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Applying Serious Games to Assess Driver Information System Ergonomics

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Resumo

O número dos sistemas de informação embutidos nos veículos e a complexidade das tarefas possíveis de realizar estão a crescer a um rácio muito elevado. Uma vez que é expectável que num futuro próximo este cenário não se altere, existe uma necessidade emergente de compreender claramente como estes sistemas afectam a distracção, a sobrecarrega cognitiva e o seu impacto global na condução.

A maioria dos estudos actuais usam simuladores de elevada fidelidade, mas a sua aquisição e manutenção possui custos muito elevados. Tradicionalmente, o recrutamento dos participantes tem como base uma quantia de dinheiro, a marcação da data e local da experiencia. Esta abordagem alicia os participantes a se comprometer com a experiencia essencialmente devido a recompensa monetária. Além do mais, devido à vida privada de cada participante, a marcação de uma data e a viagem ao local da experiência pode ser problemática. Somadas, estas restrições implicam aos investigadores desafios práticos difíceis de resolver, especialmente em situações em que a as amostras necessitam de ser grandes.

Neste documento é feito um estudo sobre a validade do uso de jogos sérios como ferramenta para avaliar a ergonomia dos sistemas de informação embutidos nos veículos. Os resultados mostram que mesmo usando um jogo sério de baixo custo é possível prever com relativo sucesso o impacto das interações na condução.

Comparando o jogo sério desenvolvido com um simulador de alta fidelidade, os resultados são promissores uma vez que mostram uma boa aproximação entre as duas plataformas. O simulador, juntamente com o jogo, foi usado para investigar o impacto na condução de duas tarefas elementares: ler texto e navegar manualmente menus. Ambas tarefas afectaram significativamente o controlo lateral da condução, e em proporção menor o controlo longitudinal.

Uma experiência final foi realizada com vista a confirmar a influência dos jogos sérios sobre os participantes. Foi possível verificar que o jogo provocou um impacto positivo no comportamento dos condutores, fazendo-os melhorar o seu controlo lateral e longitudinal do veículo.

Abstract

With the number of in-vehicle information systems and their task's complexity growing at a very high rate in the near future, we need a clear understanding of their related distraction or mental workload and their impact on driver performance.

Most studies are conducted using high cost and high fidelity simulators, but they are expensive to buy and maintain. Traditionally, participants recruitment is based on a monetary reward, and scheduling a time and place to take the experiment. This approach mainly induces participants to take experiments and be committed based on the monetary reward. Furthermore, due to subjects' private life, scheduling a time or travel to the place where the experiment takes place can be problematic. Summed up, these constraints are very hard practical challenges investigators must overcome, especially if the study requires big samples.

In this dissertation, a study of the serious games' validity for assessing the in-vehicle information systems ergonomics is presented. Results show that by using low-cost serious game it is possible to successfully predict the interactions' impact on driving performance.

Moreover, the developed serious game obtained very promising driving performance approximations to a high fidelity driving simulator. This simulator was used, along with the serious game, to study the impact of two elementary tasks in the current in-vehicle information systems: read text and navigate menus manually. Both tasks affected significantly the vehicle's lateral control, and less significantly the longitudinal control.

A final experiment was conducted to confirm the existence of the serious game influence over the behaviour of subjects. It was possible to observe that the game applied a positive impact to drivers' behaviour by improving their lateral and longitudinal control over the vehicle.

Acknowledges

I would like to thank my supervisor Dr. Rosaldo Rossetti for his support and guidance not only during this work but also during my academic life. Also, I thank Dr. Cristina Olaverri for her outstanding support and help over the execution of this project.

Special thanks to my parents, and girlfriend for their unconditional support and love.

Vítor Joel Moura Gonçalves

Table of Contents

List of Figures

List of tables

Abbreviations

ADAS	Advance Driving Assistance Systems
AR	Augmented Reality
CD	Compact Disk
COCOM	Contextual Control Model
CPA	Critical Path Analyses
DVD	Digital Versatile Disc
ECOM	Extended Control Model
HA	Heuristic Analyses
HCI	Human Computer Interaction
HTA	Hierarchical Task Analyses
HUD	Head Up Display
IVIS	In-vehicle information systems
JCS	Joint Cognitive Systems
PC	Personal Computer
SD	Standard deviation
SDLP	Standard deviation of lateral position
SHERPA	Systematic Human Error Reduction and Prediction Approach
SMS	Short Message Service
SUS	System Usability Scale
TV	Television

Chapter 1

Introduction

1.1 Motivation

Nowadays, there is a large number of in-vehicle information systems (IVISs) for enhancing driving performance or for entertainment that the driver can operate simultaneously to the driving task. Some of those systems integrate for example a communication module consisting of telephone or Internet, as well as an entertainment module with radio, video or music, or a navigation system module. Additional equipment such as driver assistance systems that support the driver in the driving task (e.g. collision avoidance systems, night vision systems, etc.) or laser projections and head-up displays to provide the driver with relevant information might be included as part of the IVIS.

The variety of heterogeneous IVISs results from new technological advances and is a logical consequence of up-to-date consumer's expectations. The rate of IVISs in the market increased by a factor of ten in the last years [1]. The relatively low cost of some IVISs raises expectations that these systems will equip future vehicles even more.

The potential distraction of IVISs has been thoroughly investigated in an ample number of studies. For example, it has been shown that the use of cell phones during driving increases the rate of accidents [2]. Likewise the manipulation of navigation systems as well as adjusting the radio or CD constitutes a source of distraction [3], [4].

IVIS development processes are time consuming and require expensive tools like high cost simulators or real driving experiences [5]. Although these tools provide good information, their acquisition and maintenance are very expensive making researchers study alternatives like low-cost simulators [6–8].

Serious Games are a class of games which addresses serious purposes [9]. They resemble simulators by their realistic characteristics but distinguish from them by providing challenges, player evolution and fun.

1.2 Research Questions

In this thesis, there are three main research questions to be addressed:

- To what extent can we rely on a low-cost driving serious game to assess IVIS ergonomics?
- Do driving serious games influence the players' behaviour in the real world?
- What are the impacts of reading an email and navigating through a menu, while driving, on driving performance and task execution?

The first bullet is the main research question of this work. Since acquisition and maintenance of high fidelity simulators is very expensive, alternatively there are low-cost simulators. But this alternative comes with the cost of less reliable data, hence if a new low-cost tool is created its validity must be assessed.

Second bullet tries to address the lack of serious game's behaviour influence experiments documented in the driving genre. This confirmation would be an interesting input to the community and open up an opportunity for a new type of driving tools.

The last bullet aims to have a clearer understanding on how basic secondary tasks like reading and manually interacting with a menu can impact the driving performance.

1.3 Aim & Goals

The work's vision is to create an automatic platform for IVIS ergonomics assessment and driver behaviour extraction. Such a tool would provide valuable information for IVIS development processes as well as for driving simulators.

In order to differentiate from other works, we aim at a solution based on serious games for taking advantage from game's industry tools, peoples' natural competition and curious attitude, and the serious games' potential to influence players.

Specifically to the work herein documented the goals are:

- Create a solid basis for a fully automated framework for assessing IVIS usability.
- Develop and validate a low-cost driving serious game.
- Confirm the existence of any behaviour influence characteristics from the serious games.

1.4 **Expected Contributions**

This work's contributions are the exploratory study of using serious games in the IVIS assessment context, as an alternative to low-cost simulators, and the development of an automated framework for integrating usability evaluation and driving behaviour profile extraction.

1.5 **Organization of the document**

The document is organized as follows. In Chapter 2 - Literature Review we review in detail IVISs' categories, introduce the basic concepts associated with ergonomics and usability, and some already developed driving serious games. Then Chapter 3 - Methodological Approach & Experimental Setup presents a detailed description of the proposed software solution methodology and also defines the practical experiments to be conducted in this work. The Chapter 4 - Preliminary Results and Analysis presents the results from the first experiments conducted to assess the serious game quality by comparison with a high fidelity simulator, and analyses the data. Finally the Chapter 5 - Conclusions chapter draws the final observation about the work, presents the next logical steps and points future directions.

Chapter 2

Literature Review

The structure of this chapter is divided in two main parts, the background and the related work. The background section introduces the basic concepts of IVIS and ergonomics, giving a broader view to the reader of the importance of this subject and future trends. The objective of the Related Work section is to specialize the reviewed literature in tools and techniques used in this work. Works aiming at similar approaches or objectives are also addressed in the later section.

2.1 Background

2.1.1 IVIS

Information systems are becoming more ubiquitous, reaching markets like automotive vehicles. In this section we review the IVIS categories available and disclose some future applications. To complete this section we present an explanation about concepts like ergonomics and usability allowing readers to understand the basic concepts underlining IVIS evaluation.

2.1.1.1 Navigation & Travelling Systems

Once a luxury, Navigation & Travelling Systems technology is widely disseminated nowadays [1]. These systems allow drivers to achieve desired destinations even through unfamiliar routes or locations while being informed of local events or points of interest. Navigation & Travelling Systems aim to efficiently use roads by providing tools for drivers to plan and decide their travels [2].

a) Navigation System integrated.

b) Route Guidance System.

Figure 1: Navigation & Navigation Systems examples.

Usually, the driver initiates by manually entering this desired location using keyboard, joystick or by voice recognition. After some processing time, the system calculates a route considering user pre-defined settings (e.g. shortest distance or avoid motorways). Then, system displays a 2D/3D representation of the planned route and instructs the driver “turn by turn“.

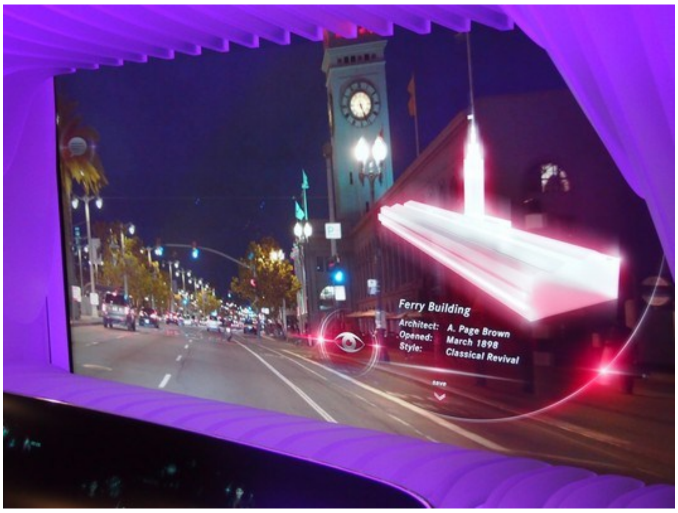


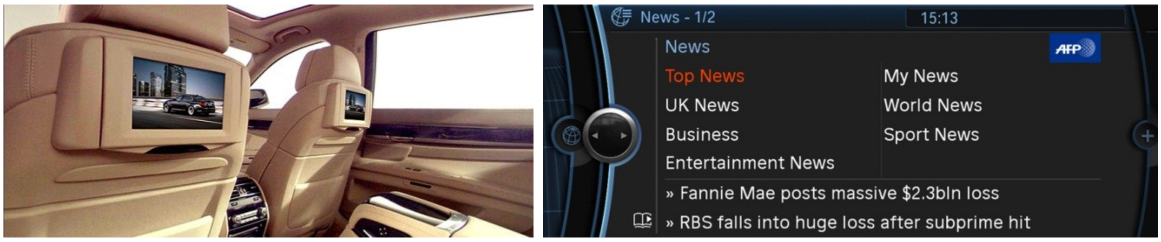
Figure 2: Augmented Reality application to Travelling Systems still in development [3].

Traveling related information systems inform users about local events near the vehicle current position or interesting points concerning the travel plan (route to the destination). This information improves the driver knowledge about its near location, and some examples are: restaurants, monuments, parking lots, and gas stations. Typical applications of these technologies are integrated to navigation systems as optional features (Figure 1b). Access to these functionalities is via a menu-based navigation controlled by touch screens or rotary controller. The information output is the device screen; however future trends (Figure 2) may use head-up displays (HUD) and Augmented Reality (AR) technologies to improve aesthetic quality.

2.1.1.2 Entertainment

IVIS can also be used to entertain the driver. Most automobiles are equipped with stereo radio, where drivers can interact with hard tactile switches and are located in the dashboard or center console. More recent vehicles also allow the interaction with joystick by integrating the radio functionality in a single system [4].

Vehicles can also access Internet allowing drivers to read news or emails Figure 3b. Multimedia devices are also allowing vehicle passengers to play CD, MP3 or even watch TV and DVDs Figure 3a. In these cases the devices are usually controlled by joystick or touch screen.



a) Multimedia devices for passengers [5]. b) Access to news [6].

Figure 3: Entertainment IVIS.

2.1.1.3 Driver Convenience Services

Convenience Services are systems created to blend with common devices (cellphone, smartphone, mp3 players or multimedia players) in order to use them in an in-vehicle environment. The devices are usually plugged in the vehicle and the driver can then use dashboard controls to interact with the device or use the device to interact with the vehicle. Most cases, smartphones (Figure 4 a) are the devices used to be integrated, allowing drivers to take advantage of the devices' capabilities (e.g. Internet, email) access them in the vehicle console through joystick or hard controls in the dashboard.

a) Smartphone integration [7].

b) Control car with application [8].

Figure 4: Driver convenience systems.

Cellphone calls while driving are prohibited in several countries due to safety issues. For drivers convenience hands-free systems were developed enabling drivers to perform calls during the driving task.

Finally, the communication channel provided allows that other devices can also interact with the vehicle. It is still an optional feature but it is possible to lock or unlock the vehicle, or even control the interior climate using a smartphone (Figure 4 b).

2.1.2 Ergonomics & Usability relation

According to [9] Ergonomics is defined as the "scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance".

Generally ergonomics can be considered as a science that handles the interactions between humans and other systems in order to ensure the safety, efficiency, effectiveness and satisfaction of the interactions.

Usability is considered a specialization of ergonomics focusing more on the productivity of the interaction [9]. Therefore, the most important assets are the effectiveness and efficiency of the interaction.

Let's consider a metaphor of a driver needing to choose between a highway and a county side road to reach a destination. From a usability perspective both are effective (reach the destination) but the highway is more efficient since it allows arriving earlier to the destination. But from an ergonomics view, the other option can be more pleasant for the driver.

Nevertheless, it is common to find in the literature definitions of usability that extend the original by aggregating other ergonomic factors like satisfaction, safety, etc. In this document we also use the "extended" form.

2.1.3 Usability

Usability is a property of the user-system interaction under a context. Although it is common to hear in common language misused sentences like "this product is ergonomic or this tool has good usability", this leads to the misinterpretation that usability is a property of the product. In Figure 5, the user could have some properties like name, gender or birth date, and the system could also have its own properties; but usability is a property of neither. Instead it is a property of the interaction user-system in the specific context.

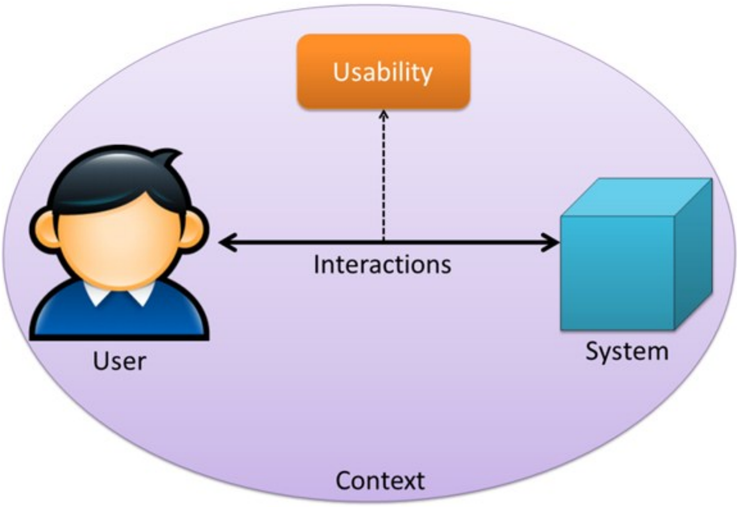


Figure 5: Usability: interaction property between user and system under a context.

Historically, the definition of usability has proven to be a hard task. In the beginning it was as simple as an "ease of use" ([10], cited by [11]), "user friendliness" [12] and "user-perceived quality" ([13]) concepts. Soon, authors perceived the need for clearer definitions that could be more substantial than a simple reminder for developers to create systems with an user-centered approach [14]. Since there is a vast taxonomy in this area, often multiple terms for the same concept, we attempt to define usability by classifying the contributions of authors in factors, goals and design principles [15].

2.1.3.1 Factors

Factors are the most commonly accepted core criteria which can be considered important in all contexts. Learnability [16][11] stands by the learning curve factor which is required to support or train the user. The Effectiveness ([11],[17]) represents the performance level required to perform a task or a set of tasks. The factor Attitude [11] concerns the bounds of acceptable amount of "human cost" like discomfort or effort. Flexibility [11] specifies the possible variations to perform a task so it can adapt to a situation or environment not initially specified.

In order to established limits to how many users like the system, it was proposed also a Satisfaction ([16], [17]) factor. Since most of the focus was on casual/beginner users, the Efficiency ([16], [17]) factor focus on users that already learned the system to understand the speed in which advanced users can perform the tasks. Memorability ([16]) defines the criteria for how good users perform after a time without using the system. Errors [16] report which tasks are error prone and its severity.

2.1.3.2 Goals

Based on the usability factors, developers can define practical goals which are concrete values for chosen factors. An example is given in [18] where it was defined: (1) time to learn for the Learnability factor, (2) speed of performance to the Efficiency factor, (3) rate of errors for the Error factor, (4) Retention over Time for the Memorability factor, and (5) Subjective satisfaction for the Satisfaction criteria.

2.1.3.3 Design Principles

With field practice of these categorization and experience in designing systems, it has emerged some design principles which are guidelines that a system designer should follow. From the relevant authors review there are some common realizations. The use of the concept of Affordance should be wisely exploited. Terms like “Use knowledge in the world and in the head” [19], “Match between system and the real world” [16], “explicitness” [20] or “recognition rather than recall” [16] points designers to use metaphors from the real world or take advantage of the users’ mental models and expectations. Authors also agree that the visual appeal and simplicity is important for the user to understand the actions they can perform and be aware of the system/process current state. The terms used by the authors are: “Make things visible” [19], “Visual clarity” [20] and “Aesthetic and minimalist design” [16]. Error management has a lot of references since this topic can be decomposed in prevention, diagnose, recognition and recovery. Although a strong error management may not be perceived by the users as a key value for the system, its inexistence or poor performance can seriously disappoint the user. The taxonomy used by the authors is: “Design for error” [19], “Error prevention and recovery” [20], “Error prevention” [16], and “Help user recognize diagnose and recover from errors” [16]. The authors alert for the lack of consistency within the system and between different systems as problematic since it can break the affordance rule and also makes hard for users that need to interact with multiple systems where similar objects provide different functionalities. So it is stressed the importance of the consistency throughout the system, and the use of standards. Authors refer to this subject as “Consistency” [20], “Consistency and standards” [16] and “When all else fails, standardize” [19]. The user exploration of the system and how the system reacts to the user interaction was also identified as a design principle. The system may allow the user to freely explore the system but should restrict the functionalities available depending on the context. As for the feedback, it helps the user to perceive its influence on the system and understand that the system is actually responding to the user interaction. The taxonomy used was: "Feedback" [20], "User Control" [20], and "User control and feedback" [16]. Apart from the shared design principles, each author proposes unique principles:

- **Norman**. In the "Simplify the structure of the task" [19] the author highlights the importance keeping the interaction with the system as simple as possible in order to not overload the user short-term memory while a good concept model can aid the long-term memory. Users have mental models that perform an important role when using a system, so the design principle "Get mappings right" [19] stresses this point. A good choice of natural mappings or metaphors can enhance the user familiarity and experience with the system. A bad mapping can turn the system's interaction confusing and unpleasant for the user since the system usage does not meet the expected behavior the user has within its mental model. Similar to the previous design principle, the "Exploit the power of Natural and artificial constraints" [19] suggests that designers should use natural constraints in order to give hints of how the system can be used.

- **Jordan**. The "Compatibility" [20] design principle stands for the system being adapted to the user, meaning that it meets the expectations and the user abilities. "Consideration of the user resources" [20] is an important design principle for the IVIS since the author realizes the importance of taking into account the motor, verbal, memory, auditory or tactile capabilities. Jordan considers also important the "Prioritization of functionality and information" [20]. This principle states that information and functionality should be correctly clustered and hierarchically organized which otherwise would be very susceptible to errors. Other unique proposition is the "Appropriate transfer of technology" [20] which reminds designers that systems are commonly used along other systems so the context of use is important for the system and user safety. This topic is relevant for the IVIS context.

- **Nielsen.** System design should consider novice and expert users, so in the design principle "Flexibility and efficiency of use" [16] recommend the user of accelerators. This later concept allows expert user to use 'shortcuts' in order to perform their tasks more efficiently. However a slower and informative option should be available for novice users. This helps covering a wide user range while maintaining the efficiency for advanced users. Despite a system should be used without the need for documentation, in "Help and documentation" [16] Nielsen recommends that there should be supportive documentation. This documentation should be easy to access, search and oriented to task.

2.1.4 IVIS Usability context

Although these definitions can be acceptable from a theoretical point of view, they are still too general and vague. The usability concept is easy to understand and demonstrate in a "good versus bad" example but it is hard to explain. Furthermore, it is clear the several design principles and even factors share common ground where we cannot see a clear distinction between them. The major problem for this situation is the lack of context.

The context of use assumes a major role in the usability assessment in the sense that it sets the system acceptability. Under a specific context, we can properly translate the design principles into usability factors and goals which otherwise would not be possible due to the lack of notion of what is acceptable and what is not. Further, it can also help realize the importance that each factor represents. For example, in an IVIS context we can argue that the flexibility to perform a task in multiple ways can be trade by a more rigid approach that ensure a single way where the user resources are minimal. So we clearly give more importance to "Consideration of user resources" [20] since it would be safer to have a single approach to perform a task if this approach is considered the safest way to do it. A similar decision on a computer desktop environment would not be adequate in most cases.

2.1.4.1 Dual task

The most important difference from "normal" human-computer context is the dual-task performance because during the IVIS interaction the user is also driving a vehicle. Controlling the vehicle is considered the primary task while the IVIS interaction (usually for communication, entertainment or navigation purposes) is considered a secondary task [21]. A deficient interaction with the secondary task can have the following consequences: (1) The user is using a non-critical vehicle function, so if the system annoys or frustrates him, the user will likely not use the system; (2) it can interfere with the primary task which is considered a safety critical-task since mistakes can compromise the safety of both system and user.

Most of the interaction the driver does with the IVIS is using its motor capabilities, usually using one of its hands. IVIS interfaces that require motor skills can affect the driving performance, specifically the vehicle lateral control [21]. As the driver takes one from the steering wheel to interact with the IVIS it has been noticed that drivers tend to lose the sense of lateral position [21], so the vehicle starts getting closer to the lane edges. IVIS requiring motor skill to interact also are dependent on the system position [22], meaning that if the IVIS is far from the driver, it will affect more the lateral control than one closer. As for the advantage of these interfaces, drivers are quite familiar to with that interaction mode since prior to IVIS all other controls worked that way (e.g. radio).

An alternative is the use of voice commands to interact with IVIS and receive the outputs also in an auditory form. One of the main advantages of this is that it does it may not require motor skill nor visual demand to the driver. However, it was noticed in cellphone studies that even in this format the resource consumption can be significant, so it was noticed from the visual pattern that drivers loose partially their lateral field vision [23] and the vehicle velocity also increases slightly [24].

Finally, the IVIS interaction can also require the driver resources to handle visual information. This format is commonly used to provide information (output) and the system is controlled using a motor/auditory interface. It was observed that when displaying information it alters the visual pattern [24] and affects the longitudinal control, making the driver loose the sense of distance to the vehicles ahead [21].

2.1.4.2 External Environment

Several theories for explaining driver models exist (see section 2.2.4) and in all of them the driver is either taking corrective measures to controlling the vehicle (reacting to a state deviation) or being cautious (predicting a certain state will happen) in a dynamic environment where the vehicle is placed. As Jordan [20] noticed, it can be important (to both system and user) to the context the environment where the interaction takes place.

The variety of environments surpasses by far the usual desktop requirements. Some conditions to consider are: road type, road signals, traffic condition, luminosity and obstacles.

Road type affects the possible actions the user can perform, for instance in a highway it can be possible to easily overcome a leading vehicle while in a rural environment lanes are thinner and overcoming can only take place in specific segments. The three main road types considered are: rural, city, and highway.

Road signals constrains the driver behavior in the driving task. Drivers are supposed to identify them and react accordingly. It would not be admissible to miss a road signal because the driver was interacting with an IVIS. Even if the user identifies the signal, the reaction time and vehicle control must respect the signal instruction under the penalty of severe consequences, for example the driver took too much time to react to a STOP sign due to interaction workload.

Circulating in a lane is usually an activity shared by several vehicles. When a vehicle is circulating alone in a lane, its major concern is to correct the vehicle in order to respect the traffic law and control the vehicle within the lane. As other vehicles share the lane, drivers must take this into account. Traffic condition affects the IVIS interaction because it must not interfere or distract the driver in such a way that he loses the notion of the vehicle position in the lane or to near vehicles (most notably the vehicle in the front). Therefore, IVIS should be designed to don’t draw too much attention from the primary task, driving the vehicle. A classic example where IVIS related distraction could compromise the driver would be when a front vehicle suddenly stops, or an animal/object crosses the road.

The environment luminosity from both external environment and vehicle can affect the IVIS interaction. Driving can be taken place under several meteorological conditions or time of the day that can affect the luminosity inside the vehicle, where the interaction takes place [22]. For example, during night the luminosity inside the vehicle is reduced or during sunset or sunrise can glare a display.

