente 9 dias	Generally, week have 9 days	False
4	Os mecânicos trabalham nas oficinas	The mechanics work at workshops	True
5	Geralmente, as bicicletas têm duas rotas	Usually, bicycles have two wheels	True
6	Para nadar no mar é preciso um rádio	To swim in the sea a radio is needed	False
7	Quando temos sede podemos beber água	When we're thirsty we can drink water	True
8	As tartarugas são mais pequenas que os cavalos	The turtles are smaller than the horses	True
9	Podemos nascer a 29 de Fevereiro	We can be born on February 29	True
10	As serpentes não têm patas nem têm dentes	The serpents don't have paws nor teeth	True
11	Para jogar futebol é preciso uma bola	To play soccer we need a ball	True
12	Para andar de mota usa-se um capacete	To ride a motorcycle we need an helmet	True
13	Para escrever uma carta preciso de um carro	To write a letter I need a car	False
14	Os alunos estudam ciências na escola	Students study sciences in the school	True
15	Para fazer queijo são precisas bananas	To make cheese we need bananas	False
16	O número 1 é mais pequeno que o 30	The number 1 is smaller than the 30	True
17	A ovelha verde está a pastar no campo	The green sheep it's graze on the field	False
18	Os telemóveis são mais pequenos que os aviões	Mobile phones are smaller than the airplanes	True
19	O A é a primeira letra do alfabeto	The A is the first letter of the alphabet	True
20	Famalicão fica mais a Norte que Lisboa	Famalicão is further to the north than Lisbon	True
21	Os turistas andam em aviões com três asas	Tourists travel in airplanes with three wings	False
22	A minha mãe é 5 anos mais nova que eu	My mother is 5 years younger than me	False
23	Os gatos azuis dormem em cima de almofadas	Blue cats sleep on top of cushions	False
24	No restaurante podemos comer boas pizzas	In the restaurant we can eat good pizzas	True
25	As vacas comem erva e bebem muito leite	Cows eat herb and drink a lot of milk	False
26	Os ursos são animais maiores do que os cães	The bears are animal larger than the dogs	True
27	Em Inglaterra, as habitantes falam inglês	In England people speak English	True
28	O primeiro andar é mais alto que o rés-do-chão	The first floor is higher than the ground-floor	True
29	O terceiro andar é mais alto que o segundo	The third floor is higher than the second	True
30	O número 41 vem antes do 50	The number 41 comes before the 50	True
31	Os óculos servem para respirar muito melhor	Glasses are used to breathe much better	False
32	O pequeno-almoço toma-se ao fim da tarde	People eat breakfast at the end of the afternoon	False

33	O dia 30 de Fevereiro não existe	February 30 doesn't exist	True
34	Podemos usar um cheque para pagar as compras	We can use a check to pay the bill	True
35	Para assinar um papel é preciso um copo	To sign a paper we need a glass	False
36	Os arco-íris são muito pequenos e pretos	Rainbows are very small and black	False
37	O João tem uns lindos olhos cor-de-rosa	João has beautiful pink eyes	False
38	A menina picou-se com um balão vermelho	The girl pricked herself with a red balloon	False
39	O Verão é uma das quatro estações do ano	The Summer is one of the four seasons	True
40	A Torre Eiffel está localizada em Paris	The Eiffel tower is located in Paris	True
41	As flores devem ser pintadas dentro das jóias	The flowers should be painted inside of jewellery	False
42	O Carnaval é no dia 25 de Dezembro	The Carnival is on December 25	False
43	As motas têm só uma roda gigante	The motorcycles only have one giant wheel	False
44	O capuchinho vermelho é um rapaz alto	Little red riding hood is a tall boy	False
45	Certos pássaros fazem ninho nas árvores	Certain birds make nest in the trees	True
46	No campo os gatos miam e os galos ladram	In the fields cats meow and roosters bark	False
47	O Algarve fica mais a sul do que Lisboa	Algarve more to south than Lisbon	True
48	Braga é no interior, a norte de Portugal	Braga is in the interior, to north of Portugal	False
49	A Grécia é um país que pertence à Europa	Greece is a country that belongs to Europe	True
50	Os canhotos escrevem com a mão esquerda	The left-handers write with the left hand	True
51	O número 13 vem antes do 14	The number 13 comes before the 14	True
52	Na América as pessoas falam japonês	In America people speak Japanese	False
53	As cores amarela e vermelha são iguais	The colours yellow and red are the same	False
54	Os turistas vão ao restaurante para dormir	Tourists go to restaurants to sleep	False
55	Podemos usar jóias para cortar a comida	We can use jewels to cut the food	False
56	Para jogar futebol usa-se uma colher	To play soccer a spoon is used	False
57	Numa biblioteca existem muitos livros	There are many books in a library	True
58	O meu laranjal dá bananas muito maduras	In my orange grove have very ripe bananas	False
59	A chuva pode ser comida com arroz e sal	Rain can be eaten with rice and salt	False
60	Geralmente, os dias têm 26 horas	Usually, days have 26 hours	False
61	Quando está muito frio usamos roupa mais quente	When it's very cold we use hotter clothes	True
62	No campo, os gatos miam e os galos cantam	In the field, the cats meow and roosters sing	True
63	Para cortar preciso de um martelo	To cut I need an hammer	False
64	Os médicos dentistas tratam dos nossos olhos	Doctors dentists treat our eyes	False
65	Os prédios grandes podem ter muitas janelas	Big buildings can have a lot of windows	True
66	Os vacas amarelas são aves de estimação	Yellow cows are house birds	False
67	As rosas e os lilases são dois tipos e flores	The roses and the lilacs are two types and flowers	True
68	Uma bicicleta é maior que um autocarro	A bicycle is larger than an bus	False
69	O leite pode ser bebido quente ou frio	The milk can be drunk hot or cold	True
70	No mês de Agosto celebra-se o natal	In August Christmas is celebrated	False

Appendix IV

Questionnaire applied after the on-road experiment

Part 2 : Attentional demand and serach for information

28. Did you know the routes where you have passed during the experiment Yes / No

The navigation system

29. Specify the level of dificulty to :

29.1 read and understand the written instructions (pictograms and distances):

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

29.2 understand the voice messages :

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

30. The voice messages were sent at the good moment (not too soon or too late) to perform a turn manoeuvre ?

Yes / No

30.1 If no, why ? ________________________

31. Estimate the level of help brought by the navigation system:

☐ None ☐ Not important help ☐ Important help ☐ Very important help

32. Estimate the level of disturbance related to the utilization of the navigation system:

☐ Not disturbing ☐ A bit disturbing ☐ Disturbing ☐ Very disturbing

Navigation system + mobile phone task (the double tsk situation)

33. In the double task situation did you have the impression of having neglected a source of information?

Yes / No

33.1 If yes, which was it :

- ☐ the mobile phone conversation
- ☐ the visual information transmitted by the navigation system
- ☐ the voice messages of the navigation system
- ☐ the road environment
- ☐ other ______________________

34. To which source of information did you give priority (classify)?

_______ to the mobile phone conversation
_______ the information sent by the navigation system
_______ the route information
_______ other: ______________________

35. In the double task situations, do you think to have perceived globally the events of the road environment?

Yes / No

35.1 If not, why? ______________________

36. In the double task situations, the management of the information was done:

36.1 While turning to the left:

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

36.2 While turning to the right

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

Part 3 : The driving behaviour

37. Did you feel any difficulties while driving? Yes / No

37.1 If yes, they were due to:

- ☐ the vehicle (not adjusted to this vehicle)
- ☐ the utilization of the navigation system
- ☐ the mobile phone conversation
- ☐ the management of both sources of information (navigation and mobile phone)
- ☐ the traffic
- ☐ other ______

38. Do you consider to have changed your driving behaviour while interacting with both systems at the same time?

Yes / No

38.1 If yes, this modification had consequences on :

- ☐ checking the mirrors
- ☐ checking the control panel
- ☐ the apprehension of the road information
- ☐ the activation of the turning indicators
- ☐ the gear management
- ☐ other ______

39. In the double task situations, do you consider to have had the time to manage all the road information (vertical signs, traffic lights, pedestrian crossings…)?