It is usual in several simulations and real world experiments [21] to test the driver reaction time by suddenly introducing an obstacle in the vehicle course, which in a real world example could be a person crossing a road with low visibility. A good IVIS interaction would allow the driver to timely identify and react to the obstacle.

2.1.4.3 Range of Users

In IVIS context, the system user is the driver or other vehicle passengers. There are two main characteristics which distinguish users, namely age and experience [15].

Age affects motor, cognitive and sensory capabilities of the driver. Old drivers usability concerns are studied in [25][26] and can be quite challenging since IVIS interaction uses a considerable amount of their already scarce resources.

The amount of driving time experience also is recognized as an important factor. Inexperienced drivers tend to allocate their full resources into the driving task, which means that an interaction with an IVIS would likely create a problem of scarcity of user resources.

2.1.4.4 Initiation

Almost every commercial device has instructions manual and cars are no exception. The drivers' expectation is to be able to drive the car without needing for special training period or reading the manual. In fact, as Llaneras and Singer [27] observed, buyers tend to not use the manuals at all, while some training period would probably not please consumers.

For living up to the expectations, IVIS should be explicit and simple in order to maximize the learnability factor. In this case, the initial interactions will be decisive because they will help realize the learning curve and also understand the extent of satisfaction in using the system.

2.1.4.5 Frequency of Use

The IVIS role is to provide secondary functions, which means that they are not critical for the driver's mobility despite the improved value added to the driving experience. As a consequence, the use of these systems was observed by [28] as a rare interaction. Under this factor, usability "general" literature recommends a good memorability and affordance to the systems design.

2.2 Related Work

2.2.1 IVIS Usability Assessment

The development of IVISs is based on an iterative loop of implementing features, testing with users, and applying changes based on the feedback. This continuous process requires several iterations which raise the cost of production and is time consuming.

One of the main objectives of evaluations is to identify design problems as earlier as possible consuming a few resources. Hence, evaluators apply different methods to assess the system depending on the system current stage.

2.2.1.1 Desktop methods

Desktop methods predict the system usability by using cheap paper based prototypes. These methods are applied in early development stages to assess basic usability issues. Initial evaluations aim at:

- **Interactions**. Each interaction is detailed and analyzed to identify redundant, inconsistency or errors.
- **Errors**. Considers possible error occurring during the interactions and its severity.
- **Design principles considerations**. Experts evaluate if the system considers common good practices.
- **Aesthetics**. IVIS interface is analyzed and tested by users.

The specification of each interaction is carried out by Hierarchical Task Analyzes (HTA) [29]. In this method the evaluators define goals of use for users and detail each activity needed to be performed to achieve the goal. Then, using the activity diagrams, evaluators can study the problem in an organized way; this approach enhances the evaluators' perception of similar activities, allows easier comparison between related tasks, and eases the detection of inconsistencies. Then using activity diagrams it is more perceptible similarities that could lead to errors, redundant activities that hint about new efficient ways to perform the task and comparison between related tasks could highlight activities or order inconsistency.

Some errors can be predicted using HTA, however this tool is normally used as input for error focused methods such as Multimodal critical path analysis (CPA) [30] and Systematic human error reduction and prediction approach (SHERPA) [31]. These techniques use the HTA as input by assuming that each task specification is the expected way users will interact so they formulate possible problems that might happen to each specific activity (e.g. for a press button activity he does not press with enough strength), classify the errors based on its severity and study if the system can help recover from those errors.

A popular method is the Heuristic Analysis which uses a "checklist" of good practices and compares the system with it. The evaluation is usually carried by outside of the project experts. Heuristic analysis checklist is based on design principles defined in the 2.1.3.3 Design Principles section.

2.2.1.2 Experimental methods

For later stages of development, desktop methods become pointless since there should be already some functional prototypes. So paper prototypes are abandoned, and users interact using driving simulators or driving a real vehicle.

In this stage, the focus of evaluation is on:

- **Driver Performance**. This data is gathered from the vehicle control metrics. Obtained when only driving or while interacting with the IVIS.

- **IVIS Interaction**. The interaction with the IVIS to perform the tasks is evaluated.

- **Task Interference**. Evaluators access how the secondary task can interfere to the primary task.

- **User Satisfaction**. After completing the tests the user is prompt to report his perception about the IVIS.

Driver performance metrics are used to measure the vehicle control execution during the test. Metrics can be divided in two main categories: longitudinal control and lateral control. The former addresses speed and headway management related to the lead vehicle, while the later addresses the vehicle position management in the lane. A list of common metrics used is available in Appendix O's Table 54 and Table 55.

The IVIS interaction measures address specific usability factors defined in IVIS Usability context. Table 56 presents the metrics used for each factor.

In IVIS context, Task interference can be detected by comparing the primary task performance without performing other task with performing primary task while executing a secondary one. IVIS can influence by distracting the driver or by stressing the cognitive workload. Distraction takes place when the interaction captures too much attention from the driver, while cognitive workload happens when the driving task and IVIS interaction are demanding too much of its mental capabilities.

As part social products, IVIS depend on users' perceived value. Satisfaction is measured using subjective self-reports like System Usability Scale (SUS) (proposed in [15], e.g. Appendix Q's table Table 57).

2.2.2 Driving Simulation

Driving simulators are quite used for evaluation purposes, specifically in intermediate and advanced development stages. The purpose of these tools is to mimic the real condition where the IVIS would take place in the real world since contexts of use are dangerous (interacting with IVIS might be) or unpractical to conduct experimental methods. Concerning IVIS context, simulators usage avoids: drivers' injuries; need for public roads for experiments or reserving private roads; and vehicle and its maintenance cost. In this document, driving simulators are divided in high-cost and low-cost.

2.2.2.1 High-Cost

High-cost simulators are simulators that whether by their hardware or software capabilities are very expensive so they are restricted to some industry companies or research centers. Typically they are set up in an exclusive room for that purposed, have a fixed vehicle (vehicle fully equipped but without the motor), has big screen, and also the rear view. Concerning software, specific solution are home-made by each research team. Examples of these types of simulators are illustrated in Figure 6.

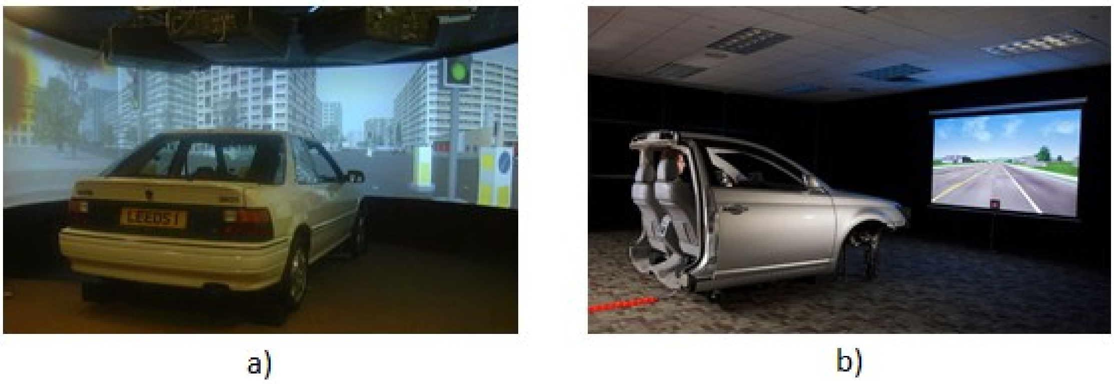


Figure 6: High cost simulators with fixed vehicle. A) The Leeds driving simulator with 180º viewport. B) Toyota driving simulator [32].

Even in the high cost simulators there are a class of mobile simulators equipped with haptic interfaces [33] for more realistic approaches. Example is given in Figure 7.

Figure 7: VTI driving simulator (hydraulic systems simulate vehicle motion) [34].

2.2.2.2 Low-Cost

Low-Cost simulators distinguish from the high-cost in terms of price and fidelity. Although there is no specific threshold for defining which one is low or high cost, it is acceptable to consider high-cost simulators costing several times the price of the low-cost ones. For example, the Leeds driving simulator was 3 million euros [35] , while a good low-cost simulator can be obtained under 3000 euros. Simulation fidelity is lower due to lack of haptic feedback [33] or reduced viewport [23], [36].

Unfortunately high-cost simulators are very expensive so IVIS researchers explored the use of low-cost simulators to assess these systems. There are successful cases of evaluating visual and cognitive workload from the DriS project [24], cellphone usage [23] and navigation systems [36].

2.2.2.3 Validation

Simulator validation is an important step since it allows evaluators to perceive to which degree the data obtained from the simulator can be reliable. There are two types of validity: absolute and relative. If the results from the simulation are very similar to the real-world it is achieved absolute validation. Otherwise, if the results are not similar but still comparable it is called relative validation.

According to [37] there are four approaches to validate the behavior driving simulator:

- **Comparison of system output**. Compare the output with real driving data.

- **Comparison of workload**. Compare the workload under a simulator and under real driving.
- **Subjective criteria.** Compare the difficulty and perceived similarity of self-report subjective answers.
- **Transfer of training.** The skill transfer during the simulation can be observed in the real world.

The most common approach is the system output comparison. In low-cost drivers context, this comparison can be made with real world data [23] or with high-cost simulators [36].

2.2.3 Driving Serious Games

Serious games are a subcategory of games which address serious subjects. They have been applied to many areas like Military, Edutainment, Healthcare [38] or Vehicle driving [39].

Normal games main objective is to entertain players, while serious games aim to teach or influence the player's behavior in a serious theme. In practice this means that the realism and real-world problems are present in the game, even if sometimes unpleasant, but still have game characteristics like fun or competition.

Instead, if we compare simulators with serious games one of the main differences is the serious game's game component. Despite both addressing serious subjects, serious games provide a Gamification [40] approach with techniques such as progress bars, reward systems or achievements badges.

As traffic safety is a common goal and driver behavior causes 95% of all accidents[41], driver skill enhancement is the primary approach to a lower accident rate. As already mentioned, the potential of games to improve specific player's skills can be transferred to the specific need of improving driving performance. Some driving serious games are already available and can be classified according to their purpose: learning or influencing.

2.2.3.1 Learning Purposes

Driving serious games can teach basic driving skills for a complementary approach to normal driving teach, like [42] where players could start getting confidence and learn the basic maneuvers safely (Figure 8 a). There is also [43] a very specific serious game targeting teenagers Figure 8 b). They can be considered a risk group due to their more natural risky behavior teenagers and small driving. Therefore the game addresses some of common tasks younger drivers usually perform like driving in night time, using cellphone and driving with loud music. This game also tries to persuade the players by showing how difficult the driving task could be under certain conditions.

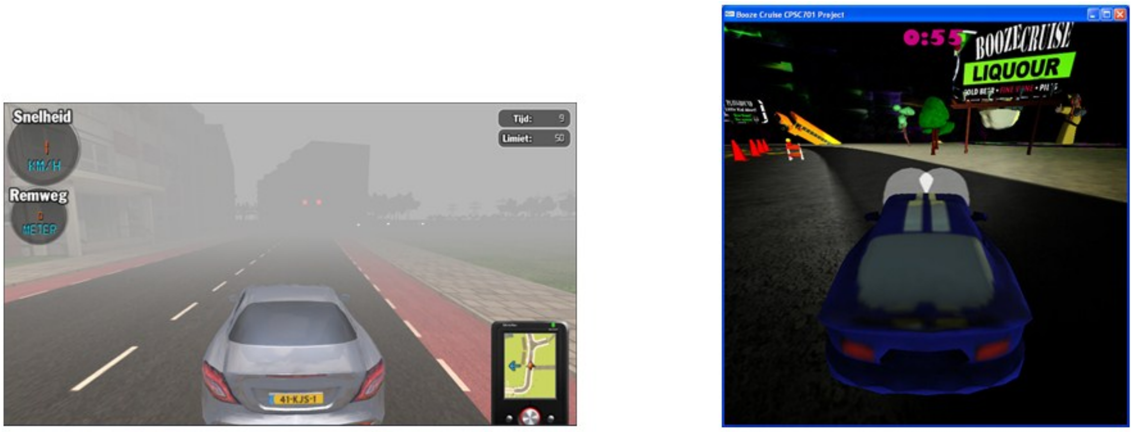
a) b)

Figure 8: Driving serious games teaching skills to players. A) 3D-Fahrschule. B) Road Ready Streetwise.

2.2.3.2 Influence Purposes

The ability to influence the player is one of the major strengths of the serious game concept. Requested by the Dutch Government, [39] is a popular driving serious game where players have a set of timed based missions to perform but they have to obey the traffic laws otherwise their score is penalized as depicted in Figure 9 a).

Alcohol can have very serious consequences in driving performance, but still many people think that they are able to drive properly. In [44] the example presented in Figure 9 b) tries to persuade drivers to recognize their very limited capabilities and the risk they represent to themselves and others by simulating alcoholic conditions.



a) b)

Figure 9: Influencing the player using Driving Serious Games. A) Verkeerstalent Online. B) The Booze Cruise.

2.2.4 Driving Models

Driving models are frameworks that conceptually structure the driving behavior. These models are based on assumptions about human cognition. This subject is particularly interesting for this thesis since the driving data by itself has limited use, but using the same data we can create concrete rules for these modules.

2.2.4.1 Single Task support

Singe task driving models focus only on the primary task, so they do not consider the possibility of performing a secondary task while driving (e.g. interacting with an IVIS).

In [45] Michon proposed a driving model based on the assumption that driving has hierarchical structure composed by: operation, tactical and strategic layers. Operation tackles corrections to the current driving performance, tactical layer reasons about the vehicle position based on the environment, and in the strategic the objectives like pleasure, time to reach destination, etc… More recent driving models are based on this work.

Also very important is the Contextual Control Model (COCOM) described in [46] which has a framework to understand how driver behavior is structured. This framework is based on Control theory and the Joint Cognitive Systems model (JCS).

Based on control theory, the controller (driver) has two types of loops for controlling the vehicle: (1) **feedback** when controller takes corrective actions to compensate the actual state with regard to the desired one, (2) **feed forward** when controller anticipates actions based on their predictions. Driving requires each loop or even mixes [47] to achieve a set of goals. Controller pursues these goals as a *Satisficer*, meaning goals have acceptable ranges where the controller tolerates the state [48].

Joint Cognitive Systems is a human-machine interaction model aiming to integrate the interaction with the user behavior. Event / Feedback concept use both feedback and feed forward mechanisms to feed the Construct's perception. The construct concept is responsible for creating an internal representation of the environment upon an execution plan is defined to be performed. Actions also modify the environment state which will be once again perceived by the constructor (closing the cycle). In JCS time plays an important role since sets the time of the cycle as the sum of perceive, decide and act times. Therefore some characteristics can be drawn: (1) if a task needs to be performed it should take equal or less than the cycle time otherwise control will deteriorate, (2) interferences or overload increases the cycle time, (3) cycle time deficit can be compensated by increasing the task execution time (slowing down the pace).

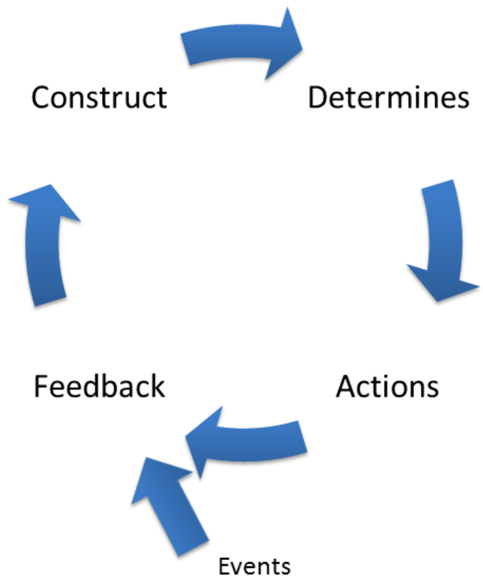


Figure 10: Scheme of Contextual Control Model (COCOM).

2.2.4.2 Multiple task support

Both previous models did not account for the possibility of performing another task while driving. This more recent model not only accounts for the driving task but also handles second task performance.

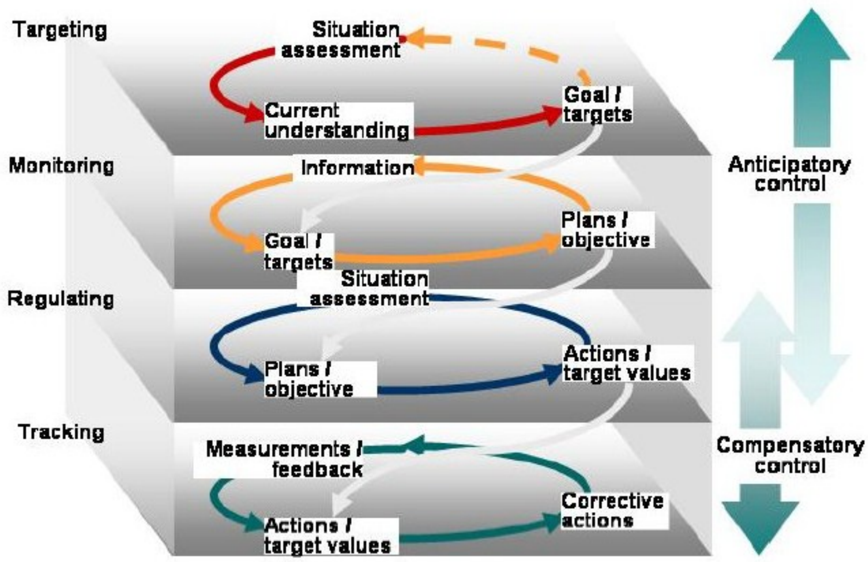


Figure 11: Scheme of Extended Control Model (ECOM) [21].

Extended Control Model (ECOM) was proposed [49] in order to extend the COCOM to pursue multiple goals at the same time. ECOM is divided in tracking, regulating, monitoring and targeting layers. These layers form a hierarchical structure, each layer can interact with adjacent ones and the layer goals are set by upper layer output. Tracking layer handle automated corrections to deviations (for example, compensate velocity due to road declination). Regulating layer is responsible for deliberating actions in order to satisfy comfort margins (e.g. keep distance to lead vehicle). Similar to the constructor form the COCOM, Monitoring layer interpreters the system state in the current environment (e.g. identify a road signal). Global goals, like go from house to job, are defined at the targeting layer.

Second tasks interact in targeting and monitoring layers. If we consider the use of a navigation system, the intention of using such a system would be considered at targeting layer while the act of paying attention to the information provided during the travel would be at the monitoring layer.

2.3 Summary

IVIS technology and applications are growing at a fast pace. Despite their added value to the driving experience, they tend to increase drivers' distraction and cognitive workload to dangerous levels.

Current driving interference problems associated to IVIS have been identified has a ergonomics issue, more specific as usability problems. Typically Human Computer Interaction (HCI) problems require multi-disciplinary knowledge and they are very sensitive to context. It is precisely the complexity and number of different driving contexts that makes hard to solve the security related issues within the Human-Vehicle-Environment framework.

Meanwhile, some approaches start emerging to tackle the problem. Simulators emerged as a popular tools for conducting experiments and studies due to their ability for creating different scenarios, safety even in "danger" contexts (e.g. alcohol and drug scenarios), and their results' validity. Despite their success, these simulators are quite expensive. Naturally, low-cost simulators appeared to decrease the costs, but with a cost of lower results validity. Several driving models were also proposed to model decision-making and vehicle control.

The serious games concept is used to create low-cost games for addressing important issues. This class of games distinguish from simulators for its fun, challenge, and mainly for its feedback and behaviour influence. Some authors used this concept already, to influence players behaviour towards alcohol effect on driving, meteorological conditions and to train novice drivers.

In the next chapter, a methodological approach is presented which uses serious games. However, this approach aims to use this concept to influence the driving performance and to elicit driver behaviour.

Chapter 3

Methodological Approach & Experimental Setup

The chapter Methodological Approach & Experimental Setup is composed by two main subdivisions: methodological approach and experimental setup. The methodological approach section addresses the methodology for conducting this work and how to evaluate it. As for the experimental setup section, a detailed description of the experiments conducted during this work.

3.1 Research approach

In this dissertation three main research questions are proposed to be answered:

1. If a driving serious game is developed as a tool for capturing players' driving behaviour, then how can we assure the validity of such tool?
2. If the serious game from the previous question is also used to assess the usability of IVIS, then how can we assure the validity of the assessment?
3. The main characteristic that distinguish the serious games from simulators is the behaviour influence documented in other works. Does this tool also influence the driving behaviour outside the gaming sessions, during a real scenario?

In order to properly answer this questions, this section proposes a methodological approach for solving this problems and also to evaluate the answers.

3.1.1 Serious Game validity for capturing driving behaviour

The traditional way to capture the driving behaviour is based on the observation/record of the driving performance. High fidelity simulators or even real cars are used to obtain this driving performance, in a certain context, to model the driver behaviour. However, in this case we use a low-fidelity simulator, thus it is indispensable to assess the validity of the captured data.

3.1.1.1 Evaluation

An evaluation procedure is proposed in Figure 12. The main objective is to assess the validity of the driving performance captured by a serious game. Thus, the input that will be used to evaluate is the game's driving performance.

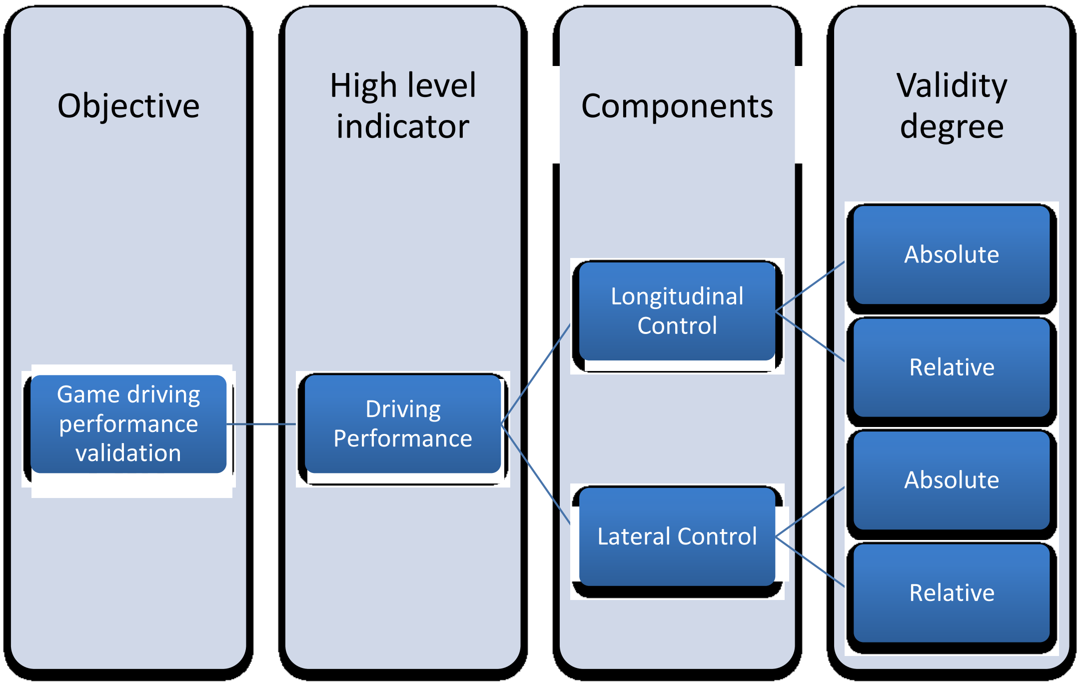


Figure 12: Validating the game's driving performance.

The high level indicator is then decomposed in lesser components, mainly their longitudinal and lateral control metrics. Then, for each metric the results must be compared with data captured in a higher fidelity setup, like fixed/mobile simulator or even real vehicle driving.

Using statistical tools like t-Tests for testing the similarity (null hypothesis assuming no difference) of two sample means, the result can be either positive or negative. If the result is negative, then there is no significant difference in the metric tested, therefore this metric has an absolute validity. On the other hand, if there is a significant difference between samples then the metric is classified with relative validity.

There are numerous metrics that can be used for representing the longitudinal and lateral control, so to maintain the validity classification simple a final verdict should be associated to the longitudinal and lateral groups. A group is classified as absolutely valid if all or the majority of relevant metrics for a given problem has the absolute classification; otherwise it is relatively valid.

3.1.1.2 Methodology

The methodological approach for tackling this problem is presented in Figure 13. There are 4 main phases: Setup phase, perform experience in game, perform experience in higher fidelity setup, and data analysis.

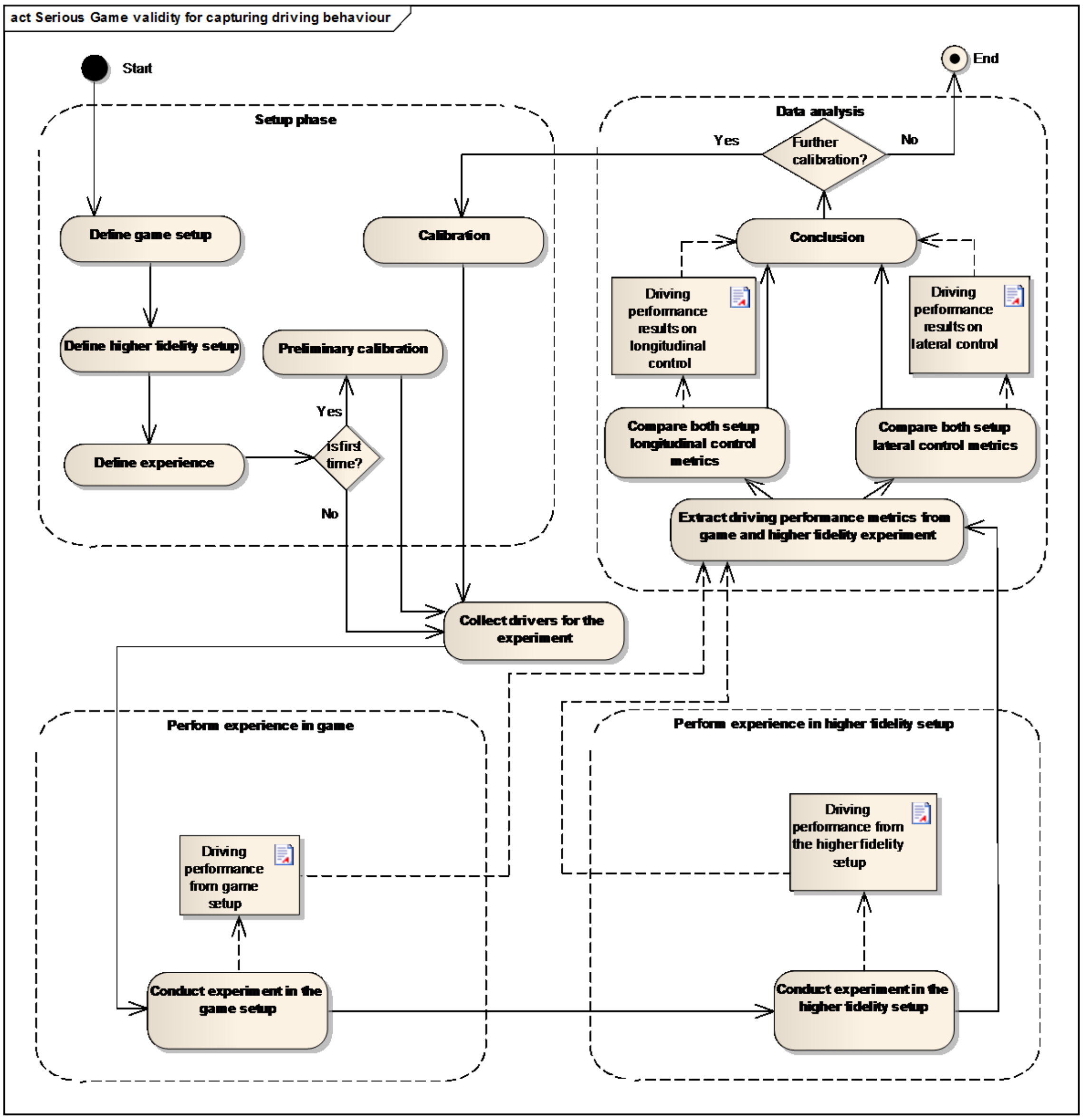


Figure 13: Methodological approach for validating the serious game captured driving behaviour.

The methodology starts by the Setup phase. This phase focus on defining the details of the experiment to be conducted, the platforms selection and configuration; and calibration of the serious game. A very important decision in this phase is the definition of the higher fidelity setup, because this is a practical issue whether to get access to a high fidelity simulator or the logistics involved in a real vehicle driving. Nevertheless, the closer to reality or the higher fidelity setup is possible to use, the better comparison data is provided. Concerning the game calibration, this methodology recommends a preliminary calibration for the first time the game is compared to the other setup. This calibration helps giving people a more smooth transition between setups, otherwise people complain about the reduced realism of the game. Further calibration may be performed, depending on the final results in order to adjust the game's driving dynamics to the higher fidelity simulator. The experience also needs to be defined in terms of the map, configuration of the elements within it and the track to be performed by the subjects in both game and higher fidelity setup.

After the Setup phase, a crucial task in this methodology is the recruit of subjects for the experiments. This step is important due to the practical difficulties of convincing people to participate. Upon scheduling the subjects, the data capturing starts by completing the experiment in the game. Furthermore, the experiment is repeated in the higher fidelity setup. Both data captures provide the driving performance for the next phase.

As capturing the data is completed, the data is then used to extract the driving performance metrics. In the Data processing phase, the driving performance metrics extracted are grouped in the longitudinal and lateral control groups. Each metric is then evaluated as described in the previous section 3.1.1.1 by statistically compare the result from the game with the correspondent result from the high fidelity platform.

3.1.2 IVIS usability assessment validity using serious game

IVIS development uses a user-centred approach for implementing features and also for detecting unsafe driving functions. This approach suffers from two main disadvantages: people recruiting and setup cost. From a resource perspective, recruiting people is a time consuming task, for both recruiter and recruited; it often involves a monetary compensation. The setup where the experiment takes place usually occurs at very high cost equipment and maintenance.

The use of low-cost equipment for rapid assessment is a natural option, triggered by the high cost of the current equipment used. The following methodological approach targets serious games, but it can be applied to other types of software(e.g. simulators).

3.1.2.1 Evaluation

The IVIS usability assessment validity will be evaluate with the scheme proposed in Figure 14. Although the diagram has some similarities to the one in Figure 13, this evaluation also takes into account the driving performance but in a more IVIS usability perspective.

High level indicators focus on the IVIS interaction itself, and its impact on driving performance. The interaction results in the effectiveness and efficiency each subject demonstrates while performing a specific task.

Since the interaction must be set in a human-machine-environment framework where the interaction itself is a secondary task, its impact on driving performance will result in the deviations observed from the "natural" driving performance. Once again the two main components are the longitudinal and lateral control, but aiming at the metrics' ratio of non-performing tasks and performing tasks.

The use of difference ratios, instead of the quantitative values minimizes the dependency on the game calibration. If the game is not calibrated, using ratios helps understanding the trend of the impact on the metrics, whereas if it is calibrated not only it is possible to realise the trend but also the quantitative values.

Similar to the previous evaluation framework, each components' metric validity will be classified either as absolute or relative. The same classification domain is assigned to the components based on the majority of their metrics validity degree.

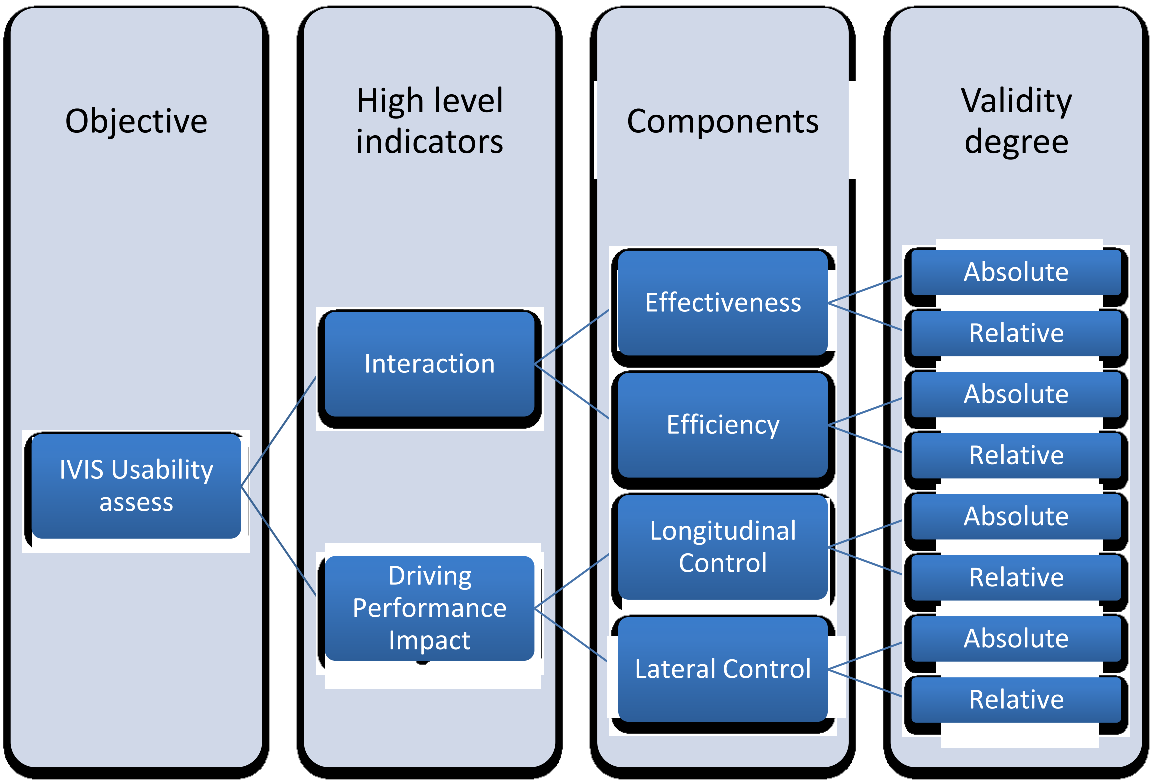


Figure 14: Evaluating the results from an IVIS usability assessment using the serious game.

3.1.2.2 Methodology

Developing a methodological approach for the IVIS usability assessment validity has similarities to the serious game validity itself, but the IVIS' interaction must be taken into account. Figure 15 proposes a methodology for validating the IVIS usability investigations using serious games.

As in the previous methodology, see Figure 13, it starts by the Setup phase. The definition of the game tool and its associated hardware and software; and also the usable higher fidelity setup must be defined. The experiment definition component is extended to consider the tasks to be performed. In this context a task is a procedure subjects must accomplish while driving, interacting with an IVIS through a modality (visual, auditory, motor, etc…); practical examples could be: dialling a number in a mobile or insert an address in the navigation system. Furthermore, most tasks may require variable input or provide variable output (e.g. write/read an e-mail) that must be taken into account in order to properly assess the impact of the tasks in extreme situations (e.g. write very long emails). Hence, the investigator should consider the variability of the input/output, define a reasonable number of difficulty degrees, and create prototypes that take this into account. Still in the setup phase, a preliminary calibration (if not calibrated already) should be done.

As the setup phase is completed, the methodology advances by recruiting drivers for the experiment and explain them the procedures of the experiment. After a brief period of training, subjects start the first round of the experiment by driving game's map without performing any task. When the first lap is completed, the vehicle departures from the same initial position as before, but in this round through the map, the game requests the user to accomplish the defined tasks with the different difficulty degrees previously defined. After finishing data collection in the game, the experiment continues by performing the same procedure from the game but in the higher fidelity setup.

Game and higher fidelity setups' data acquisition produces two types of data: driving performance and IVIS interaction. These data are the input to the Data analysis phase. The evaluation is performed using the framework defined in Figure 14. A significant difference from the methodological approach in Figure 13 is that Data analyses should produce a report to clearly summarise the evaluation and the effect of tasks onto the driving performance.

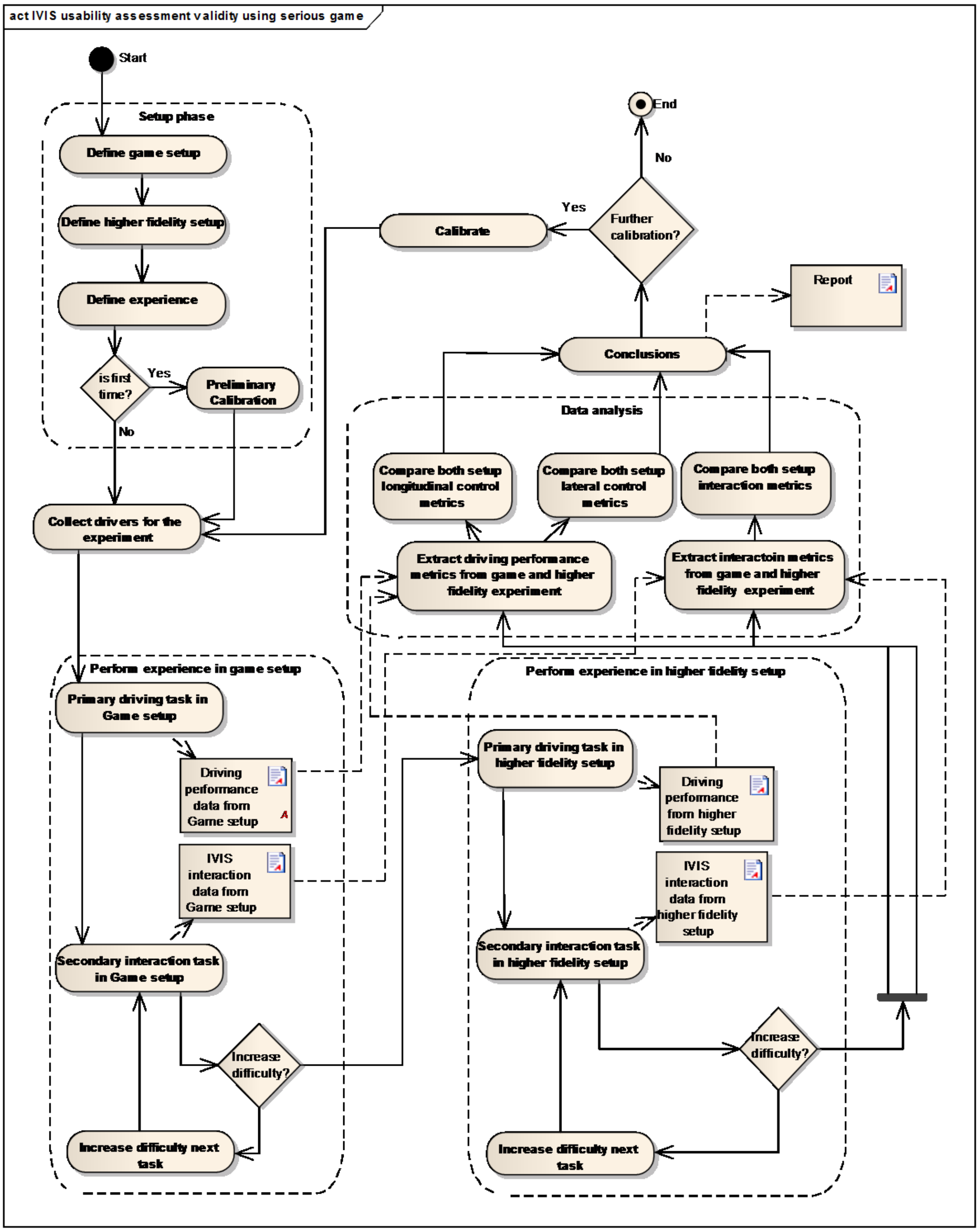


Figure 15: Methodological approach for the IVIS usability assessment validity.

3.1.3 Behaviour influence investigation using serious game

The most significant characteristic intrinsic to serious games is the behaviour influence. Games provide feedback to players about their actions within the game, so if the game simulates a real environment/situation it can be used to train the players performance or to influence their behaviour.

Although the behaviour influence is recognized in the literature. To the author's best knowledge there is no record in the literature for driving serious games. Thus it is important to verify their existence and document it.

3.1.3.1 Evaluation

The evaluation process proposed is presented in Figure 16. The objective is to understand how drivers change their driving behaviour, after being exposed to a training period.

Once again, the focus will be on the observed driving performance, specifically its longitudinal and lateral control components. For each metric a threshold must be defined in order to later decide whether the metric suffered a significant change or not. This is especially important if the samples available are small and the average difference of behaviour are small, so the evaluator should define a value.

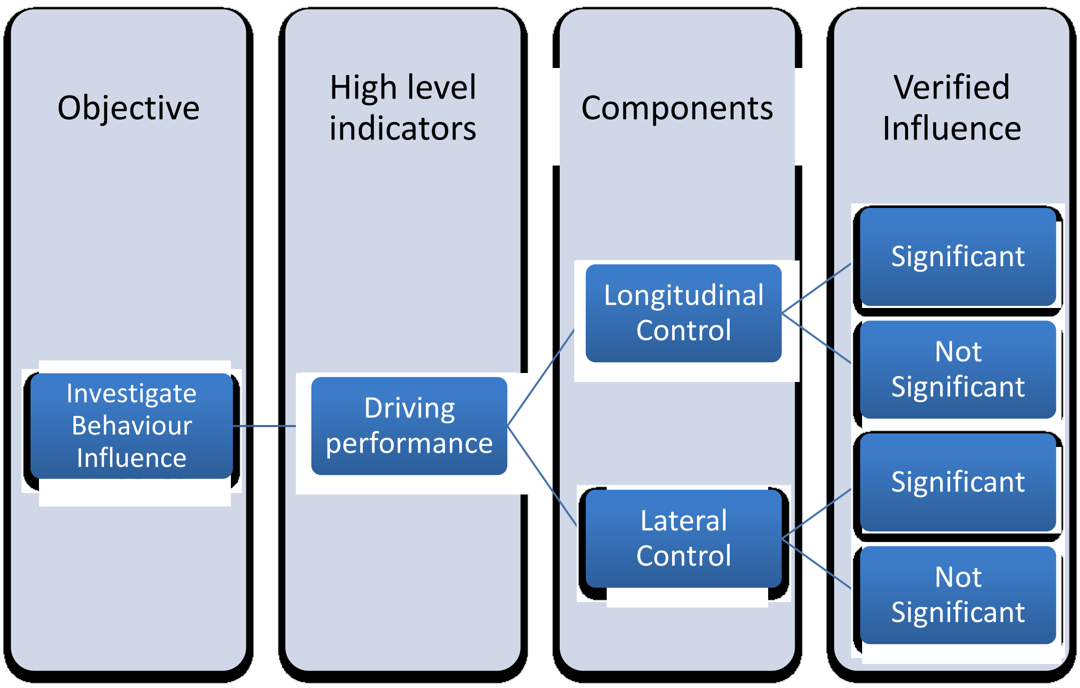


Figure 16: Evaluating the influence of serious game in real life scenarios.

When data from both before and after training is available, the comparison for each metric can be made. Depending on the thresholds defined for each metric, the evaluator can then decide whether there is a significant difference (whether positive or negative depending on the metric) or no significant difference.

3.1.3.2 Methodology

The initial phase, depicted in Figure 17, is similar to the other approaches from Figure 13 and Figure 15. A new approach for defining the experience in this situation is the training period of time.

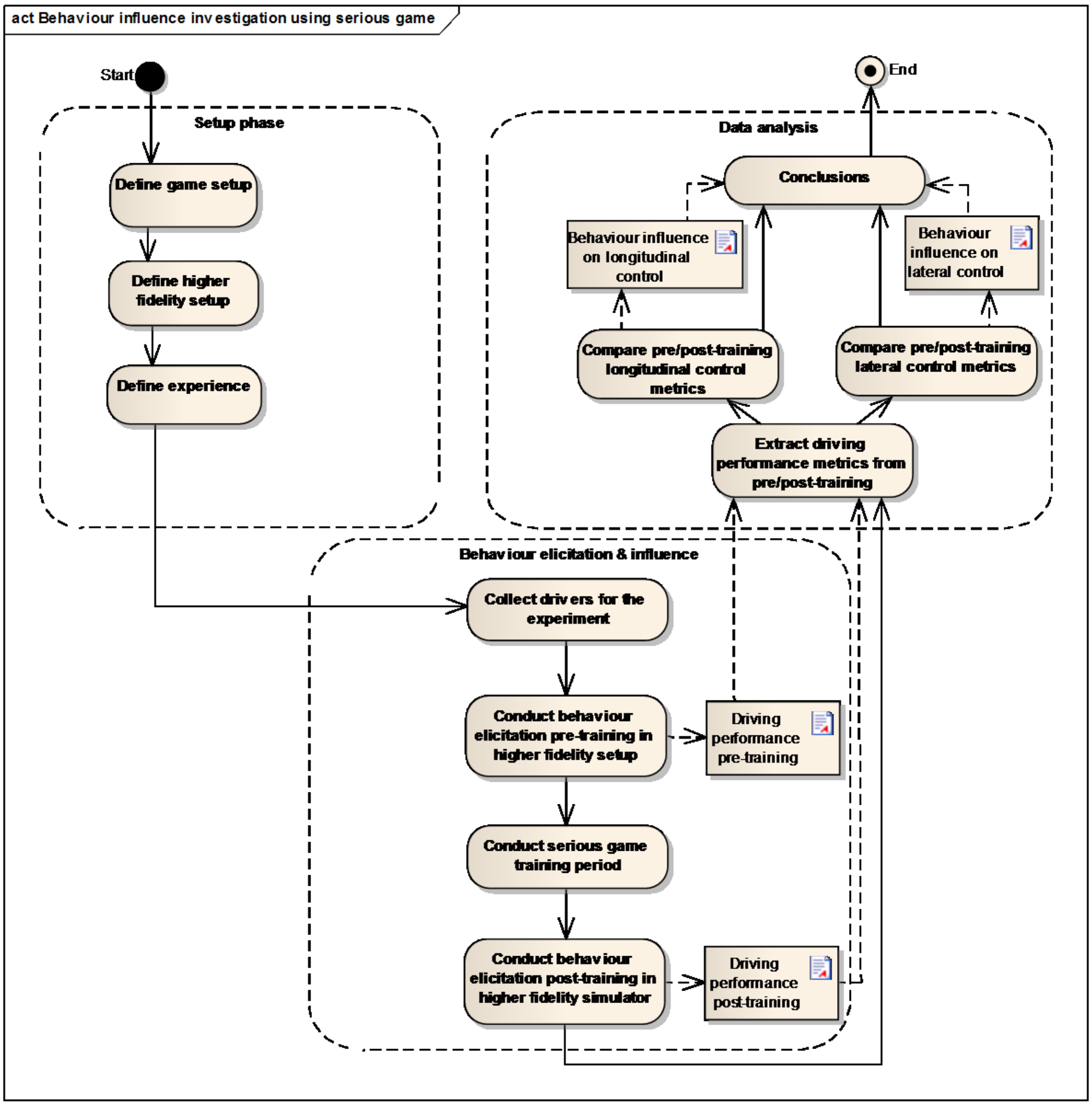


Figure 17: Methodological approach for investigating the behaviour influence of serious game.

Upon collecting drivers to the experiment, it is crucial to ensure their commitment to the experiment since their training period should be done in their home environment without supervision of the investigator.

Continuing to the behaviour elicitation, subjects should drive on a higher fidelity setup in order to elicit the driver behaviour as close as possible to the real world conditions.

Once this is done, the training period with the game starts. The game penalizes bad driving decisions in order to influence the driver behaviour. Ultimately, the game aims to influence the driver behaviour outside the game environment.

Finally, the driver should perform the same initial procedure in the higher fidelity setup. Thus, investigators can observe if there were significant differences between the first and the second samples.

3.2 Experimental Setup

3.2.1 Metrics

One of the objectives of this thesis is to create a solid foundation for future driver behaviour studies and its integration on existing traffic simulators. The most basic structure of the driving behaviour is its position in the lane width and its velocity management. As presented in Table 54 and Table 55, there are numerous metrics for both longitudinal and lateral control.

The selection criteria was based on follow criteria:

- Metrics representative of the longitudinal and lateral control behaviour.
- Metrics to capture the variation of the longitudinal and lateral control behaviour.
- A metric already implemented in the high fidelity simulator.

Longitudinal control is measured using the following metrics: mean velocity and standard deviation of velocity. As for lateral control the selected metrics are: mean lateral position and standard deviation of lateral position (SDLP).

For extracting the metrics from the data logged, data is filtered by roadway segments. This approach ensures metrics extraction is based on same lane conditions for driving only or performing tasks while driving; and eases the implementation of metric extraction modules for the lateral control metrics.

Considering the secondary tasks the metric used are whether the task has been completed and the completion time.

3.2.2 Hardware setup

In terms of hardware there are significant differences in both platforms that naturally influence the results.

3.2.2.1 Simulator

The high fidelity simulator is composed by a fixed vehicle, a projection system composed by multiple screens and a surround sound system. The vehicle is a BMW 6-Series with its interior fully equipped with the series' normal equipment (including pedals and steering wheel). The projection system is composed by three screens in the front to give a 180º viewport, and 3 in the back so subjects can use the side and rear mirrors in a realistic manner. The sound system, composed by 6 channels gives a good 3D notion of the simulation acoustic environment.

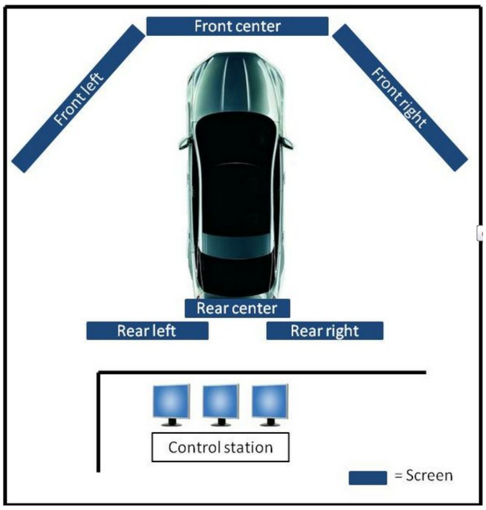


Figure 18: Picture of the simulator at left. Simulator setup scheme at right.

3.2.2.2 Serious game

The serious game hardware setup was composed by a PC and a gaming steering wheel. The computer's monitor was 21" size and had two columns for sound. Attached to the computer was a Logitech G27 gaming steering wheel.

3.2.3 Dual task interference experiment

The dual task interference has multiple goals to achieve:

1. Assess the use of serious games to evaluate IVIS interaction
2. Obtain data to calibrate the serious game
3. Study the impact of reading and menu navigation while driving on driving performance, incrementing the level of difficulty.

For this experiment both high fidelity simulator and serious game were used. Prior to the data acquisition in each platform there is a training period in the map the subject will be performing the experiment. Subjects are encouraged to spend the time they desire until they feel certain they are adapted to the platform.

In the beginning, subjects need to complete a lap over the circuit by just driving. This data captured without any secondary task interferences is saved as the baseline values. After completing the first lap the platform is shut down. Two minute pause is elapsed and then subjects need to drive through the same circuit but performing secondary tasks.

This 2-lap procedure was adopted for both platforms.

3.2.3.1 Email reading task

Email reading tasks simulate the arrival of a new email to the IVIS, and the user would have to read it as soon as it arrived. An example of an email used is presented in Figure 19.