☐ Never ☐ Rarely ☐ Frequently ☐ Always

40. In double task situations, were you surprised by some event clearly visible?

☐ Never ☐ Rarely ☐ Frequently ☐ Always

41. In double task situations, do you consider to have had an adapted driver behaviour to all the driving situations?

Yes / No

Part 4 : Remarks

42. Do you have special remarks concerning the joint interaction with the mobile phone and the navigation system? ____

____

____

____

____

43. Do you have suggestions to improve the management of the different sources of information? ______________________

____

____

____

____

44. Do you have special remarkes concerning one of the equipments?

____

____

____

____

Appendix V

Observational table used in the on-road experiment

Observation Table

Order Nr: ____________ Sujet n°: ____________

Intersection n°: 1 - TL (Genas => Guillermin)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Rear mirrors	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Intersection n°: 2 - TL (Guillermin => H. Boucher)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Intersection n°: 3 - TL (Brosselette => Montferrat)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

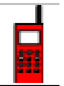
Intervetion of Driver Instructor — Observations

Intersection n°: 4 - TR (Montferrat => F. Buisson)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor — Observations

Intersection n°: 5 - TL (G. Philipe => R. Rolland)



Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 6 - TR (Guillermin => Genas)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 7 - TL (Genas => Salengro)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 8 - TL (Ch. Gaulle => Elysée Reclus)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 9 - TR (Catalogne => Elysée Reclus)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 10 - TL (Elysée Rclus => Bruyères)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioir	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 11 - TL (Bruyères => Vaucanson)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioir	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 12 - TR (Barbezat => Bruyères)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

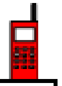
Intervetion of Driver Instructor — Observations

Intersection n°: 13 - TL (Bruyères => Edelweiss)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor — Observations

Intersection n°: 14 - TL (Acacias => Jonquilles)



Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

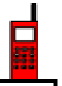
Intervetion of Driver Instructor Observations

Intersection n°: 15 - TR (Jonquilles => Raspail)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Intersection n°: 16 - TR (Berthelot => République)



Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Intersection n°: 17 - TR (République => Emile Zola)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Intersection n°: 18 - TL (Emile Zola => Jean Macé)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Pedestrian Crossing	
	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

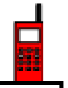
Intervetion of Driver Instructor	Observations

Intersection n°: 19 - TL (Raspail => Jonquille)

Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor	Observations

Intersection n°: 20 - TR (Jonquille => Elysée Reclus)



Navigation	Slow down right after message	
	Ask for help	
	Hesitation	
	Navigation Error	
Turning indicator signs	No sign activation	
	Too Soon	
	Too Late	
Driving behavioiur	Hesiate to start the manoeuvre	
	Start manoeuvre abruptly	
	Start manouvre with other vehicle near	
	Start manouevre without certainty	
	Break abruptly	
	Accelerate suddenly	
Trajecoire	Bad	
Interaction with other vehicles	Force others to slow down	
	Force others to accelerate	
	Step on the other lane	
Road Signs	Do not respect	
Visual Behaviour	Rear mirrors	
	"dead angle"	
	Check intersection area	
Gear	Do not manage gear	

Intervetion of Driver Instructor Observations

Appendix VI

Questionnaire filled in before the on-road experiment

Questionnaire

Subject number: ____________________

Part 1 : Information regarding the subject and his/her habits

1. Gender : .... Female / Male .... **2.** Age:

3. Education level (only one answer)

- ☐ did not go to school

Finished the school at:

- ☐ primary school (4 years)
- ☐ elementary school (2 years)
- ☐ middle school (3 years)
- ☐ high school (3 years)
- ☐ undergraduation ____________________
- ☐ post-graduation course ____________________

3.1 Higher school level ____________________

______ ____________________

3.2 Have you ever had a job during your life? .... Yes / No ....

if yes, do you still have a job? .... Yes / No ....

3.3 What was the longest job that you had? ____________________

____

3.3.1 Was it as: ☐ employee ☐ employer

3.4 What was your last job? ____________________

____

3.4.1 Was it as: ☐ employee ☐ employer

4. Driving licence date : ____________________

5. Do you have a vehicle? .... Yes / No ....

6. Number of kilometres travelled per year:

- ☐ from 5000 to 10 000 km
- ☐ from 10 000 to 20 000 km
- ☐ more than 20 000 km

7. Frequency with which you use your vehicle?

- ☐ every day
- ☐ several times per week
- ☐ occasionally

8. Do you have an hearing impairment ? .... Yes / No ....

9. Do you have a visual impairment? .... Yes / No ....

if yes, is it corrected ? .... Yes / No ....