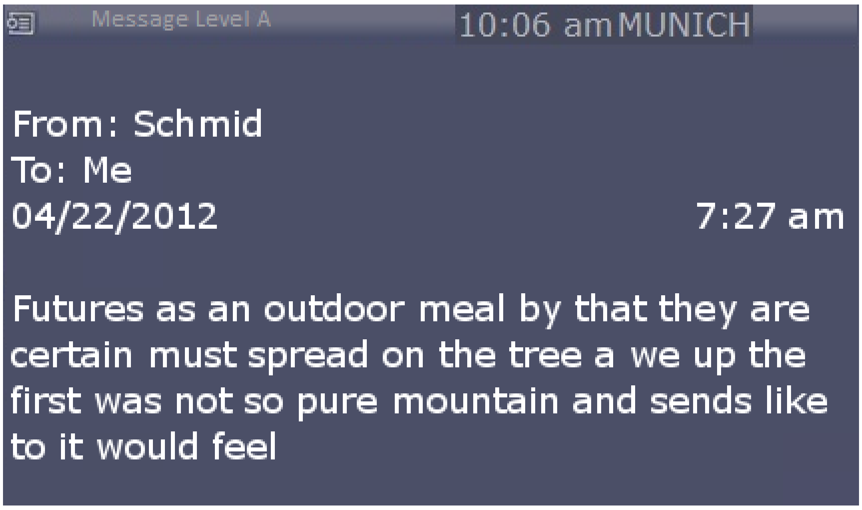


Figure 19: Example of the email reading hard level prototype.

The difficulty level of the reading task consists in the message size. The example in Figure 19 is the harder level, containing 150 chars like an SMS. The easy and medium level contain 10 and 50 chars, respectively. Subjects need to read only the content of the message, the header is just for giving the “look and feel” of an email.

An important practical problem of this experiment is to ensure the subject is really reading the content, measure the start time and the end time. In order to force the subject to be really distracted reading the email, the messages semantics make no sense hence the brain cannot help complete the sentences. For the measure of performance, subjects need to read aloud the message content, so a microphone captures a sound output.

3.2.3.2 Menu navigation task

Menu navigation tasks require users to coordinate their motor capacity by manually using a hard device to navigate through the menus with their visual capacity to read the current menu options. An example is illustrated in Figure 20.

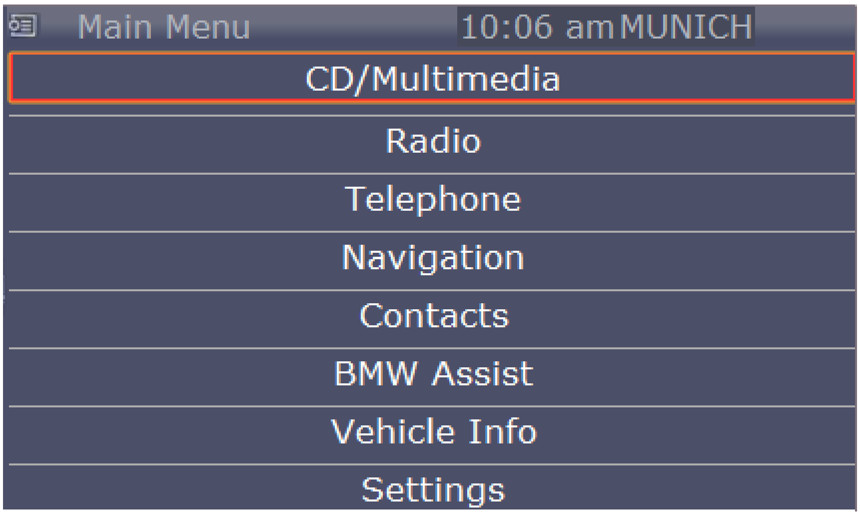


Figure 20: Example of menu navigation prototype.

The task difficulty is modelled by request menu options located in hierarchical levels further away from the main menu. The options for the easy, medium and hard levels required to subjects navigate through 2, 3, and 4 hierarchical levels, respectively.

In both platforms, the input device was a numerical keyboard containing the 4 direction arrows in order to navigate through the menu using the same hardware. The up and down keys were used to navigate within the current menu, the back key to return to the predecessor menu and the right key to enter the current submenu option.

Each key pressed is captured and associated with the simulation time, in order to extract the completeness and performance metrics desired.

3.2.3.3 Map

A scheme of the map used in both simulator and game is presented in Figure 21. The data filters are applied to each edge of the round corner squares which is exactly where the secondary tasks take place. For example, the data from the first lap is reduced to those segments and the metrics are calculated for each segment, therefore obtaining the baseline values; these baselines are associated with the respective task performed in the specific segment.

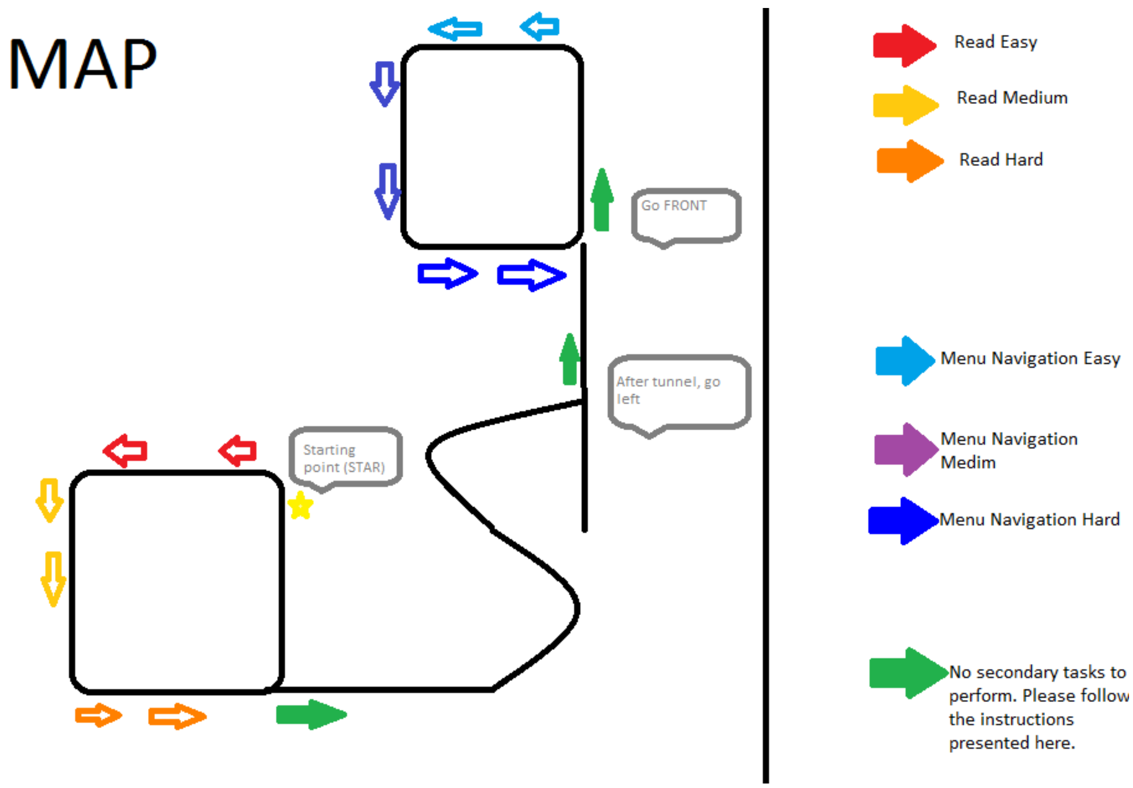


Figure 21: Dual task map. Scheme of the map and the section where secondary tasks take place.

3.2.4 Behaviour Influence experiment

In this second experiment the main goal was to observe the effect of playing the game during 3 days in a real scenario. Since an actual scenario has many practical restrictions, it was decided to use the high fidelity simulator as the real driving situation.

The experiment design is the following:

1. Drive in the simulator for the baseline values.
2. Serious game training period of 3 days.
3. Drive in the simulator for the post-training values.

Initially, the subjects can train up to 5 minutes in the simulator in order to get used to the vehicle. In the first part of the experiment, before any exposition to the game, subjects complete a lap of a circuit in the simulator. With this lap the pre-training values are obtained.

During the next 3 days after the simulator initial experience, subjects need to play the serious game. This game version contains a feedback system that monitors the player longitudinal and lateral control. The feedback system provides warnings in order to allow players correct inappropriate behaviours.

There are two types of warnings:

- Longitudinal control warning. Activated if the player's vehicle surpasses or equals 51 Km/h.
- Lateral control warning. If the player's vehicle exceed the lane limits.

The feedback is provided using both visual and auditory feedback. An example of a situation where the vehicle is exceeding the late limits and exceeding the velocity limit is provided in Figure 22. The visual feedback is displayed in the windshield in form of traffic signals. Simultaneously to the signals appearance, a loud sound is played. This sound helps players recognize the error and helps players avoid errors under penalty of being to annoyed hearing the sound constantly.

Figure 22: Example of a situation where both warnings are activated. Warnings are projected onto the windshield.

Chapter 4

Preliminary Results and Analysis

4.1 Driving performance without performing secondary task

The game driving performance comparison with the fixed simulator's, without considering any IVIS related secondary task, is fundamental. The comparison provides insights into how reliable the game's data is for the purpose of capturing human driving performance using a low-cost setup.

4.1.1 Longitudinal Control

Mean velocity results, in Figure 23, show that despite the recommendation of driving as in a real urban city with maximum velocity allowed of 50 Km/h, in average no subject was able to accomplish such a requirement. Six out of ten subjects drove faster in the simulator than in the serious game, however the mean velocity of 54.73Km/h and of 54.01 Km/h (simulator and game, respectively) were close.

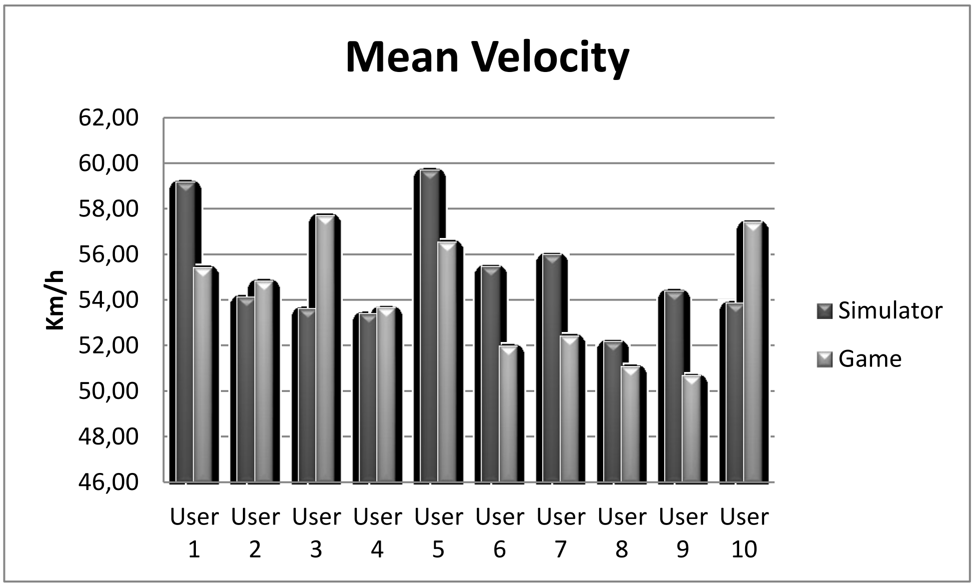


Figure 23: Mean velocity results, when only driving, in the high fidelity simulator and the serious game.

Figure 24 presents the standard deviation of velocity results. With exception to User 5, all subjects had greater standard deviation in the simulator than in the game. The average was 7.47 Km/h and 4.04 Km/h for the simulator and the serious game, respectively.

Therefore, in average, subjects had a better control over the vehicle longitudinal position in the game than in the simulator. These results can be an indicator that further calibration needs to be performed in the game's acceleration and deceleration dynamics.

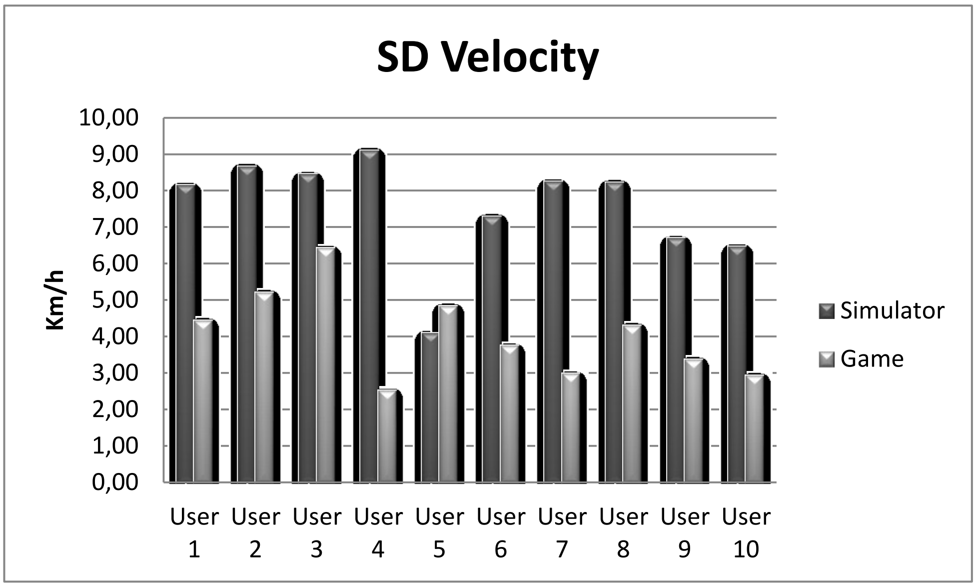


Figure 24: Standard deviation of velocity results, when only driving, in the high fidelity simulator and the serious game.

4.1.2 Lateral Control

The results presented in Figure 25 presents the mean distance chosen by the subjects to position their vehicle in the lane. Considering the results, in average, all subjects positioned themselves further away from the right side of the lane in the game (average: 1.86 m) than in the simulator (average: 1.28 m).

These results indicate that there is a different perception from the vehicle lateral position in both tools. Assuming the subjects tend to position themselves in their lateral comfort zone under same conditions, which implies that there is significant differences in the environment perception.

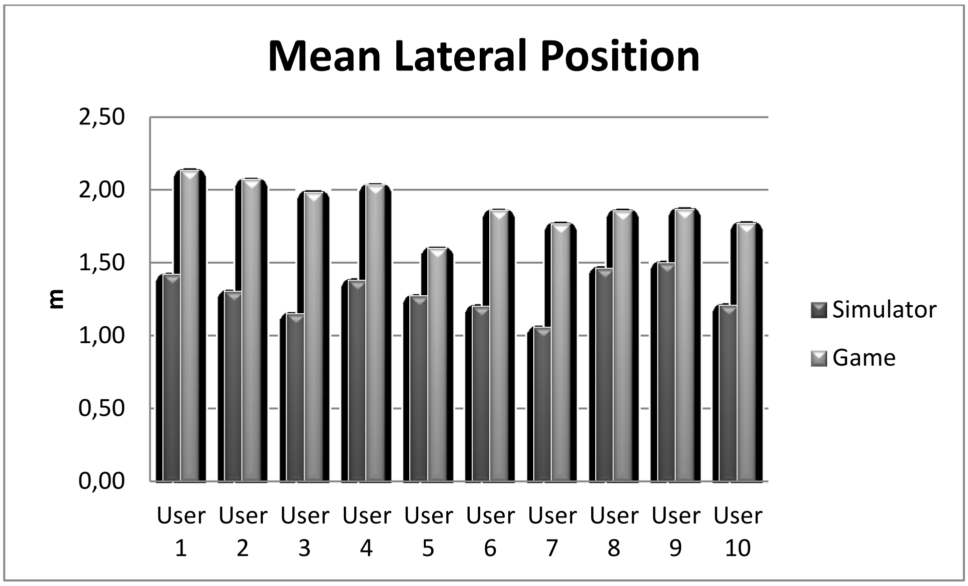


Figure 25: Mean lateral position results, when only driving, in the high fidelity simulator and the serious game.

The results from the standard deviation of lateral position, in Figure 26, show that in average the lateral position suffer higher variations in the serious game than in the simulator. Specifically, the means were 0.39 m in the game whereas 0.19 m in the simulator.

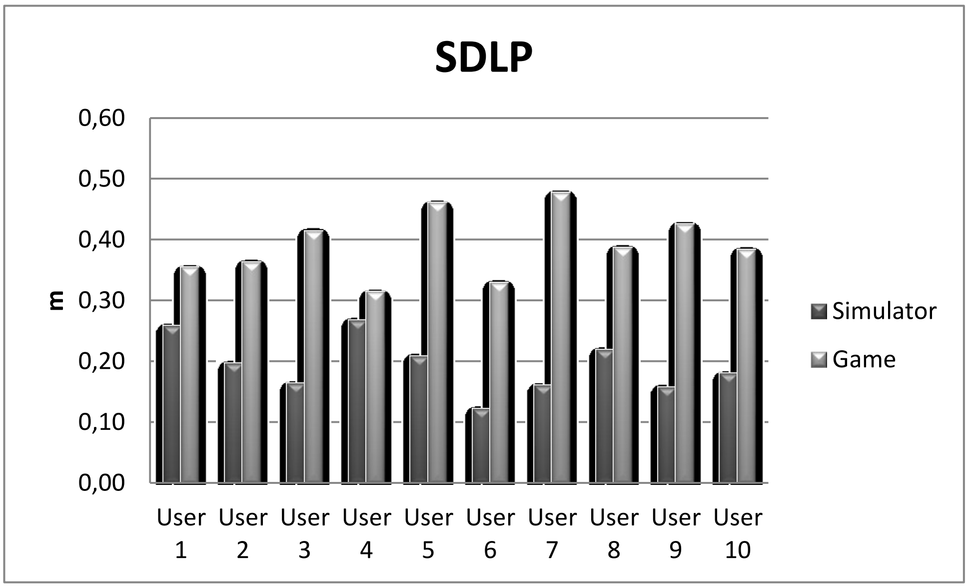


Figure 26: Standard deviation of lateral position results, when only driving, in the high fidelity simulator and the serious game.

4.1.3 Summary of evaluation

A summary of the data obtained from the serious game and the fixed simulator is provided in Table 1.

Table 1: Descriptive statistics from the data captured without performing secondary tasks.

	Simulator				Game			
Metric	Min	Max	Average	SD	Min	Max	Average	SD
Mean Velocity (Km/h)	52,14	59,68	54,73	2,04	50,6	57,6	54,01	2,56
SD Velocity (Km/h)	4,09	9,11	7,47	1,46	2,52	6,42	4,04	1,20
Lateral Position (m)	1,05	1,50	1,28	0,14	1,59	2,07	1,86	0,14
SDLP (m)	0,12	0,27	0,19	0,04	0,31	0,48	0,39	0,05

A t-Test was conducted to investigate the existence of statistical difference between the mean velocity data from the simulator and the game. The two-tail test accepts the null hypothesis, meaning there is no significant difference between mean velocity data from simulator and the game (Appendix A). This allows concluding that the serious game is a reliable tool for capturing the mean velocity people tend to use.

Concerning the SD Velocity, the two tailed test null hypothesis was rejected (Appendix B). This means that there is a significant statistical difference between the game's data and simulator's data; in this case the simulator SD Velocity data is higher.

Serious game's longitudinal control results can be considered mixed. On the one hand the mean velocity turns out to be a reliable metric, which is very important to understand the driving behaviour and is a widely used metric. On the other hand, the standard deviation for velocity results were lower than the simulator meaning further calibration in the vehicle's dynamic and pedals feedback needed to be conducted.

Mean lateral position results show a significant difference between the simulator and the serious game (Appendix C), but they must be carefully interpreted due to the tool's different scales and realism. Albeit using the same metric unities for building the map, there is no actual correspondence in the real setups. For example, drivers have a different perception from a 3.5 m lane width in the game's screen and the same "size" lane in the high fidelity simulator due to the different screen size and objects scale. Other relevant factor that influences is the subject's viewport differences. Game's screen has a reduced field of vision due to the flat screen, thus only focusing the vision on the direction in front of the subject. Whereas in the simulator's 180º front views, there is a more realistic perception of the vehicle position in the lane.

Standard deviation of lateral position still needs improvements since there is a significant difference between the platforms (Appendix D). There are two main factors contribute to these results: the steering wheel hardware and the steer calibration. The steer used in the game has less realism than an actual steer equipped in real cars, particularly in terms of feedback. The steering wheel used for the game showed a very sensitive behaviour for small angles (considering the steer is centred) while in higher angles it was necessary to induce more force to rotate the steering wheel further. The simulator's steering wheel had a more linear behaviour, meaning that it was always necessary to apply a reasonable force to move the steering wheel.

Overall the results seem very promising. In the longitudinal control, the game is able to capture the drivers' desired velocity which is a very important metric to understand the driving behaviour. The standard deviation of velocity is a less used metric but still can be used in terms of longitudinal control errors detection or driving performance evaluation. From the results obtained, an increment of the acceleration coefficients should help approximate the results. As for the lateral control metrics, the mean lateral position is unlikely to improve significantly the results by the reasons already mentioned and as documented in other works (see section 2.2.2.2). Since data showed that game's SDLP tend to be higher than in the simulator, the rotation factors should be adjusted to reduce the rotation. Furthermore, if possible the force feedback from the steering wheel should be incremented.

4.2 Secondary task performance

This section presents the results of subject's task performance. During the experiments, users had to perform secondary tasks while driving which would force a shared attention division by the driver. As showed in section 2.1.4 this dual-task situations can affect driving performance thus this work proposed to study two tasks in which we expected IVIS users to perform on a high frequency basis.

During the experiments all subjects completed the tasks. Only the voice for the reading task and the keys pressed for the menu navigation were recorded, and there was no significant mistakes in performing such tasks.

4.2.1 Email reading task

As detailed in section 3.2.3 the email reading task difficulty was modelled by increasing the number of characters in the message content. Therefore, the easier levels have the lower number of characters and the harder levels the higher.

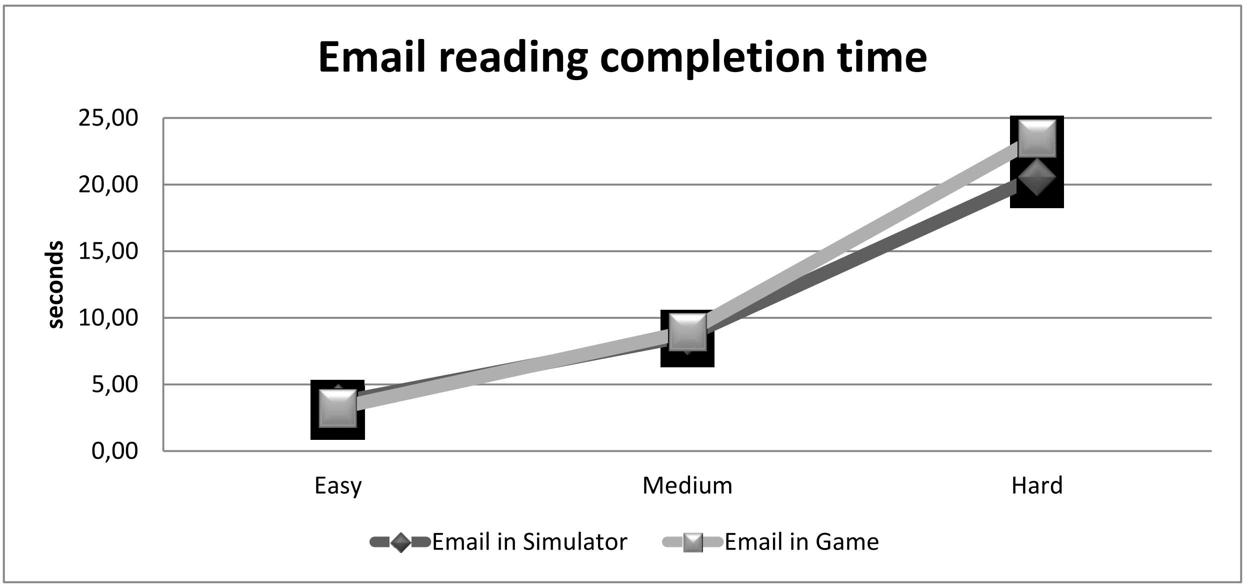


Figure 27: Reading email completion time with increasing difficulty.

It was used similar prototypes in the serious game and in the simulator. The email reading screen appeared on a device in the bottom-centre of the vehicle interior whereas in the simulator it appeared in the top-centre.

Figure 27 presents the mean completion times as the difficulty increases, whereas complete results are available in Appendix E. As expected, the completion time scales with the length of the message, ranging from averages 3.42 seconds for shorter emails to 22.04 seconds in larger ones.

Results show that there was no significant difference between completing the reading task in the simulator prototype and in the game prototype (Appendix G).

4.2.2 Menu navigation task

Menu navigation using a hard device is a very common task drivers do while driving (e.g. tuning the radio). Using a menu structure based on hierarchical structure, the increasing levels of difficulty results from the number of hierarchy levels the users must navigate in order to reach the desired option as defined in section 3.2.3.2.

As in the email task, the prototypes were displayed in the centre-top, and centre-bottom of the vehicle interior, for the simulator and game respectively. Concerning the manual input, in the simulator the number pad was placed near the hand break while in the game it was near the steering wheel. In both cases the subject could adjust its position freely.

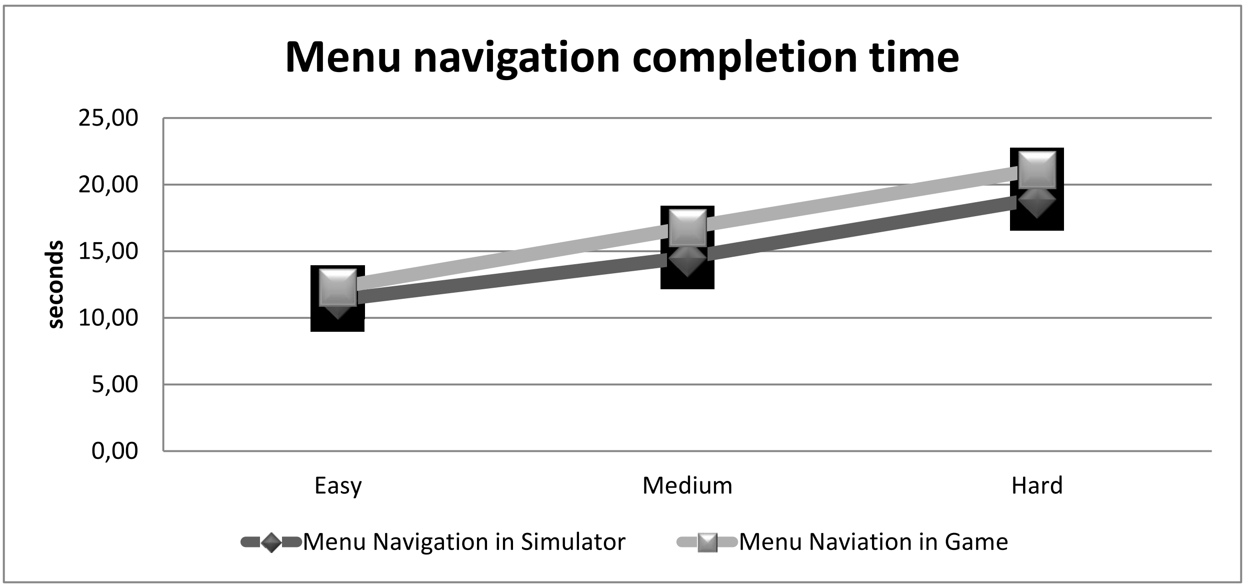


Figure 28: Menu navigation completion time with increasing difficulty.

A representation of the average completion time for each level of difficulty in the simulator and in the game is depicted in Figure 28. All data are available in Appendix F whose results confirm that completion time increases with difficulty level. In average, the subject take 11.81 seconds to reach the desired option under 1 level in the hierarchy whereas 20.01 seconds when selection is under 3 levels in the hierarchy.

The t-Test performed in Appendix H proves there is no significant statistical difference between the simulator and the game.

4.3 Driving Performance while performing secondary task

4.3.1 Email reading task

In this case study, the impact of email navigation is evaluated. Furthermore, the results from a same experiment are conducted using the serious game in order to access the use of this tool for evaluating the usability.

4.3.1.1 Longitudinal Control

Figure 29 shows the results from mean velocity in the email reading investigation. It is clear that while reading the email, subjects slightly reduce their velocity to cope with the dual task situation. The mean velocity had a slight reduction in all cases, ranging from -7.02% to -3.46%; for the current conditions (urban environment), the mean velocity results have a consistent decrement but are not affected linearly with the message size.

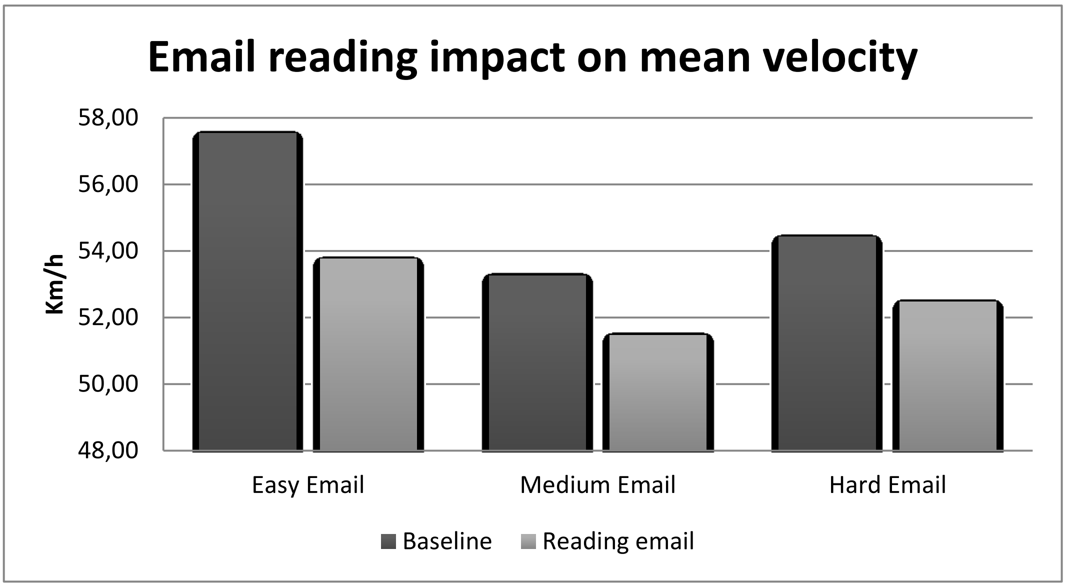


Figure 29: Email reading impact on mean velocity. Results from the high fidelity simulator.

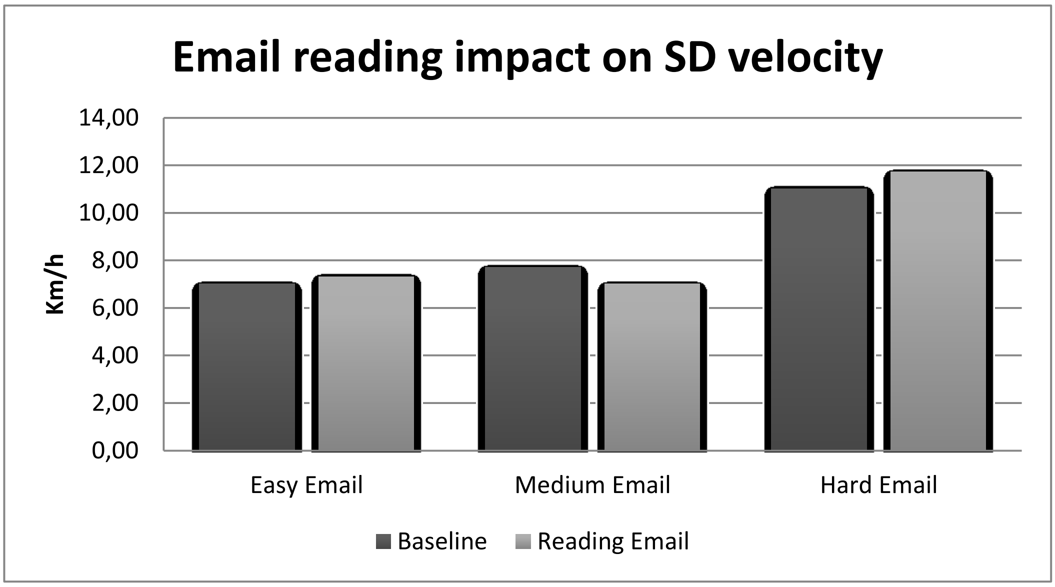


Figure 30: Email reading impact on standard deviation of velocity. Results from the high fidelity simulator.

In terms of the speed variation, in average all subjects maintained the same behaviour while reading an email. The results obtained show the standard deviation of velocity increased in the easy and hard email, whereas it decreased for the medium case. The results are interpreted as the reading task does not affect this metric, as Figure 30 shows.

Table 2 shows a comparison between the game and the simulator in terms of reading tasks affecting the subjects' longitudinal control. Correlation matrices are available in Appendix K, and from a qualitative analysis it is possible rely on the game to reach conclusions in the mean velocity metric. For instance, if there was no simulator available, with the data from the game we conclude that email reading interference on mean velocity value was in average a decrement of 6.30% (-3.40% in the simulator), thus suggesting that people tend to reduce their velocity. In terms of quantitative analysis, the correlations show that easy email (0.67) and medium (0.50) performed well were verified, but in the hard email the results were disappointing (-0.15); although this correlation results, there is no significant difference between the average mean velocity of both platforms.

Table 2: Summary of longitudinal control evolution as subjects read email. Comparison on both platforms' sensibility.

Level	**Simulator**		**Game**	
Metric	Mean velocity (%)	SD Velocity (%)	Mean velocity (%)	SD Velocity (%)
Easy	-7,02	4,24	-5,19	6,44
Medium	-3,46	-9,93	-4,15	7,73
Hard	-3,71	6,09	-9,58	8,15

4.3.1.2 Lateral Control

Concerning the mean lateral position, results show no evidence it is affected by the reading email task (Figure 31). The relative differences are low and have mixed signals: easer emails made vehicles position more to left whereas in the other cases more to right.

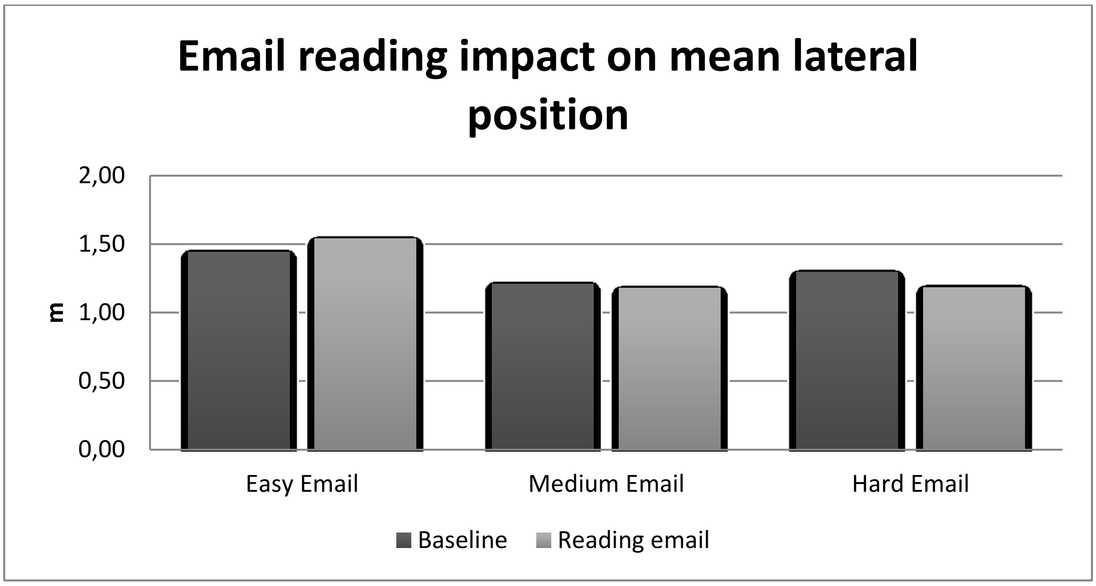


Figure 31: Email reading impact on mean lateral position. Results from the high fidelity simulator.

SDLP appears as a good indicator for measuring the distraction reading induces on driving. Figure 32 results show that in average all levels of difficulty made the lateral position variation increase, especially in the hard email. Like in the longitudinal control, there is no correlation between the size of the message and the impact on the mean lateral position variation since, as presented in Table 3, the values tended to be constant (18.39% to 25.16% increments).

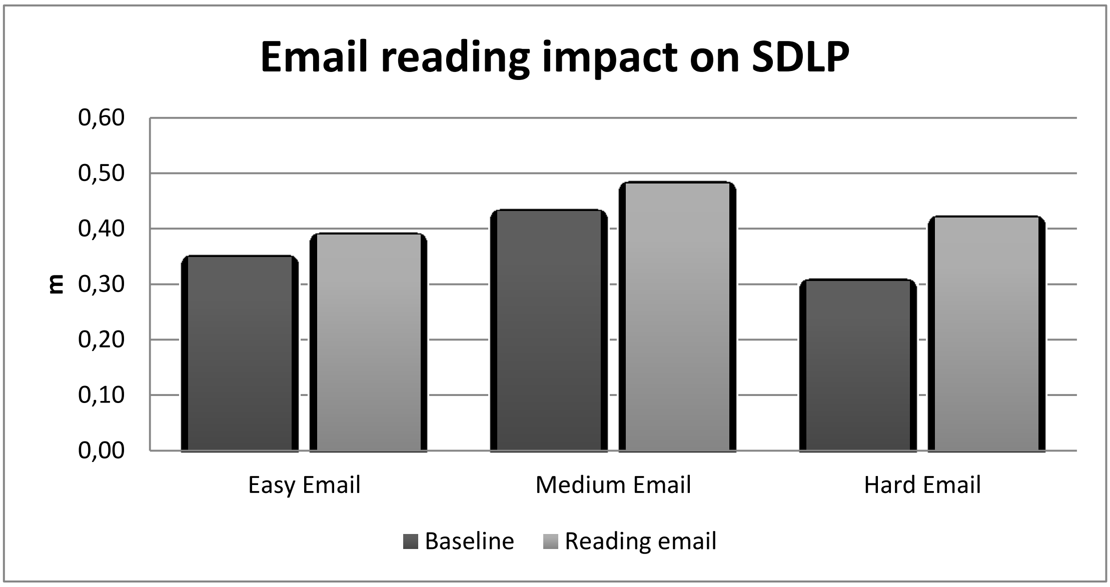


Figure 32: Email reading impact on standard deviation of lateral position. Results from the high fidelity simulator.

The comparison between the game and the simulator results show that, as expected due to the deficient calibration, the mean lateral position metric had mixed behaviour in both platforms. Despite not being correctly calibrated, SDLP turned out to be quite reliable in terms of qualitative analyses since in all cases it increases significantly. For easy and medium emails the game had a considerable less sensibility values, but for the hard level it performed very close to the real simulator. Thus, despite the calibration restrictions, it is possible to rely on this metric to understand the tendency effect the interaction plays on lateral control.

Table 3: Summary of lateral control evolution as subjects read email. Comparison on both platforms' sensibility.

Level	**Simulator**		**Game**	
Metrics	Mean LP (%)	SDLP (%)	Mean LP (%)	SDLP (%)
Easy	6,32	18,39	-0,88	10,43
Medium	-2,23	25,16	-1,83	10,37
Hard	-9,27	23,36	-4,91	27,17

4.3.2 Menu navigation task

Menu navigation is a very basic task performed by IVIS' users. Similarly to the email reading task, a case study was conducted to investigate the impact this task has on longitudinal and lateral control using a high-fidelity simulator. Then the results are compared with the same procedure but using the developed serious game.

4.3.2.1 Longitudinal Control

It was observed a reduction of the mean velocity while performing the menu navigation task, as Figure 33 depicts. This effect results from the cognitive overload and distraction induced by the secondary task which forces subjects to reduce their velocity to cope with the workload.

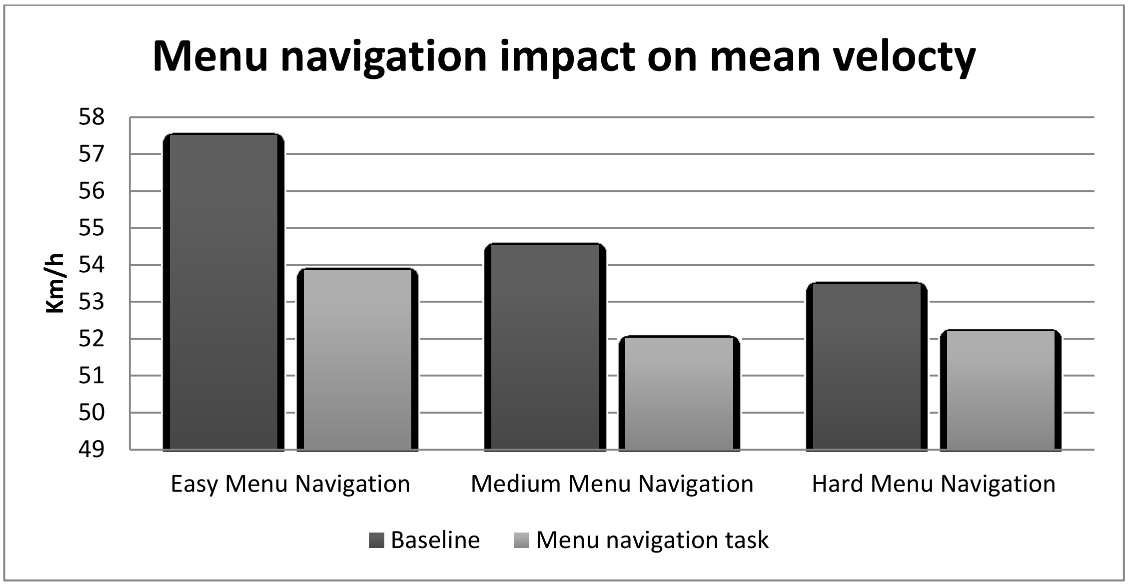


Figure 33: Menu navigation impact on mean velocity. Results from the high fidelity simulator.

Concerning the standard deviation of velocity results presented in Figure 34, in average this metric increased for all menu navigation tasks. This performance deterioration is caused by the distraction of interacting with the menu, thus making subjects fail to properly maintain their velocity.

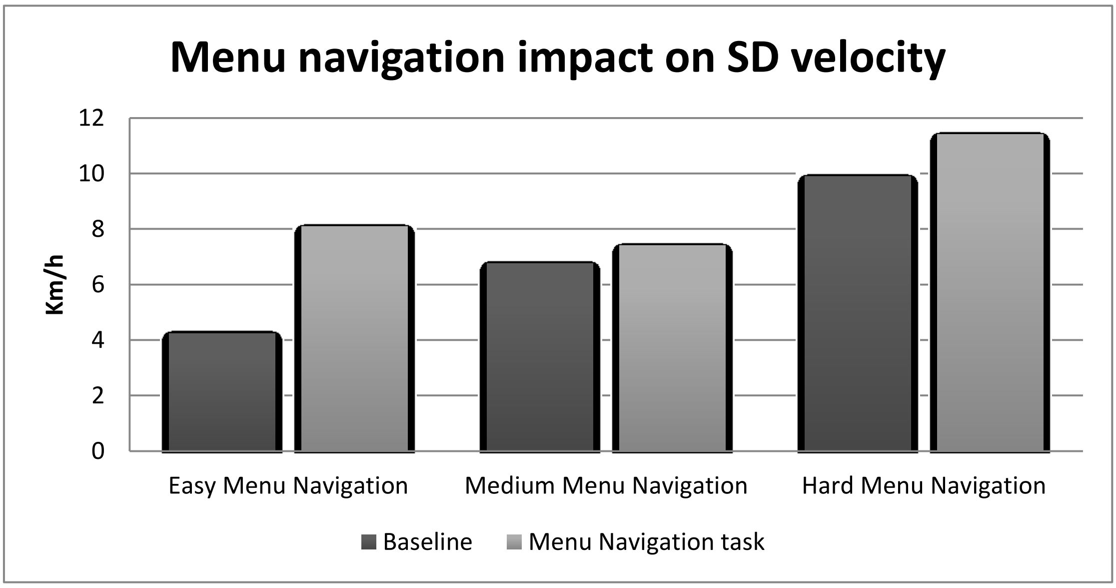


Figure 34: Menu navigation impact on standard deviation of velocity. Results from the high fidelity simulator.

Table 4 presents the relative longitudinal control comparison between the game and the simulator results. Overall, results show longitudinal control is very affected by this task. As expected, the game correctly captured the mean velocity decrement and there is no significant difference between the mean values as results show in Appendix M.

Considering the standard deviation of velocity both platforms behave similarly; the highest differences are found for the easy menu navigation and the lowest to the medium menu navigation. Despite the significant mean differences (Appendix M) it would be possible to predict the metric increase trend using the game.

Table 4: Summary of longitudinal control evolution as subjects navigate through menus. Comparison on both platforms' sensibility.

Level	Simulator		Game	
Metrics	Mean velocity (%)	SD velocity (%)	Mean velocity (%)	SD Velocity (%)
Easy	-6,78	47,56	-4,81	34,71
Medium	-4,84	8,75	-2,88	11,34
Hard	-2,45	13,25	-6,23	20,31

4.3.2.2 Lateral Control

The mean lateral position metric did not receive a significant impact from the menu navigation as Figure 35. The results were mixed but with low differences, ranging from 5.61% to -1.90%, illustrated in Table 5.

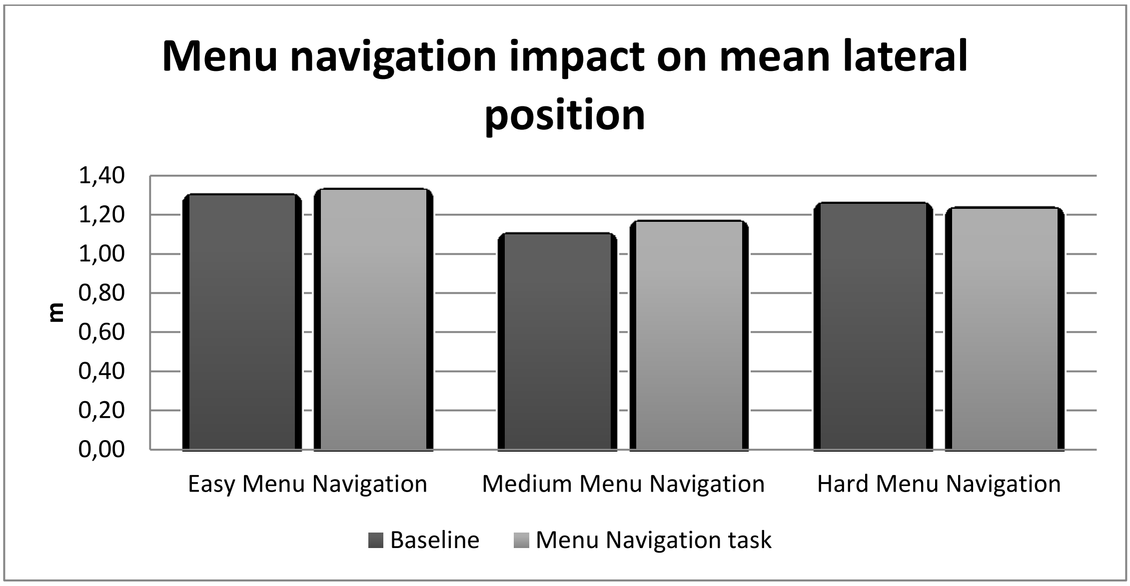


Figure 35: Menu navigation impact on mean lateral position. Results from the high fidelity simulator.

Similarly to the email reading task, SDLP revealed a good indicator of task interference. In all menu navigation tasks, in average, there was a significant increase of this metric. This represents performance degradation due to such a high lateral position variation and caused by the subject’s distraction.

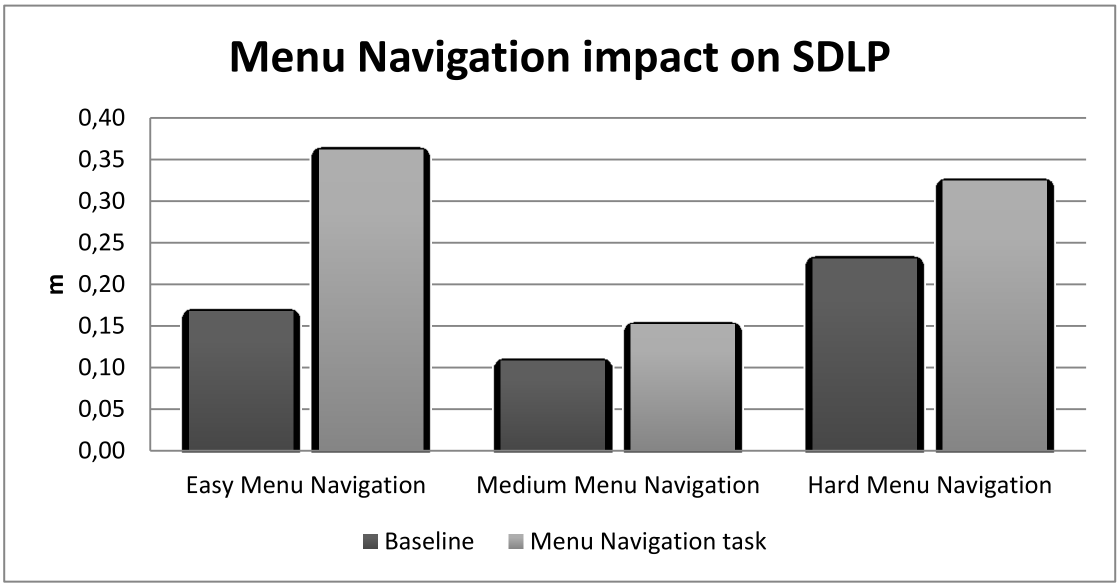


Figure 36: Menu navigation impact on standard deviation of lateral position. Results from the high fidelity simulator.

Results presented in Table 5 show the comparison of using the simulator and the game to perform the same lateral control study. There is a significant difference between the mean lateral position in the game and in the simulator. This can be explained by the need for more calibration and the inherent restrictions of the game setup. In the concerning SDLP, the game correctly captured the metric trend, especially in the medium and hard navigation tasks; overall, the game can be used to predict the SDLP impact the game showed less sensibility to interference, especially in the easy level.

Table 5: Summary of lateral control evolution as subjects navigate through menus. Comparison on both platforms' sensibility.

Level	**Simulator**		**Game**	
Metrics	Mean LP (%)	SDLP (%)	Mean LP (%)	SDLP (%)
Easy	1,94	53,63	9,98	17,77
Medium	5,61	28,72	4,30	26,73
Hard	-1,90	28,80	3,00	26,53

4.4 Behaviour influence

In this case study, serious games' influence characteristics are assessed. While in [50] the study focus was on how the feedback changed the in-game behaviour, this experiment uses the same game idea but also investigates whether subjects change their driving behaviour outside the game.

For a detailed setup of the experiment see section 3.2.4.

4.4.1 Longitudinal Control

It was noticed in the previous experiment (Driving performance without performing secondary task), that subjects tended not to properly control their velocity in both platforms. As expected, the mean velocity before the training period has an average of 55.74 Km/h (54.73 Km/h in previous experiment). This behaviour represents a good opportunity for the serious game's influence characteristics to positively influence the subject's behaviour.