10. Do you use glasses? .... Yes / No ....

Attitudes towards the use of mobile phone devices

11. For how long do you have a mobile phone ? ____________________

10.1 For how long do you use it at the wheel? ________________________

12. In average, how many call do you have per week (total number of mobile phone conversations)?

____

13. In general the calls are:

- ☐ Private
- ☐ Professional

14. The mobile phone calls at the wheel are:

- ☐ Private
- ☐ Professional

15. Per week, how may calls do you receive or make while driving?

- ☐ at least one per day
- ☐ several per week
- ☐ some per month
- ☐ less

15.1. Specify how many if "at least one per week": ____________________

16. While driving, do you use any hands-free kit? Yes / No

16.1 If yes, specify the type of hands-free kit device that you have: ____________

16.2 Specify if you use it very often: ____________

17. Do you usually answer to all the mobile phone calls (independent of the situation)?

Yes / No

17.1 If no, what are the situations that you avoid :

- ☐ dense trafic
- ☐ intersections
- ☐ round-abouts
- ☐ motorways
- ☐ city roads
- ☐ rural roads
- ☐ never make a call
- ☐ other: ____________

18. Do you choose specific moments to make calls? Yes / No

18.1 If yes, which ones :

- ☐ motorways with low density of traffic
- ☐ traffic lights
- ☐ straight roads
- ☐ rural roads
- ☐ traffic jams
- ☐ other: ____________

19. When do you are surprised by a critical situation (for example a pedestrian that comes near the road), is it easy for you to deviate your attention from the mobile phone to the road ahead?

☐	☐	☐	☐
Without difficulty	A bit difficult	Difficult	Very difficult

Attitues towards the use of a navigation system

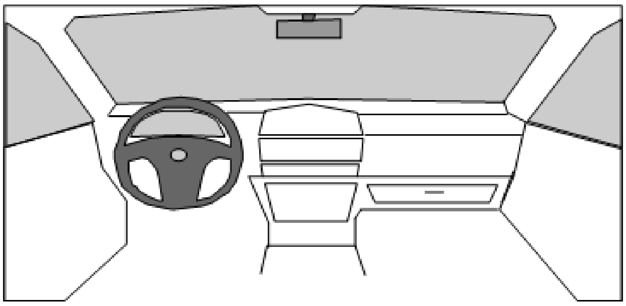
20. Have you ever used a navigation system ? Yes / No

21. Do you have a navigation system on your vehicle ? Yes / No

If yes, continue the questionnaire

22. The navigation system is nomadic or fitted by standerd ? ____________

23. Where is it placed (localize it on the sketch):



24. What type of messages do you use?

- ☐ a map
- ☐ pictograms
- ☐ a map and a pictogram
- ☐ others ____________________

25. Do you use the voice messages of the navigation system ? Yes / No

25.1 If yes, why: ____________________

26. In which type of environments do you use your navigation system?

- ☐ unfamiliar roads
- ☐ familiar roads
- ☐ rural roads
- ☐ urban roads
- ☐ secondary roads
- ☐ other: ____________________

27. Is it possible to connect your mobile phone to your navigation system ? Yes / No

27.1 If yes, what happens if a mobile phone call arrives ?

- ☐ reduce / suppress the volume of the navigation system
- ☐ reduce / suppress the volume of the mobile phone system
- ☐ do not make an action
- ☐ do not know