After training, all subjects decreased their mean velocity. The average mean velocity lowered to 46.69 Km/h which represents an average reduction of 19.40%. Furthermore, only 1 out of 5 participants continued with the mean velocity above 50 Km/h as results show in Appendix I.

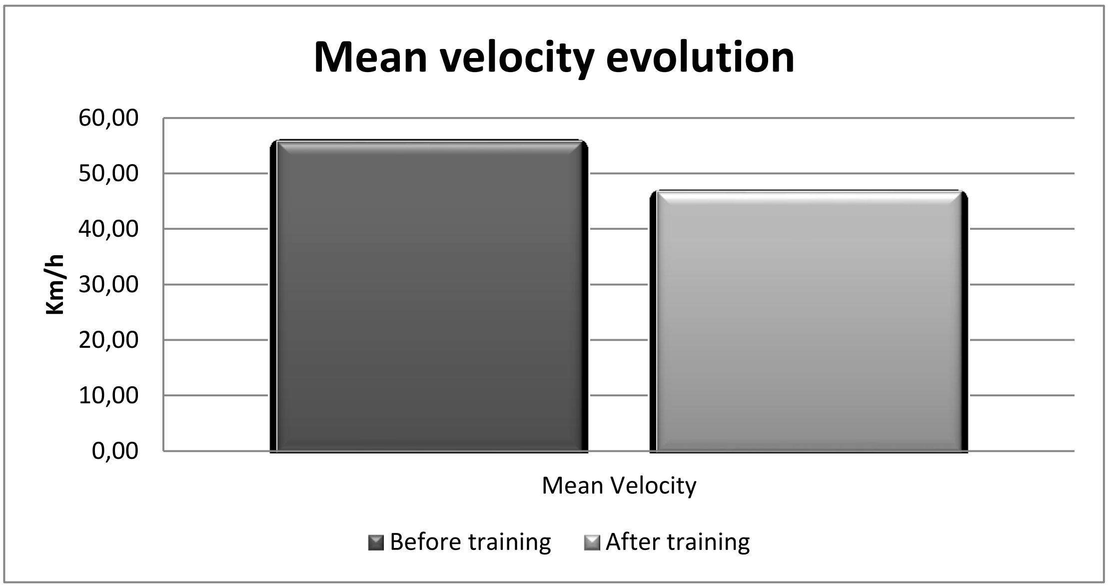


Figure 37: Average evolution of mean velocity.

SDLP before training had similar results to the previous experiment, with 8.87 Km/h and 7.47Km/h for this experiment and the previous one, respectively. As consequence of the training period with the game, it was registered a significant reduction to an average of 3.78 Km/h which represents an evolution of -134.80%. All results are available in Appendix I.

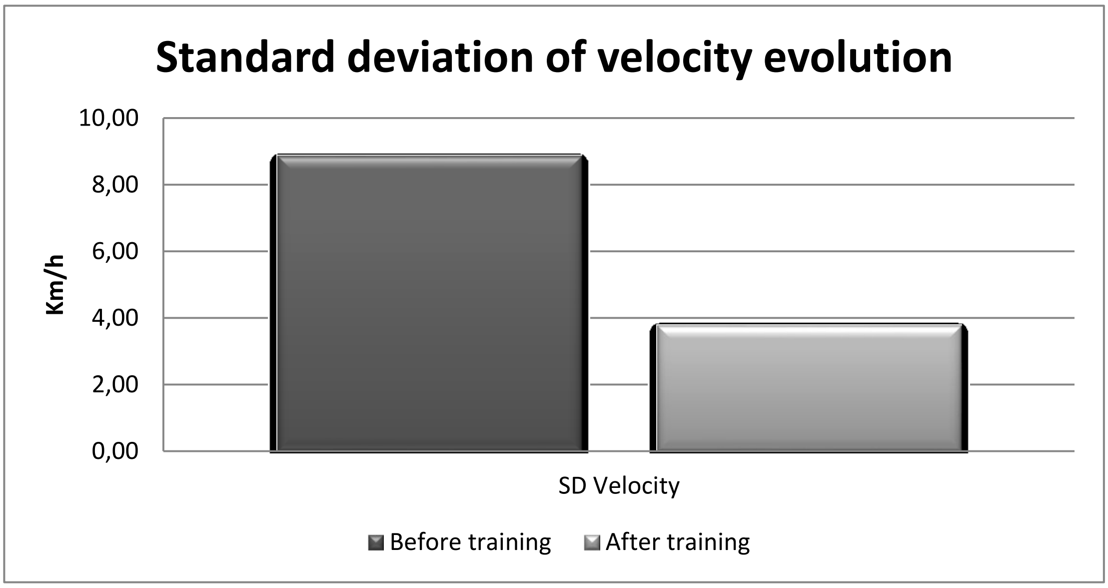


Figure 38: Average evolution of standard deviation of velocity.

4.4.2 Lateral Control

Concerning the mean lateral position, the average was 1.30 m before training which is similar to 1.28m from the previous experiment. After being exposed to the game, results show participants tended to get closer to the right side of the lane, with a lower average of 1.15 m distance to the right side of the lane. This represents a reduction of the distance in 13%.

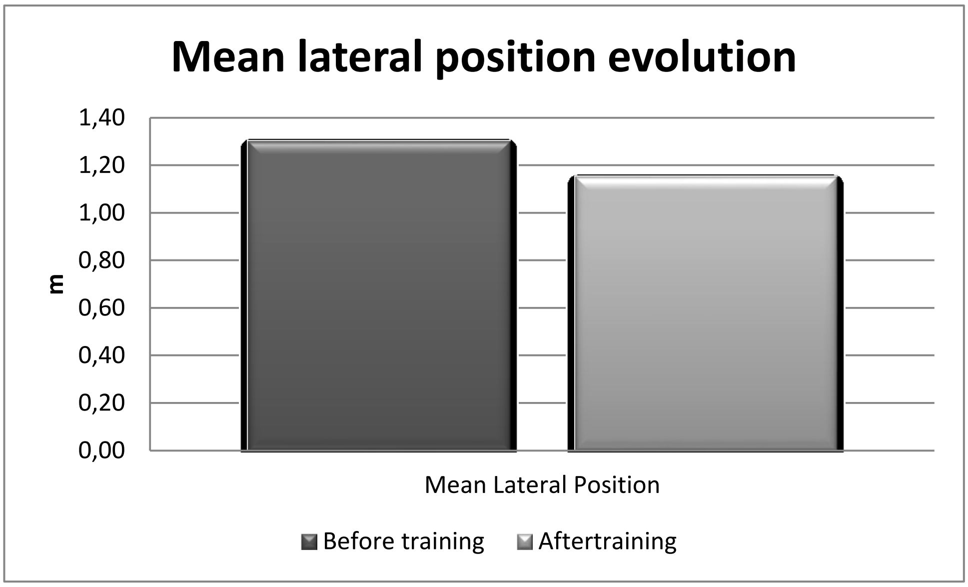


Figure 39: Average evolution of mean lateral position.

Standard deviation of lateral position results with the 5 samples scoring an average of 0.17 m, hence very similar to 0.19 m from the previous experiment. The final SDLP average results scored a 0.18 m, representing an increment of 4.42%.

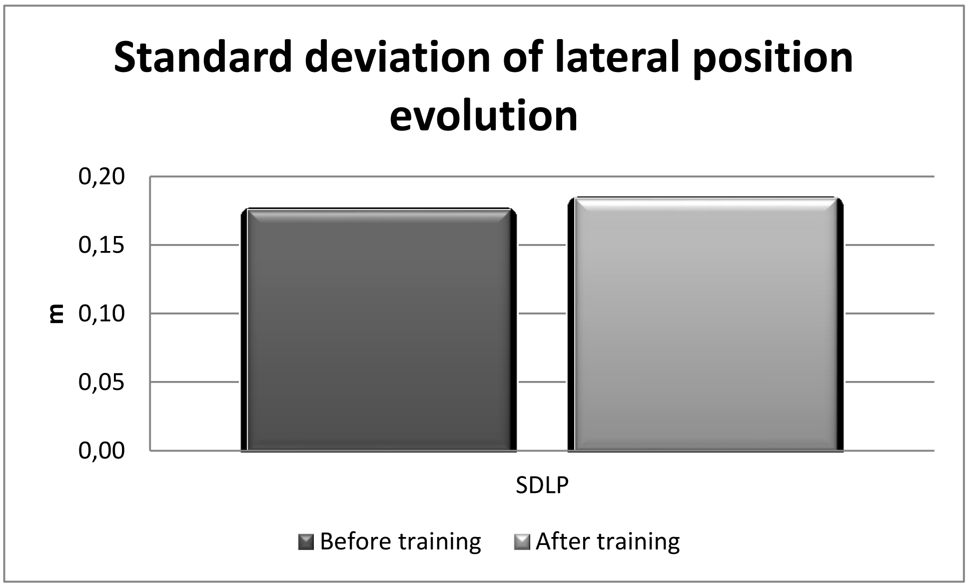


Figure 40: Average evolution of standard deviation of lateral position.

4.4.3 Summary of evaluation

Overall the results from the experiment were quite successful, despite the reduced number of subjects (n=5). As presented in Table 6, the majority of the metrics considered had a positive evolution as consequence of the game's feedback.

The longitudinal feedback had very promising results, in both mean velocity and standard deviation of velocity. In the mean velocity metric the feedback successfully influenced lower velocity values to a desirable range. Thus, drivers had an adequate driving behaviour with the help of the game. The standard deviation of velocity had higher absolute influence by the training with a difference of 134.80% (in this specific case a decrement). Therefore the feedback provided by the game proved to be very effective improving driver's longitudinal control in a real situation.

Results in the lateral control were less expressive and mixed. Mean lateral position decreased 13%, which does not necessarily mean a better lateral control. During the experiments no "potential dangerous" lateral position was observed therefore a slightly closer displacement to the right side of the lane does not necessarily mean a better driving performance.

The standard deviation of lateral position in average increased slightly by 4.42%. The evolution ranged from User 2 with -14.98% to User 4 with 23,89%. It is not likely the feedback could influence an increase in the SDLP. Due to the low increase value, a bigger sample is needed to determine if this increase was situational or it was actually influenced by the game.

Table 6: Behaviour influence after 3 days training period for a sample of 5 subjects.

Metric	Before training	After training		Evolution
Mean Velocity (Km/h)	55,74	46,69		-19,40%
SD Velocity (Km/h)	8,87	3,78		-134,80%
Mean Lateral Position (m)	1,30	1,15		-13,00%
SDLP (m)	0,18	0,18		4,42%

Chapter 5

Conclusions

5.1 Final remarks

Current IVIS assessment tools are based in very expensive high fidelity simulators which are hard to purchase and have an expensive maintenance. Furthermore, testing with IVIS development requires many subjects which usually are paid. Current approaches do not encourage developers to perform several iterations with users, in order to refine the product, due to the process high cost.

The preliminary results show that low cost serious games may be reliable tools for assessing IVIS ergonomics. Specifically, during the dual-task scenario, the impact of the secondary task had an absolute validity, either reading an e-mail or navigating through the menu. The most important measures, mean velocity and SDLP, had good scores while SD velocity and mean lateral position had a relative validity. These results align with the achievements from works presented in subsection 2.2.2.2. Hence, low-cost serious games distinguish themselves from high/low-cost simulators due to their low-cost solution, easy deployment, no restriction of schedule or experiment place, and uses entertainment as motivation to participate.

From a perspective of driving only, results show a similar longitudinal control. However, lateral control had bad performance. Two main restrictions contributed to this: calibration and low cost setup. Thus, more calibrations iterations would improve results significantly, but restrictions like inexistence of 180º viewport is very likely to never be solved with current low-cost hardware.

Email reading task while driving showed a significant reduction of the mean velocity indicator. In terms of lateral control, SDLP demonstrated to be very sensitive to the secondary task performance.

Concerning the menu navigation task, results show that longitudinal control suffers a greater impact. While mean velocity decreased to cope with task difficulty, SD velocity increased. This can be interpreted as worst driving. Once again SDLP provided an excellent indicator of performing a secondary task.

Results from driver behaviour allowed to confirm the existence of driving behaviour influence induced by playing the serious game. Using the serious game as a influence tool, participants were submitted to a three day training with the game. Data recording before and after the training was taken in a high fidelity simulator to represent real life. The preliminary results confirm the behaviour influence, especially in the longitudinal control SD velocity metric.

5.2 Further Developments

Albeit the encouraging results, further developments should be done in order to accomplish the desired vision of this work.

5.2.1 Calibration

For a preliminary calibration, subjects already familiarized with the high fidelity simulator took a subjective questionnaire. The aim was to calibrate the coefficient variables associated with both steer and pedal thrust of the game.

Further calibration is needed to strength the game's validity. However, this calibration process should now be based on driving performance results elicited from experiments. All metrics with an absolute validity score is highly unlike to happen, nevertheless a reasonable number of iterations could be performed until the number of samples is big and the relative validities are acceptable by researchers.

5.2.2 Platform enhancement

Overall the development objectives for the platform were achieve. Still, technical issues in the game's deployment and data dissemination need to be corrected for future experiments. Specifically, we need to develop an installer to handle the installation of the game in the remote devices, and support high volume data reception at the server over an reasonable amount of time.

5.3 Future Work

5.3.1 Driver Behaviour

The driving performance saved from each driver *per se* is not sufficient to be used for studding driver behaviour. Effort must be made to extract driving performance patterns and classify them. Such information would allow a better understanding of driver behaviour models, help validate microscopic and macroscopic traffic simulators and provide valuable data to other intelligent transportation system research topics.

Another interesting view of driver behaviour introduced by this work is the ability to influence the driver in the real world by playing the game. This new dimension should be explored, since it can help compensate problematic driving behaviour in a safe and enjoyable way to the driver.

5.3.2 Tailoring IVIS design

With the basic platform ready to be used, new perspectives may be explored in the IVIS development process. The platform is able to be easily deployed by the Internet which represents a worldwide medium for conducting data collection.

Existing differences between cultures could be better understood by introducing the IVIS in the game and request players to accomplish tasks with them while driving. Combining the subjective assessment with objective driving performance data, a better understanding of cultural expectations and IVIS design patterns would be expected to emerge. This would represent a scientific opportunity for HCI while providing valuable information to the industry.

5.3.3 Augmented Reality based ADAS & IVIS

In a future not far away, augmented reality technologies will be widely disseminated in the automotive industry. The ability to assist the driver and vehicle occupants by changing the visual perception and assisting in decision-making constitutes a very attractive path to explore by the industry.

From a more scientific perspective, presenting information with the environment perceived by the driver minimizes distraction by taking eyes off the road. However, such an approach can cause confusion or be ineffective if information is not properly presented and if it requires too much interaction from the driver.

Current serious game based tool provides an excellent start point for testing possible presentation patterns for this specific problem, since game tools allow a rapid prototyping for efficiently study different solutions.

Furthermore, since the game’s world is totally controlled by the programmer it allows to easily evaluate presentation algorithms under specific driving contexts. This would allow to study how drivers perceive the value of these technologies in the driving task and how effectively they support the driver.

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Appendix A

Driving without performing secondary task: mean velocity statistical tests

Table 7: Driving without performing secondary task. Mean velocity F-test.

F-Test Two-Sample for Variances

	Simulator Mean Velocity	*Game Mean Velocity*
Mean	55,17001349	54,15201712
Variance	6,147111555	6,751012465
Observations	10	10
df	9	9
F	0,910546616	
P(F<=f) one-tail	0,445634816	
F Critical one-tail	0,314574906	

Driving without performing secondary task: mean velocity statistical tests

Table 8: Driving without performing secondary task. Mean velocity t-test.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator Mean Velocity	*Game Mean Velocity*
Mean	55,17001349	54,15201712
Variance	6,147111555	6,751012465
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	0,896361008	
P(T<=t) one-tail	0,190945858	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,381891716	
t Critical two-tail	2,10092204	

Appendix B

Driving without performing secondary task: SD velocity statistical tests

Table 9: Driving without performing secondary task. Standard deviation of velocity F-test.

F-Test Two-Sample for Variances		
	Simulator SD Velocity	*Game SD Velocity*
Mean	7,539635054	4,076851349
Variance	2,190679819	1,452021238
Observations	10	10
df	9	9
F	1,50871059	
P(F<=f) one-tail	0,274925385	
F Critical one-tail	3,178893104	

Driving without performing secondary task: SD velocity statistical tests

Table 10: Driving without performing secondary task. Standard deviation of velocity t-test.

t-Test: Two-Sample Assuming Unequal Variances		
	Simulator SD Velocity	*Game SD Velocity*
Mean	7,539635054	4,076851349
Variance	2,190679819	1,452021238
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	5,737379791	
P(T<=t) one-tail	1,20842E-05	
t Critical one-tail	1,739606726	
P(T<=t) two-tail	2,41684E-05	
t Critical two-tail	2,109815578	

Appendix C

Driving without performing secondary task: mean lateral position statistical tests

Table 11: Driving without performing secondary task. Mean lateral position F-test.

F-Test Two-Sample for Variances		
	Simulator Lateral Position	*Game Lateral Position*
Mean	1,291392403	1,890496825
Variance	0,020876248	0,026563205
Observations	10	10
df	9	9
F	0,785908497	
P(F<=f) one-tail	0,362763825	
F Critical one-tail	0,314574906	

Driving without performing secondary task: mean lateral position statistical tests

Table 12: Driving without performing secondary task. Mean lateral position t-test.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator Lateral Position	*Game Lateral Position*
Mean	1,291392403	1,890496825
Variance	0,020876248	0,026563205
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-8,698266111	
P(T<=t) one-tail	3,64776E-08	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	7,29551E-08	
t Critical two-tail	2,10092204	

Appendix D

Driving without performing secondary task: SDLP statistical tests

Table 13: Driving without performing secondary task. Standard deviation of lateral position F-test.

F-Test Two-Sample for Variances		
	Simulator SDLP	*Game SDLP*
Mean	0,193161025	0,390745547
Variance	0,002136659	0,002874372
Observations	10	10
df	9	9
F	0,743348131	
P(F<=f) one-tail	0,332886486	
F Critical one-tail	0,314574906	

Driving without performing secondary task: SDLP statistical tests

Table 14: Driving without performing secondary task. Standard deviation of lateral position t-test.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator SDLP	*Game SDLP*
Mean	0,193161025	0,390745547
Variance	0,002136659	0,002874372
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-8,826517353	
P(T<=t) one-tail	2,93949E-08	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	5,87897E-08	
t Critical two-tail	2,10092204	

Appendix E

Email reading results

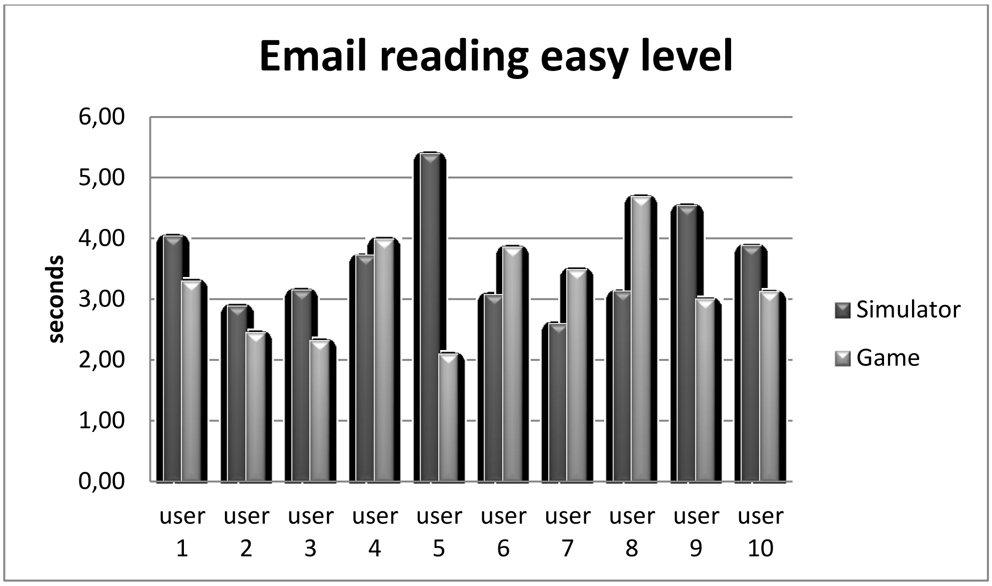

Figure 41: Email reading task completion time for easy level.

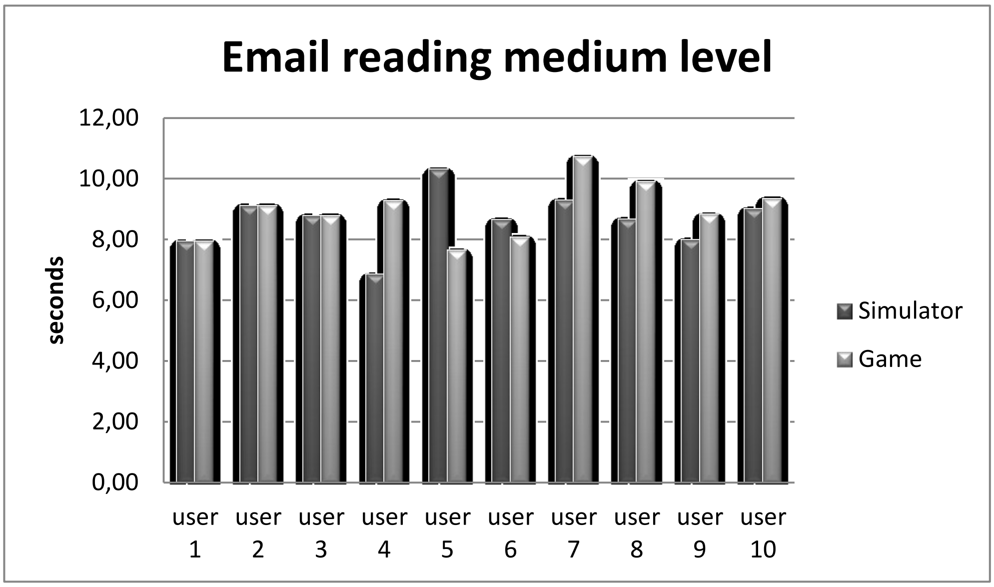

Figure 42: Email reading task completion time for medium level.

Email reading results

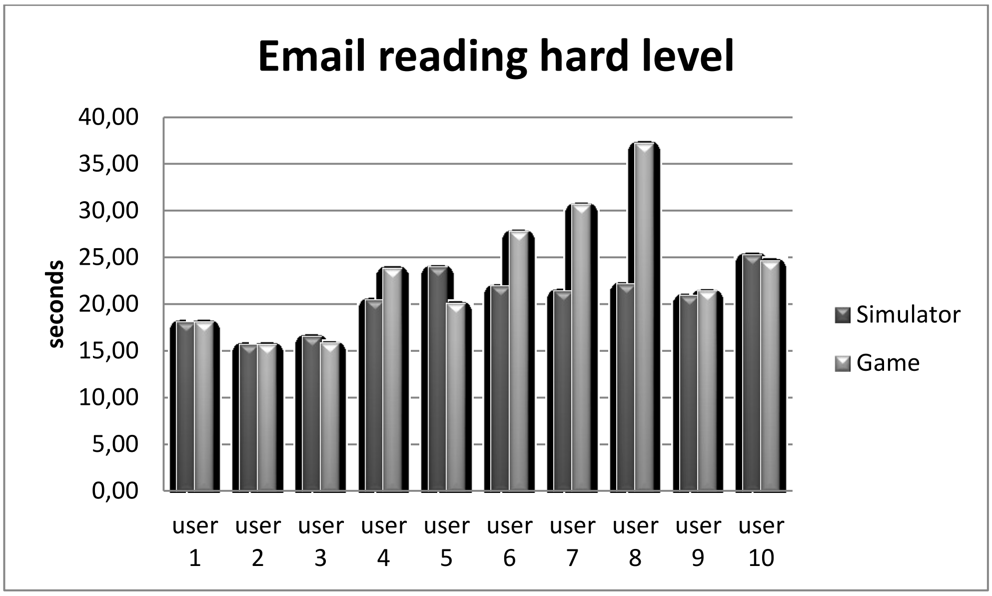

Figure 43: Email reading task completion time for hard level.

Appendix F

Menu navigation results

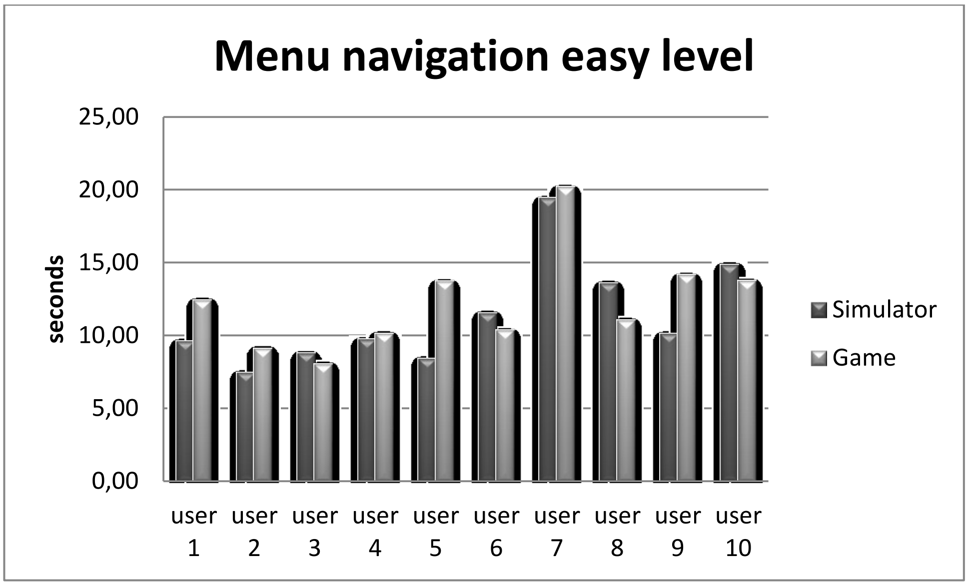

Figure 44: Menu navigation task completion time for easy level.