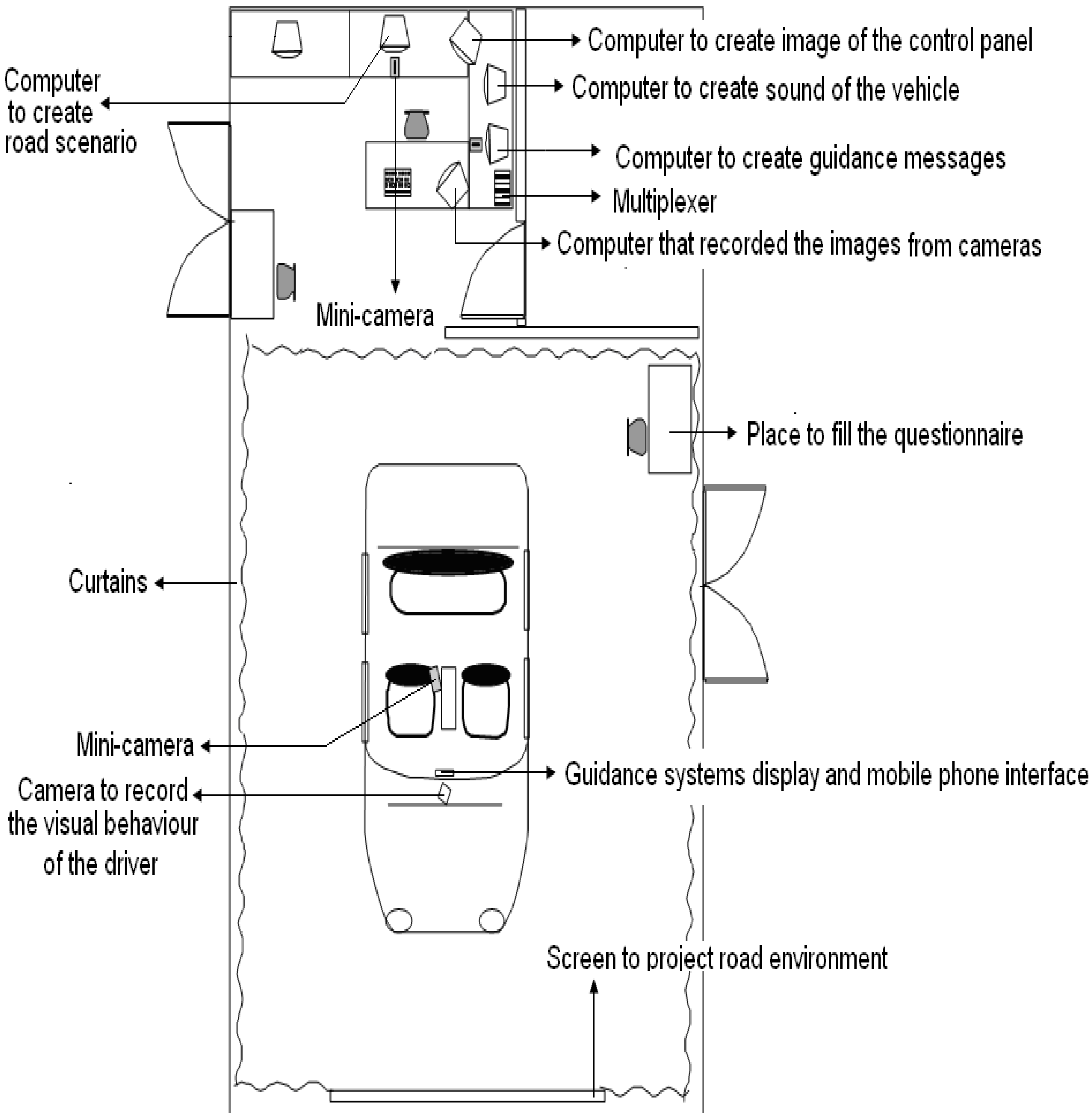
Appendix VII

Order of the mobile phone calls for the on-road experiment

	Course A		Course B
	Start		**Start**
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Right		Turn Right
	Turn Left		Turn Left
	Turn Right		Turn Right
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Right		Turn Right
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Right		Turn Right
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Right		Turn Right
	Turn Right		Turn Right
	Turn Right		Turn Right
	Turn Left		Turn Left
	Turn Left		Turn Left
	Turn Right		Turn Right
	End		**End**

Appendix VIII

Sketch of the rooms where the simulator experiments took part.



Appendix IX

Questionnaires after simulator experiment: baseline condition

Course A - Vertical signs

1. Indicate the level of difficulty to:

1.1 read the instructions on the vertical signs:

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

1.2 to turn right

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

1.3 to turn left

☐ Without difficulty ☐ A bit difficult ☐ Difficult ☐ Very difficult

2. Indicate the level of distraction to the driving task while reading of the vertical signs

☐ Not disturbing ☐ A bit disturbing ☐ Disturbing ☐ Very disturbing

3. Classify the situation in terms of:

Difficulty

1	2	3	4	5	6	7	8	9	10
none									**very**

Effort

1	2	3	4	5	6	7	8	9	10
none									**very**

Comments:

Questionnaires after experiment: one-system condition

Course B - Navigation System

1. Indicate the level of difficulty to:

1.1 read and understand the symbols of the navigation symbol

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

1.2 understand the vocal m,essages of the navigation system

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

2. Do you consider that the vocal messages where sent at an adequate moment?

Yes No

2.1 If No, why? ____________________

3. Indicate the level of difficulty to:

3.1 turn right

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

3.2 turn left

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

4. Indicate the level of help given by the navigation system

☐ None	☐ Help Not important	☐ Important help	☐ Help very important

5. Estimate the level of disturbance induced by the navigation system

☐ Not disturbing	☐ A bit disturbing	☐ Disturbing	☐ Very disturbing

6. Did you modify your normal driving behaviour due to the intearction with the navigation system

Yes No

6.1 If Yes, why? ____________________

7. Classify the situation in terms of:

Difficulty

1	2	3	4	5	6	7	8	9	10
none									**very**

Effort

1	2	3	4	5	6	7	8	9	10
none									**very**

Comments:

Questionnaires after experiment: two-system condition

Course C - Navegation System + Mobile Phone

1. Indicate the level of difficulty to:

1.1 understand the mobiel phone conversation.

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

1.2 turn right

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

1.3 turn left

☐ Without difficulty	☐ A bit difficult	☐ Difficult	☐ Very difficult

5. Estimate the disturbance level induced by the mobile phone on the understanding of the navigation system instructions

☐ Not disturbing	☐ A bit disturbing	☐ Disturbing	☐ Very disturbing

6. Estimate the level of disturbance that the mobile phone caused on the driving task

☐ Not disturbing	☐ A bit disturbing	☐ Disturbing	☐ Very disturbing

7. Estimate the level of disturbance that both systems caused on the driving task

☐ Not disturbing	☐ A bit disturbing	☐ Disturbing	☐ Very disturbing

8. Did you modify your normal driving behaviour due to the intearction with both systems?

Yes No

8.1 If yes, why? ______________________

9. Classify the situation in terms of:

Difficulty

1	2	3	4	5	6	7	8	9	10

none **very**

Effort

1	2	3	4	5	6	7	8	9	10

none **very**

Comments:

Appendix X

Consent term presented to participants of the simulator experiment

Subject: Experiment SYNATEL
Entities evolved: *UTL, FEUP, ISEP*
Researcher: Marta Pereira

This Consent Term contains information related with the investigation mentioned above. To assure that you are well informed about your participation in this investigation we ask you to read this document and sign it if you agree with the information. This Consent Term may have words with which you are not familiarized. Thus, do not hesitate to ask the researcher for additional explanations.

Before knowing which are the objectives of the present study you should be informed that:

. your participation is completely volunteer;

. you can freely decide not to participate or cancel your contribution to this experiment at any moment. If it occurs you are not forced to present a reason to that choice.

Goal of the experiment

The main goal of this investigation is to evaluate the influence of in-vehicle information and communication systems on the driving task. These tests do not intend to evaluate you as a driver but to evaluate the systems inside the vehicle. Throughout the analysis of several variables this study will allow to expose some conclusions that will be transformed in guiding lines. These guiding lines will be useful to develop in-vehicle equipments more adapted to the drivers and his/her driving task.

The data collected from your performance as well as all the information given by you is entirely confidential.

Consent

I declare that the goal of the study as well as the tasks that have to be performed were clearly explain to me. I had also the opportunity to clarify all my questions and ask for additional information. I know I have the right to stop my participation at any moment without giving any additional explanation.