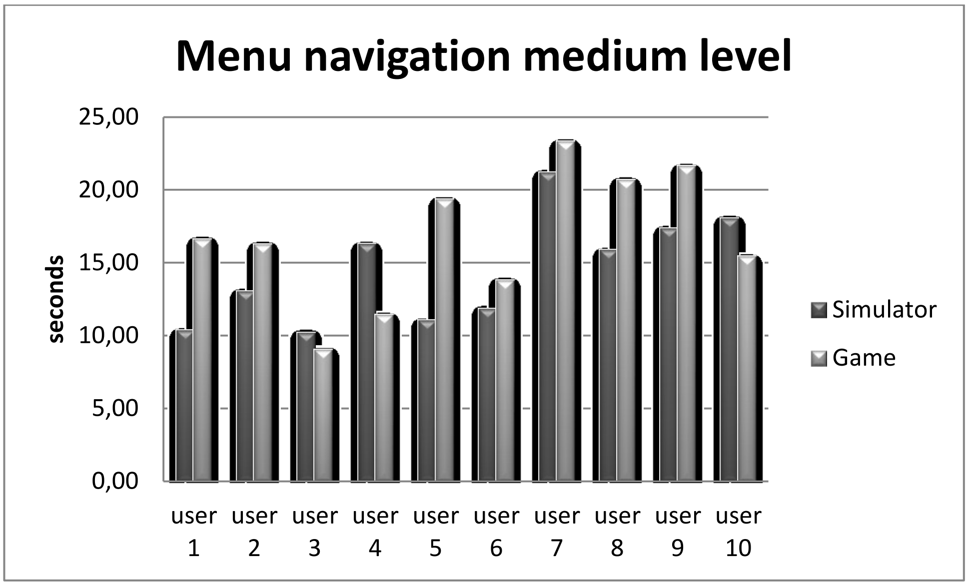

Figure 45: Menu navigation task completion time for medium level.

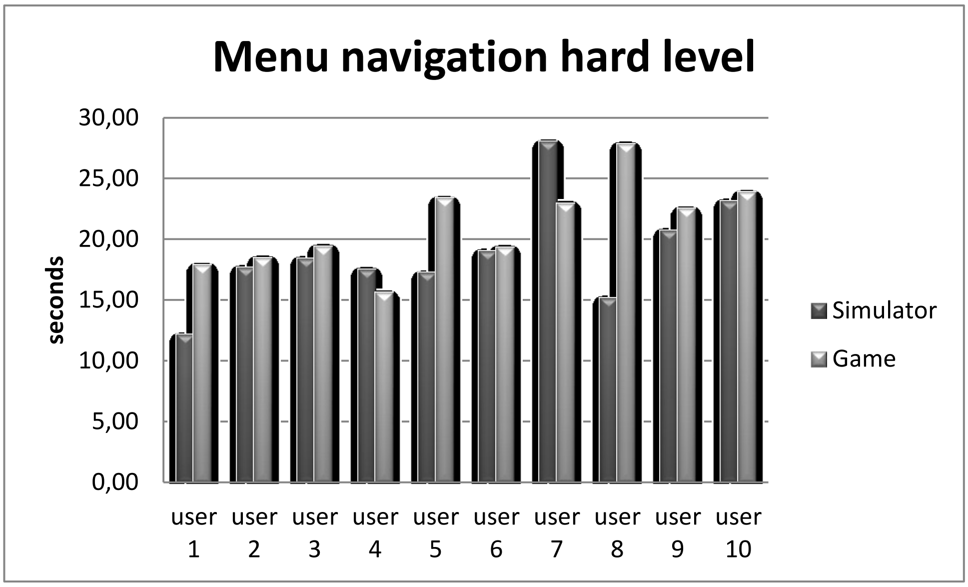

Figure 46: Menu navigation task completion time for hard level.

Appendix G

Email reading statistical tests

Table 15: Email reading task time completion from simulator and game. The t-Test for the easy level.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator email easy	*Game email easy*
Mean	3,633	3,222
Variance	0,732156667	0,661884444
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	1,100788873	
P(T<=t) one-tail	0,14274601	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,285492021	
t Critical two-tail	2,10092204	

Email reading statistical tests

Table 16: Email reading task time completion from simulator and game. The t-Test for the medium level.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator email medium	***Game email medium***
Mean	8,6473	8,9452059
Variance	0,857884011	0,873415091
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0,715967078	
P(T<=t) one-tail	0,241598704	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,483197408	
t Critical two-tail	2,10092204	

Email reading statistical tests

Table 17: Email reading task time completion from simulator and game. The t-Test for the hard level.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator email hard	***Game email hard***
Mean	20,60299	23,4786
Variance	9,384172512	47,0950456
Observations	10	10
Hypothesized Mean Difference	0	
df	12	
t Stat	-1,210000772	
P(T<=t) one-tail	0,124787569	
t Critical one-tail	1,782287556	
P(T<=t) two-tail	0,249575138	
t Critical two-tail	2,17881283	

Appendix H

Menu navigation statistical tests

Table 18: Menu navigation task time completion from simulator and game. The t-Test for the easy level.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator Navigation Easy	*Game Navigation easy*
Mean	11,3382	12,2772
Variance	13,39270529	12,05980129
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-0,58857297	
P(T<=t) one-tail	0,281730635	
t Critical one-tail	1,734063607	
P(T<=t) two-tail	0,563461269	
t Critical two-tail	2,10092204	

Table 19: Menu navigation task time completion from simulator and game. The t-Test for the medium level.

t-Test: Two-Sample Assuming Unequal Variances

	Simulator Navigation medium	Game Navigation medium
Mean	14,5273	16,7471
Variance	14,12355223	20,89948988
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-1,186142628	
P(T<=t) one-tail	0,12593992	
t Critical one-tail	1,739606726	
P(T<=t) two-tail	0,25187984	
t Critical two-tail	2,109815578	

Menu navigation statistical tests

Table 20: Menu navigation task time completion from simulator and game. The t-Test for the hard level.

t-Test: Two-Sample Assuming Unequal Variances		
	Simulator Navigation hard	*Game Navigation hard*
Mean	18,9108	21,1147
Variance	18,96115662	13,07243179
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-1,231371476	
P(T<=t) one-tail	0,117473748	
t Critical one-tail	1,739606726	
P(T<=t) two-tail	0,234947496	
t Critical two-tail	2,109815578	

Appendix I

Behaviour influence: Longitudinal control results

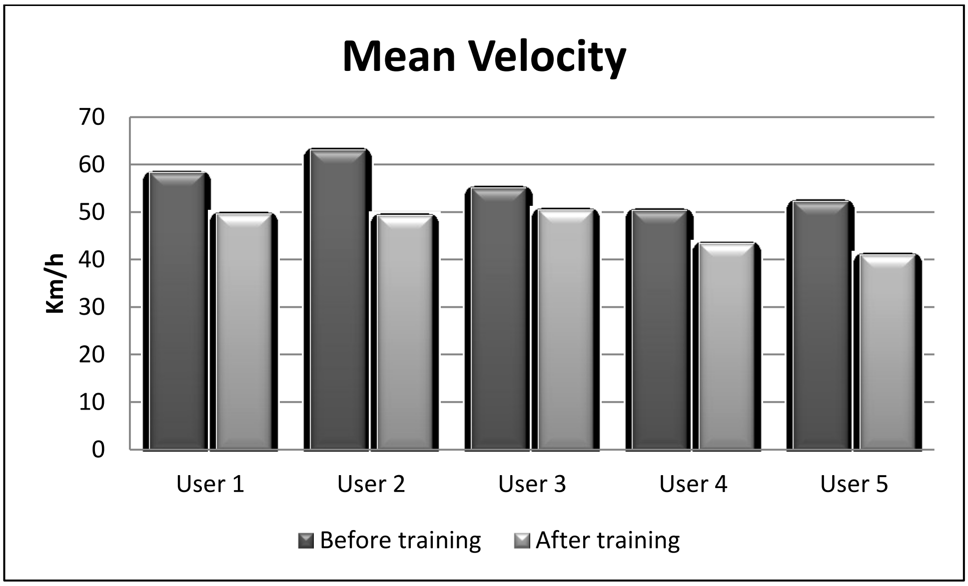

Figure 47: Behaviour influence over mean velocity.

Behaviour influence:

Longitudinal control results

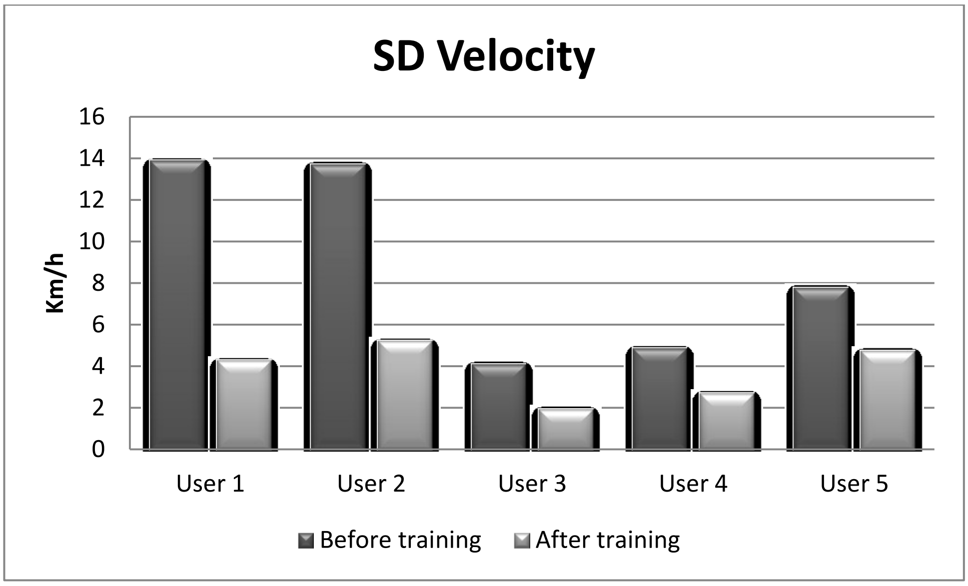

Figure 48: Behaviour influence over SD velocity.

Appendix J

Behaviour influence: Lateral control results

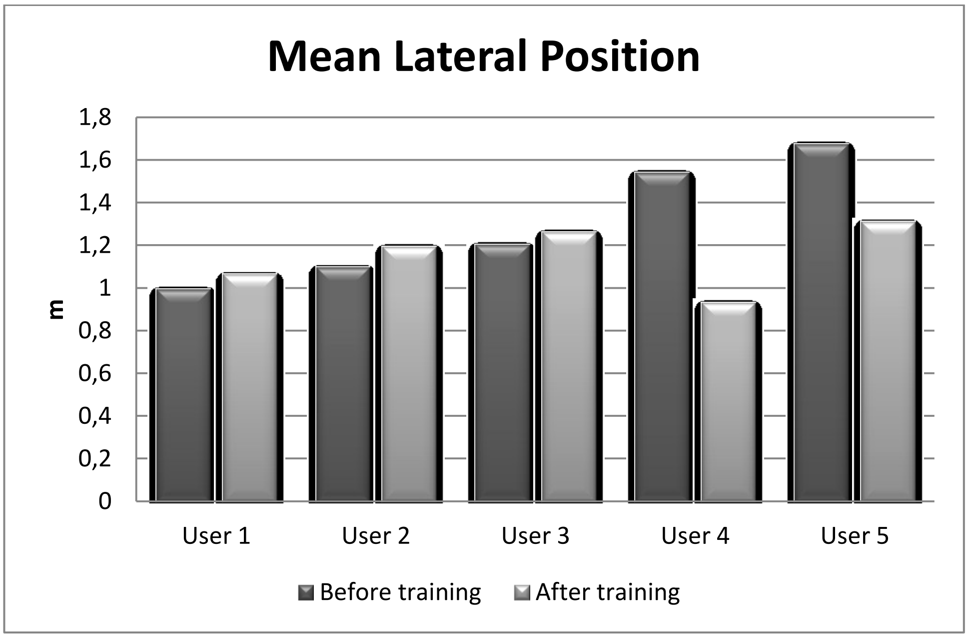

Figure 49: Behaviour influence over mean lateral position.

Behaviour influence:
Lateral control results

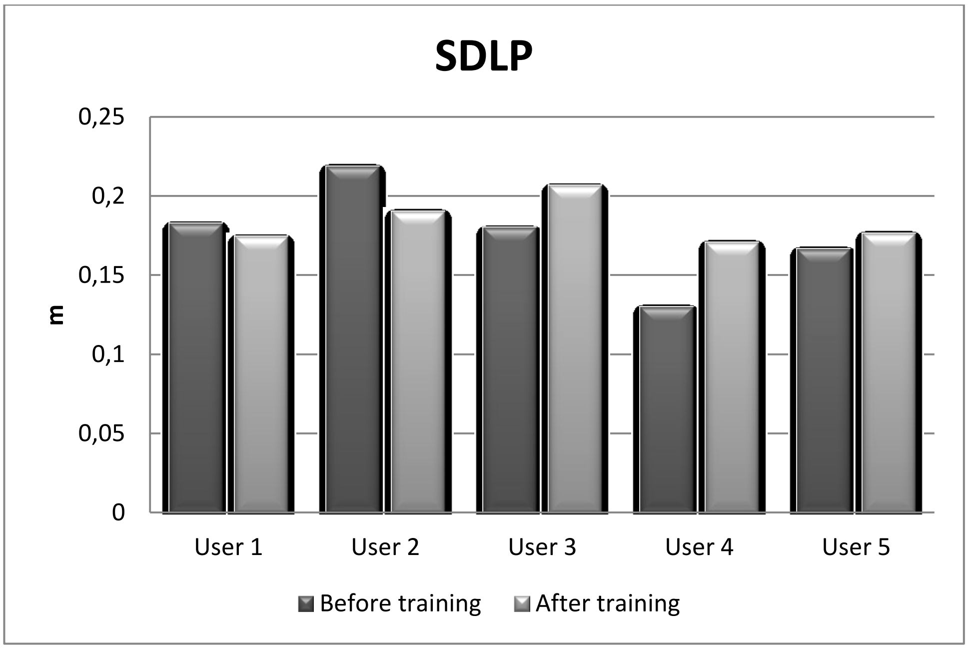

Figure 50: Behaviour influence over SDLP.

Appendix K

Driving while reading email: Longitudinal control

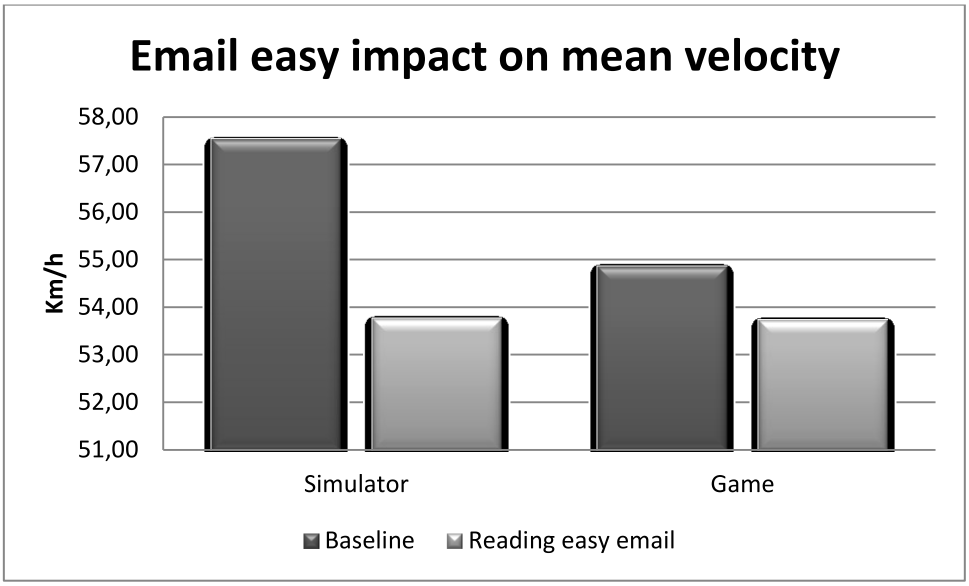

Figure 51: Email reading task's impact on mean velocity at easy level.

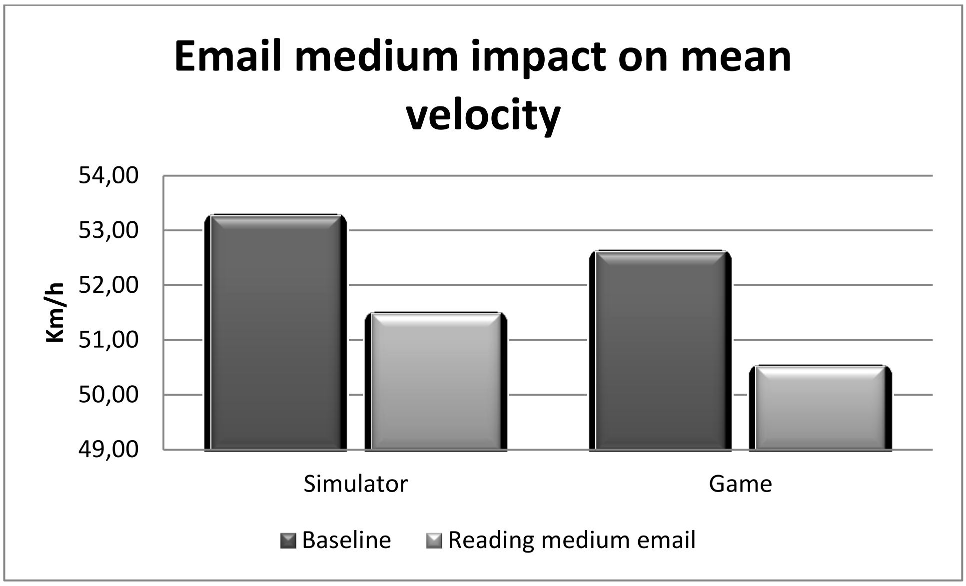

Figure 52: Email reading task's impact on mean velocity at medium level.

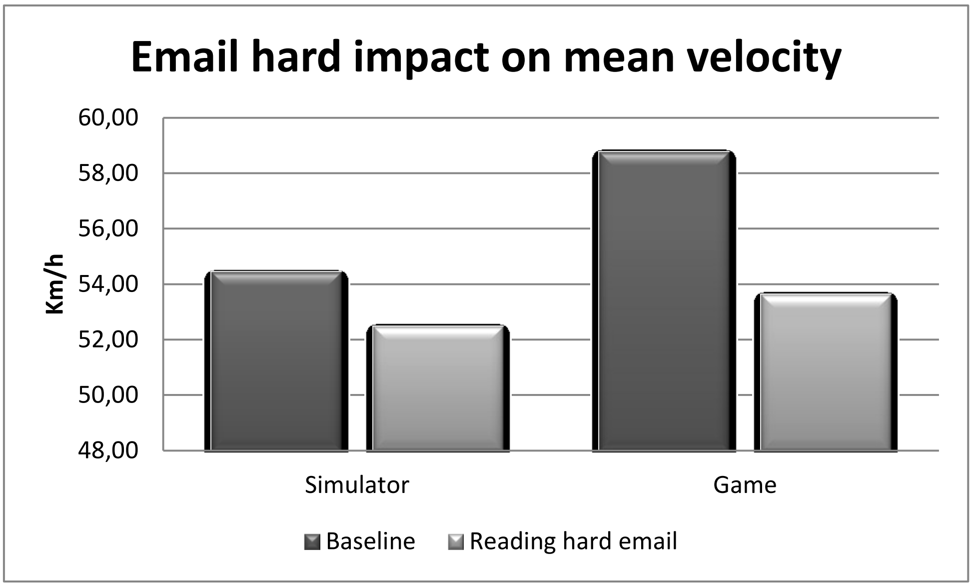

Figure 53: Email reading task's impact on mean velocity at hard level.

Table 21: Detailed email reading task impact on mean velocity.

SIMULATOR								
	Email Easy		Email Medium			Email Hard		
Users	Baseline Mean Velocity	Mean Velocity	Baseline Velocity	Mean	Mean Velocity	Baseline Velocity	Mean	Mean Velocity
User 1	64,40	56,87		58,13	54,93		61,61	53,73
User 2	66,04	65,66		55,97	53,92		53,92	47,73
User 3	56,35	57,82		55,21	49,59		53,87	50,60
User 4	52,66	55,31		50,62	47,50		48,95	52,98
User 5	57,43	45,27		49,41	43,56		56,79	53,73
User 6	58,09	44,72		50,90	58,77		56,33	53,45
User 7	53,70	54,60		52,56	50,64		52,93	55,94
User 8	51,03	49,53		53,19	52,57		51,44	52,27
User 9	57,27	53,67		53,10	51,03		53,77	51,62
User 10	58,36	54,12		53,45	52,20		54,62	52,68
Average	57,53	53,76		53,25	51,47		54,42	52,47

GAME								
	Email Easy		Email Medium			Email Hard		
Users	Baseline Mean Velocity	Mean Velocity	Baseline Velocity	Mean	Mean Velocity	Baseline Velocity	Mean	Mean Velocity
User 1	72,02	56,87		66,81	62,44		83,90	71,45
User 2	53,82	65,66		55,30	52,52		64,43	56,40
User 3	52,85	57,82		50,57	50,28		53,49	48,69
User 4	50,39	55,31		49,59	49,04		49,94	48,91
User 5	47,90	45,27		47,65	45,17		53,48	47,64
User 6	55,43	44,72		49,38	50,13		54,45	57,37
User 7	55,50	54,60		51,88	49,28		54,99	49,27
User 8	51,09	49,53		48,92	45,83		55,49	49,41
User 9	54,18	53,40		52,45	49,70		58,40	52,66
User 10	55,39	54,14		53,49	50,69		59,04	54,45
Average	54,86	53,73		52,60	50,51		58,76	53,63

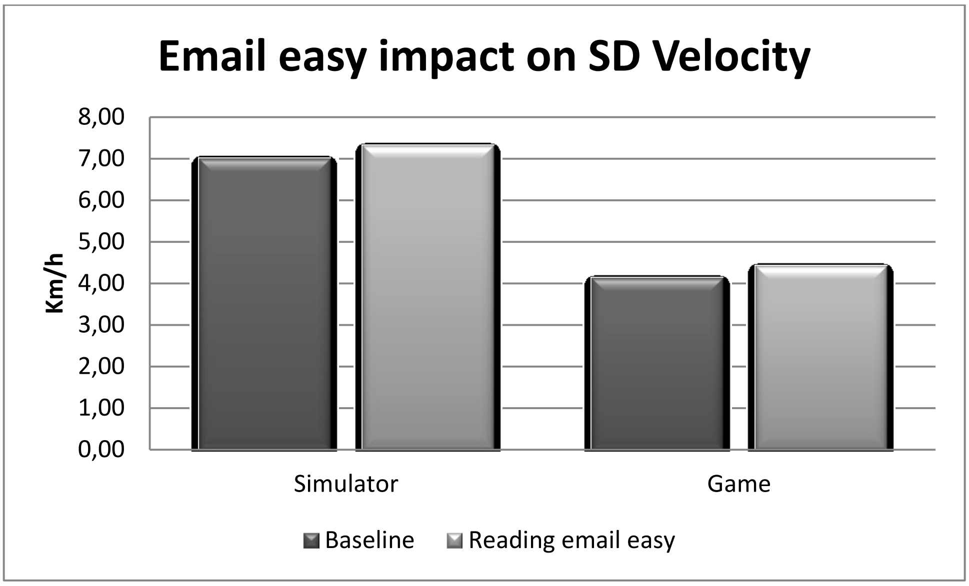

Figure 54: Email reading task's impact on SD velocity at easy level.

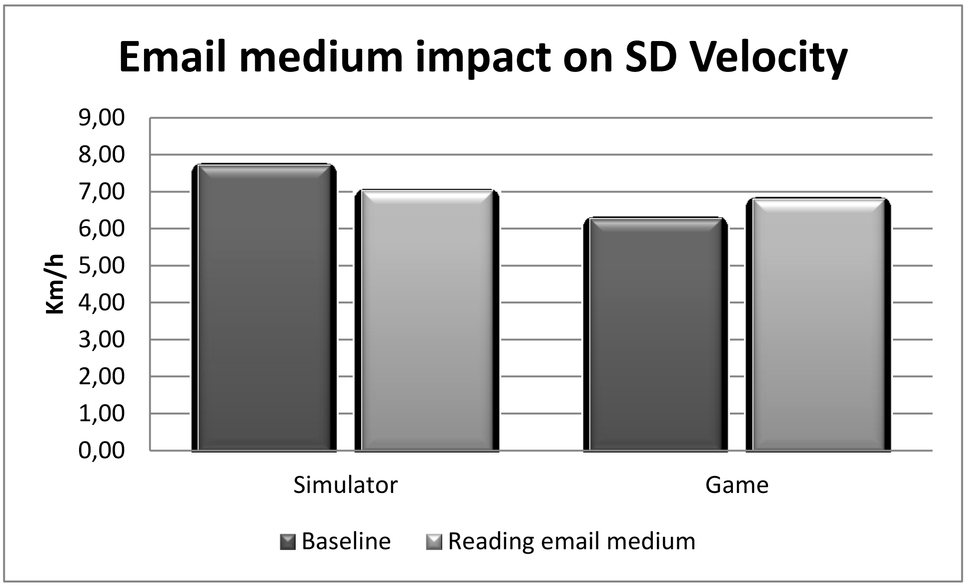

Figure 55: Email reading task's impact on SD velocity at medium level.