Name: ____

Signature: ____

Researcher:_________________________Date:_____________________

Appendix XI

Questionnaires before the simulator experiment

Questionniare

Subject number: ____________________

Part 1 : Information regarding the subject and his/her habits

1. Gender .... Female / Male .... **2.** Age: ____________

3. Education level (only one answer)

- ☐ did not go to school

Finished the school at:

- ☐ primary school (4 years)
- ☐ elementary school (2 years)
- ☐ middle school (3 years)
- ☐ high school (3 years)
- ☐ undergraduation ____________________
- ☐ post-graduation course ____________________

4. City / Place where you live: ____________________

5. Do you have an audition problem? .... Yes .... No

6. Do you have a vision problem ? .... Yes .... No

If yes, is it well corrected (glasses)? .... Yes .... No

7. Year of driving licence ____________________

8. Do you have a vehicle? .... Yes .... No

9. What type of vehicle do you usually drive?

☐ light vehicle ☐ jeep ☐ van ☐ mini-truk

Characteristics (brand and model): ____________________

10. Number of kilometres driven per year

- ☐ less than 5000
- ☐ from 5001 to 10 000 km
- ☐ from 10 001 to 20 000 km
- ☐ more than 20 001 km

11. How frequently do you drive?

- ☐ every day
- ☐ several day per week
- ☐ ocasionally

12. With which purpose do you use the car more frequently:

- ☐ to go to work
- ☐ small trips
- ☐ big trips
- ☐ to do my job
- ☐ other reasons Which? ____________________

13. How frequently do you drive in these situations:

13.1 City

☐ frequently ☐ occasionally ☐ rarely ☐ never

13.2 Rural roads

☐ frequently ☐ occasionally ☐ rarely ☐ never

13.3 National roads

☐ frequently ☐ occasionally ☐ rarely ☐ never

13.4 Highways

☐ frequently ☐ occasionally ☐ rarely ☐ never

14. Have you ever been in a dangerouse situation due to a distraction caused by a mobile phone or a navigation system?

Yes No

14.1 If **Yes** specify: ________________

Habits regarding the mobile phone use

15. For how long do you have a mobile phone? ________________

16. In average, how many calls do you make with your mobile phone per week? ________________

17. The nature of your calls:

☐ Private
☐ Professional

18. For how long do you use your mobile phone while driving? ________________

19. While driving, the nature of your calls:

☐ Private
☐ Professional

20. Per week, how many calls do you receive or make while driving?

☐ at least one per day
☐ several per week
☐ some per month
☐ less
☐ none

20.1 If "at least one per day", quantify: ________________

21. Do you use any hands-free system while driving? Yes No

21.1 If yes, which system? ________________

22. How frequently do you use that system in the vehicle:

☐ always ☐ frequently ☐ occasionally ☐ rarely

22.1 When have you bought the system:

- ☐ when bought the mobile phone
- ☐ before the new legal road code (that forbid to handle the mobile phone while driving)
- ☐ when the new code began
- ☐ after the new code
- ☐ in another moment. Specify: ____________________

22.2 Why did you buy it (you can choose more than one option):

- ☐ to respect the law
- ☐ it's more safe
- ☐ it's more confortable
- ☐ by imposition of others. Who: ____________________
- ☐ other reason. Specify: ____________________

23. Do you always answer to the mobile phone while driving? ....Yes .... No ....

23.1 If no, which situations do you avoid:

- ☐ intense traffic
- ☐ intersections
- ☐ roundabouts
- ☐ highways
- ☐ national city roads
- ☐ rural roads
- ☐ when some persons call
- ☐ outras: ____________________

24. Do you usually do, or have already done, calls while driving? ....Yes .... No ....

25. Do you choose specific moment to do some calls? ....Yes .... No ....

25.1 If **ye**, which:

- ☐ roads with flowing traffic
- ☐ roads with little traffic
- ☐ traffic lights
- ☐ straight roads
- ☐ rural roads
- ☐ traffic jams
- ☐ other ____________________

26. Before receiving or doing a call do you have any kind of different behaviour? ....Yes .... No ....

22.1 If **yes** specify which:

- ☐ reducing the speed
- ☐ stop the car in the hardsholder
- ☐ other . Specify: ____________________

27. In everage, how long last your calls? ____________ seconds

28. Do you read or send sms while driving? .... Sim / Não ....

28.1 If yes, how frequently:

☐ frequently ☐ occasionally ☐ rarely

29. How frequently these types of mobile phone conversations occur while driving:

29.1 Simple conversations with family or friends

☐ frequently ☐ occasionally ☐ rarely ☐ never

29.2 Business conversations or other type of complex talk:

☐ frequently ☐ occasionally ☐ rarely ☐ never

29.3 Other type. Specify: ________________________

☐ frequently ☐ occasionally ☐ rarely ☐ never

30. If you are conducting a mobile phone conversation and a critical situation occur, do you find it easy to divert your attention from the phone to the road?

☐ very easy ☐ easy ☐ difficult ☐ very difficult

Habits concerning the navigation system use

31. Have you ever used a navigation system? .... Yes .... No ....

32. Do you have one? .... Yes .... No ....

32.1 If **yes**, for how long? ________________

32.2 If **no**, would you like to have one? .... Yes .... No

Why? ________________________

32.2.1 Why don't you have a navigation system?

- ☐ are too expensive
- ☐ is not very important to have one
- ☐ none of the existing models are good or adequate enough
- ☐ Other. Specify. ________________________

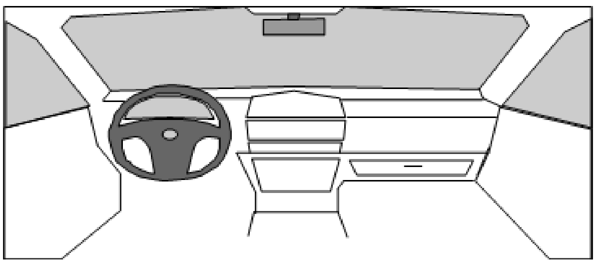
33. Which navigation system are you familiar with?

- ☐ a system fitted by standard
- ☐ a system mounted afterwards
- ☐ nomadic system

34. Brand and model of your navigation system: ________________________

Why did you choose that system? ________________________

35. Where is it placed?



36. What type of information does your system transmits (you can choose more than one option):

- ☐ a map
- ☐ written instructions
- ☐ arrows and other symbols
- ☐ vocal instructions
- ☐ other. Specify: ______________________

37. Which type of instructions do you prefer?

- ☐ a map
- ☐ written instructions
- ☐ arrows and other symbols
- ☐ vocal instructions
- ☐ other. Specify: ______________________

Justify your answer: ______________________

38. Does your system have other functions besides the guidance ? Yes No

Which? ______________________

39. How frequently do you use the audio instructions?

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

39.1 If you **don't use it always,** refer the reasons: ______________________

40. How frequently do you use the navigation system for the following situations:

40.1 Non familiar areas

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

40.2 to find out new courses in familiar areas

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

40.3 Rural courses

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

40.4 Urban courses

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

40.5 Highways

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

40.6 Other situations. Specify: ______________________

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

41. Do you avoid to use the navigation system in any situation? Yes No

Which? ______________________

42. Is it possible to connect you mobile phone to the navigation system? Yes No

42.1 If yes, what happens when the navigation system is connected and a mobile phone call arrives?

- ☐ reduction / suppression of the navigation system volume
- ☐ reduction / suppression of the mobile phone volume
- ☐ do not perform an action
- ☐ don't know

43. Do you use to connect the mobile phone to the navigation system?

☐ always ☐ frequently ☐ occasionally ☐ rarely ☐ never

44. Have you ever received a mobile phone call while getting instructions from the navigation system?

Yes No

44.1 If **yes**, what happened? ______________________

45. If you are receiving instructions from the navigation system and a critical situation occurs do find it easy to divert your attention from the phone to the road?

☐ muito fácil ☐ fácil ☐ difícil ☐ muito difícil

46. Classify the following sentences in what concers the level of distraction that they induce in the driving task:
(**1= nothing** ; **4= very much**)

46.1 Talk to a passenger

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.2 Listen to the radio

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.3 The mobile phone ringing

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.4 Type a phone number

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.5 Talk without a free-hand kit

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.6 Talk with a free-hand kit

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.7 Hang up the mobile phone

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.8 Look to a navigation system

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.9 Listen to the audio instructions of a navigation system

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.10 Insert a destination in the navigation system

☐ 1 ☐ 2 ☐ 3 ☐ 4

46.11 Look for orientations in the vertical signs along the road

☐ 1 ☐ 2 ☐ 3 ☐ 4