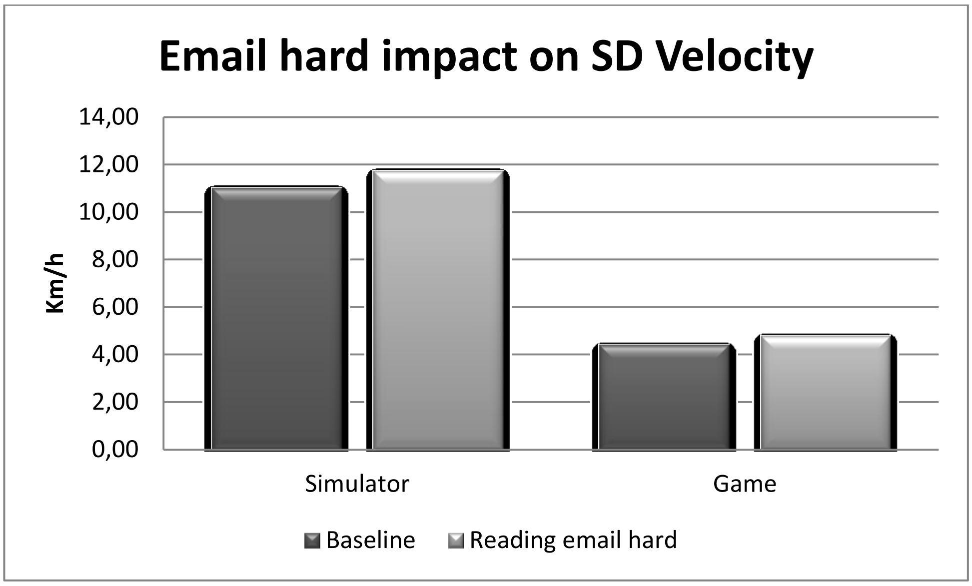

Figure 56: Email reading task's impact on SD velocity at hard level.

Table 22: Detailed email reading task impact on SD Velocity's simulator.

SIMULATOR						
	Email Easy		Email Medium		Email Hard	
Users	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity
User 1	11,28	10,56	20,66	15,99	17,75	13,67
User 2	8,72	11,73	16,32	6,96	15,70	19,39
User 3	2,90	2,11	3,52	7,60	6,90	16,38
User 4	4,40	7,22	3,95	3,93	6,24	7,32
User 5	11,25	6,94	4,39	4,71	16,10	7,99
User 6	10,34	6,50	7,61	6,52	15,36	9,51
User 7	3,89	7,64	2,66	6,80	3,91	13,05
User 8	3,67	5,48	2,62	3,42	6,13	6,93
User 9	7,41	8,12	8,07	7,65	11,96	11,87
User 10	6,20	6,86	7,25	6,50	10,10	11,17
Average	7,01	7,32	7,70	7,01	11,01	11,73

Table 23: Detailed email reading task impact on SD Velocity's game.

GAME						
	Email Easy		Email Medium		Email Hard	
Users	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity
User 1	9,80	5,87	11,96	12,44	5,98	5,33
User 2	3,25	5,56	6,88	6,82	7,89	6,79
User 3	3,05	2,50	3,59	2,27	3,70	2,54
User 4	1,44	4,07	2,40	3,99	2,02	2,20
User 5	2,59	5,10	8,19	4,20	4,07	4,22
User 6	6,51	6,99	7,51	8,66	3,78	5,28
User 7	2,25	1,91	3,63	6,87	2,87	2,75
User 8	4,19	3,21	5,33	9,22	4,69	6,20
User 9	4,83	5,05	6,96	6,87	4,87	5,20
User 10	3,42	3,91	6,17	6,53	4,14	4,40
Average	4,13	4,42	6,26	6,79	4,40	4,79

Table 24: Correlation matrix for email easy task's mean velocity.

Correlation matrix for email easy mean velocity

	Simulator free	Game free	Simulator task	Game task	Simulator sensibility	Game sensibility
simulator_free	1					
game_free	0,561822609	1				
simulator_task	0,495458372	0,2661318	1			
game_task	0,603883968	0,7573437	0,673763912	1		
Simulator sensibility	-0,247707206	0,0983466	0,71601156	0,315157324	1	
game sensibility	-0,064847863	-0,4577541	0,475786447	0,23124794	0,569495884	1

Table 25: Correlation matrix for email medium task's mean velocity.

Correlation matrix for email medium mean velocity

	Simulator free	*Game free*	*Simulator task*	*Game task*	*Simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,827374343	1				
simulator_task	0,446568078	0,408613819	1			
game_task	0,798805558	0,967320868	0,498128256	1		
simulator sensibility	-0,123265905	-0,06395833	0,83068988	0,04724959	1	
game sensibility	-0,375638535	-0,43599485	0,175484227	-0,193621238	0,408203	1

Table 26: Correlation matrix for email hard task's mean velocity.

Correlation matrix for email hard mean velocity

	Simulator free	Game free	Simulator task	Game task	Simulator sensibility	game sensibility
simulator_free	1					
game_free	0,72905291	1				
simulator_task	0,150264662	-0,18514551	1			
game_task	0,688020849	0,826971108	-0,153640491	1		
simulator sensibility	-0,79173291	-0,76580321	0,483759853	-0,70688812	1	
game sensibility	-0,39356412	-0,67187781	0,129962873	-0,140886575	0,43634118	1

Table 27: Correlation matrix for email easy task's SD velocity.

Correlation matrix for email easy SD velocity

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,581475	1				
simulator_task	0,575103	0,320286	1			
game_task	0,881227	0,583844	0,511633	1		
simulator sensibility	-0,55937	-0,29838	0,328877	-0,49492	1	
game sensibility	0,083101	-0,67708	0,110396	0,184434	-0,02774	1

Table 28: Correlation matrix for email medium task's SD velocity.

Correlation matrix for email medium SD velocity

	Simulator free	*Game free*	*Simulator task*	*Game task*	*Simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	**0,770171**	1				
simulator_task	0,169039	0,046477	1			
game_task	0,615255	0,69402	**-0,19707**	1		
simulator sensibility	-0,72562	-0,46099	0,3725	-0,35618	1	
game sensibility	-0,00121	-0,27671	-0,41146	0,467544	**-0,08891**	1

Table 29: Correlation matrix for email hard task's SD velocity.

Correlation matrix for email hard SD velocity

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	**0,83212**	1				
simulator_task	0,198531	0,563255	1			
game_task	0,652404	0,60716	**0,196436**	1		
simulator sensibility	-0,75628	-0,3476	0,451422	-0,40028	1	
game sensibility	-0,67606	-0,81945	-0,42456	-0,09542	**0,366531**	1

Table 30: Correlation matrix for email easy task's mean lateral position.

Correlation matrix for email easy mean lateral position

	Simulator free	*Game free*	*Simulator task*	*Game task*	*Simulator sensibility*	*Simulator Sensibility*
simulator_free	1					
game_free	0,400426	1				
simulator_task	0,628021	-0,26534	1			
game_task	0,425307	0,004552	0,267977	1		
Simulator sensibility	-0,21379	-0,93283	0,342188	0,353691	1	
Simulator Sensibility	-0,41525	-0,7393	0,442224	-0,20784	0,60813	1

Table 31: Correlation matrix for email medium task's mean lateral position.

Correlation matrix for email medium mean lateral position

	Simulator free	*Game free*	*Simulator task*	*Game task*	*Simulator Sensibility*	*Game Sensibility*
simulator_free	1					
game_free	0,427429	1				
simulator_task	0,824451	-0,01638	1			
game_task	0,393033	0,718857	0,261214	1		
Simulator Sensibility	-0,79549	-0,71368	-0,31551	-0,35268	1	
Game Sensibility	-0,1882	-0,62651	0,30393	0,090457	0,640023	1

Table 32: Correlation matrix for email hard task's mean lateral position.

Correlation matrix for email hard mean lateral position

	Simulator free	*Game free*	*Simulator task*	*Game task*	*Simulator Sensibility*	*Game sensibility*
simulator_free	1					
game_free	**0,15405**	1				
simulator_task	0,806096	0,516295	1			
game_task	-0,2769	-0,06392	**-0,20752**	1		
Simulator Sensibility	-0,49315	0,502559	0,115004	0,120824	1	
Game sensibility	-0,37827	-0,41636	-0,42483	0,926234	**-0,02442**	1

Table 33: Correlation matrix for email easy task's SDLP.

Correlation matrix for email easy SD lateral position						
	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,313125	1				
simulator_task	0,936403	0,387663	1			
game_task	0,58963	0,366543	0,520937	1		
simulator sensibility	0,136227	0,205905	0,461921	0,14575	1	
game sensibility	0,333094	-0,39125	0,235041	0,70628	0,055785	1

Table 34: Correlation matrix for email medium task's SDLP.

Correlation matrix for email medium SD lateral position

	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,118792	1				
simulator_task	0,309193	0,799744	1			
game_task	-0,04068	0,919664	0,844607	1		
simulator sensibility	-0,52364	0,631995	0,63404	0,826739	1	
game sensibility	-0,29862	0,08733	0,38281	0,469503	0,65461	1

Table 35: Correlation matrix for email hard task's SDLP.

Correlation matrix for email hard SD lateral position

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,640187	1				
simulator_task	0,619858	0,543261	1			
game_task	0,589146	0,735601	0,745631	1		
simulator sensibility	-0,52605	-0,10282	0,287127	0,013869	1	
game sensibility	0,224416	0,008209	0,220637	0,614357	-0,21434	1

Appendix L

Driving while reading email: Lateral control

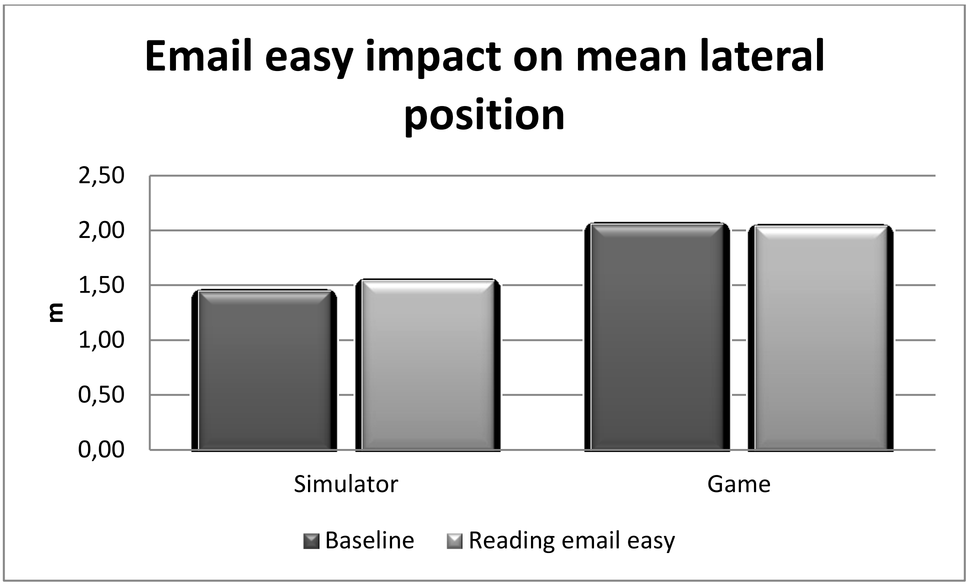

Figure 57: Email reading task's impact on mean lateral position at easy level.

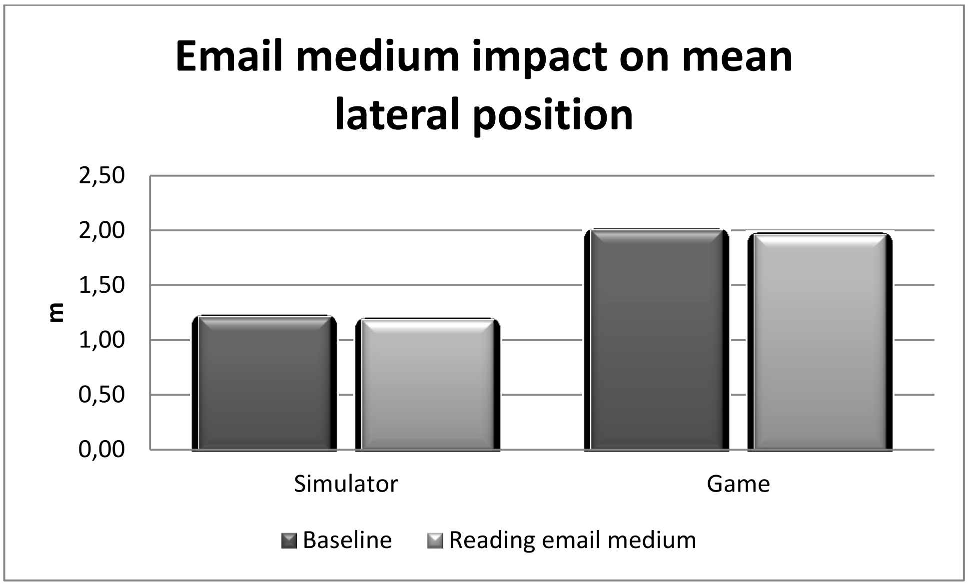

Figure 58: Email reading task's impact on mean lateral position at medium level.

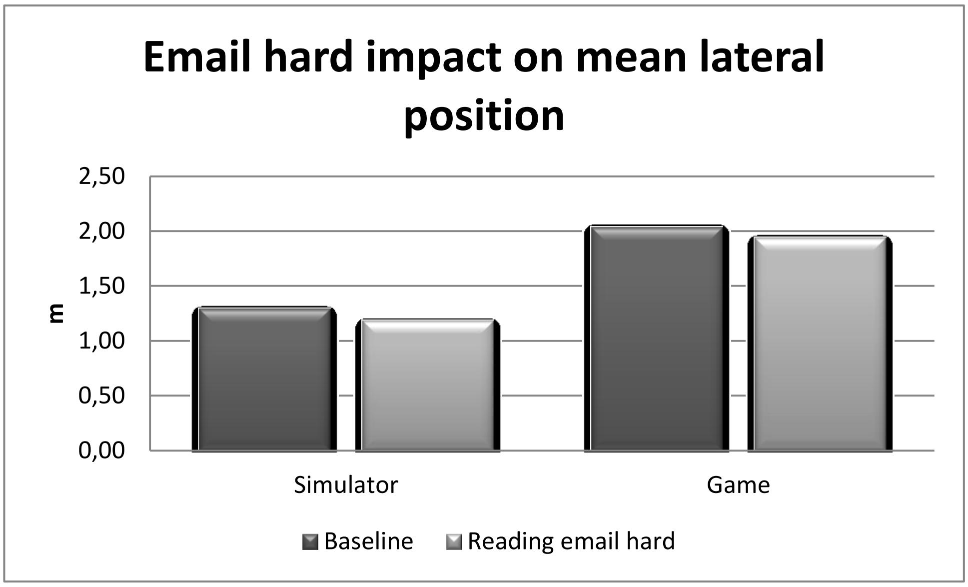

Figure 59: Email reading task's impact on mean lateral position at hard level.

Table 36: Detailed email reading task impact on mean lateral position.

SIMULATOR						
	Email Easy		Email Medium		Email Hard	
Users	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position
User 1	1,17	1,39	0,86	0,99	1,08	1,21
User 2	1,21	1,27	1,26	1,18	0,97	1,21
User 3	1,35	1,31	1,17	1,07	1,32	1,16
User 4	1,69	1,44	1,44	1,28	1,55	1,49
User 5	1,73	1,75	1,44	1,43	1,91	1,60
User 6	1,34	1,84	1,31	1,23	1,23	1,01
User 7	1,75	1,98	0,94	1,16	1,12	0,96
User 8	1,31	1,37	1,14	1,10	1,12	1,00
User 9	1,41	1,43	0,83	0,71	1,01	0,90
User 10	1,45	1,61	1,69	1,67	1,62	1,31
Average	1,44	1,54	1,21	1,18	1,29	1,18

GAME						
	Email Easy		Email Medium		Email Hard	
Users	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position
User 1	1,95	2,04	2,01	1,94	2,05	1,78
User 2	2,20	1,96	2,15	1,98	2,25	2,12
User 3	2,43	1,98	2,21	2,01	2,31	2,12
User 4	2,25	2,24	2,14	2,14	2,26	2,10
User 5	2,43	2,16	1,85	1,90	2,07	1,48
User 6	1,53	2,17	2,38	2,27	1,64	2,45
User 7	2,08	1,96	1,52	1,87	1,92	1,43
User 8	1,81	1,95	1,83	1,60	1,97	1,95
User 9	1,70	1,61	1,67	1,73	1,83	1,59
User 10	2,16	2,30	2,22	2,17	2,08	2,42
Average	2,05	2,04	2,00	1,96	2,04	1,94

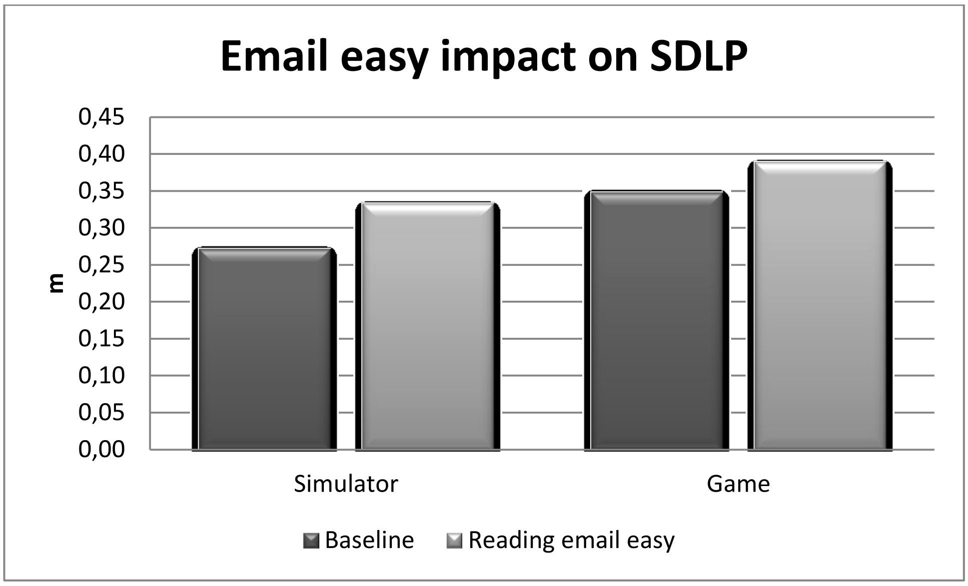

Figure 60: Email reading task's impact on SDLP at easy level.

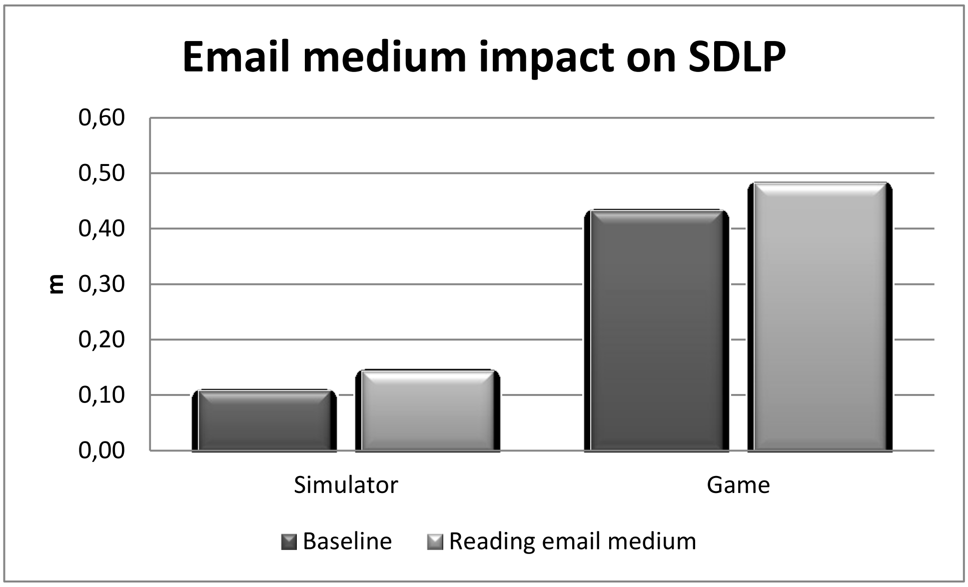

Figure 61: Email reading task's impact on SDLP at medium level.

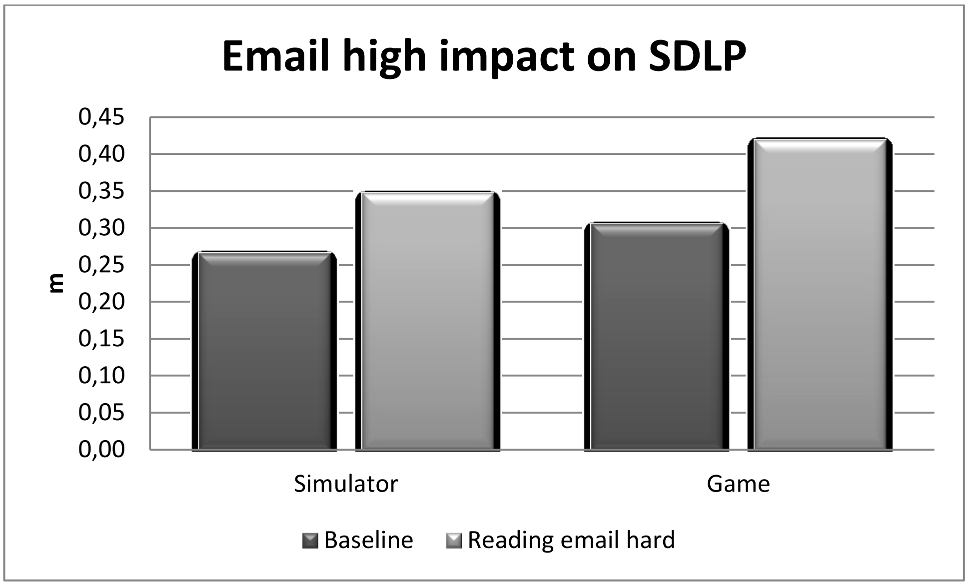

Figure 62: Email reading task's impact on SDLP at hard level.

Table 37: Detailed email reading task impact on SDLP.

SIMULATOR						
	Email Easy		Email Medium		Email Hard	
Users	Baseline SDLP	SDLP	Baseline SDLP	SDLP	Baseline SDLP	SDLP
User 1	0,35	0,48	0,09	0,15	0,19	0,19
User 2	0,21	0,33	0,18	0,15	0,32	0,31
User 3	0,32	0,44	0,10	0,17	0,24	0,43
User 4	0,13	0,16	0,11	0,10	0,16	0,30
User 5	0,23	0,18	0,12	0,11	0,12	0,23
User 6	0,32	0,38	0,16	0,24	0,36	0,70
User 7	0,51	0,61	0,09	0,18	0,52	0,46
User 8	0,19	0,22	0,10	0,15	0,28	0,28
User 9	0,22	0,26	0,08	0,09	0,24	0,29
User 10	0,25	0,27	0,04	0,07	0,22	0,29
Average	0,27	0,33	0,11	0,14	0,27	0,35

GAME						
	Email Easy		Email Medium		Email Hard	
Users	Baseline SDLP	SDLP	Baseline SDLP	SDLP	Baseline SDLP	SDLP
User 1	0,33	0,31	0,45	0,52	0,22	0,32
User 2	0,43	0,33	0,39	0,43	0,38	0,49
User 3	0,37	0,41	0,49	0,54	0,34	0,27
User 4	0,25	0,29	0,23	0,24	0,16	0,17
User 5	0,35	0,30	0,44	0,40	0,36	0,44
User 6	0,40	0,58	0,56	0,59	0,38	0,81
User 7	0,34	0,50	0,47	0,56	0,44	0,54
User 8	0,28	0,39	0,43	0,52	0,20	0,30
User 9	0,43	0,45	0,44	0,55	0,32	0,44
User 10	0,31	0,32	0,42	0,45	0,25	0,41
Average	0,35	0,39	0,43	0,48	0,31	0,42

Appendix M

Driving while navigating menu: Longitudinal control

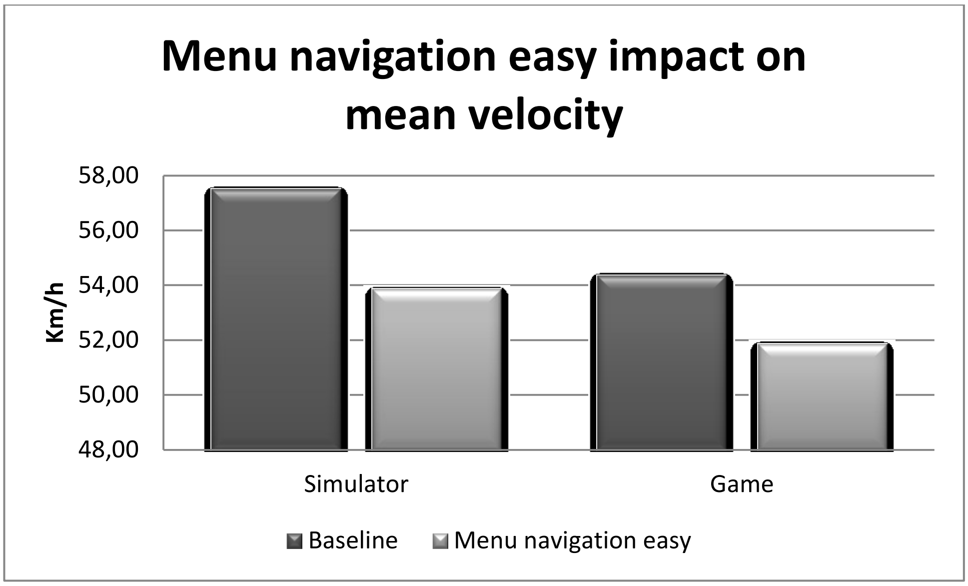

Figure 63: Menu navigation task's impact on mean velocity at easy level.

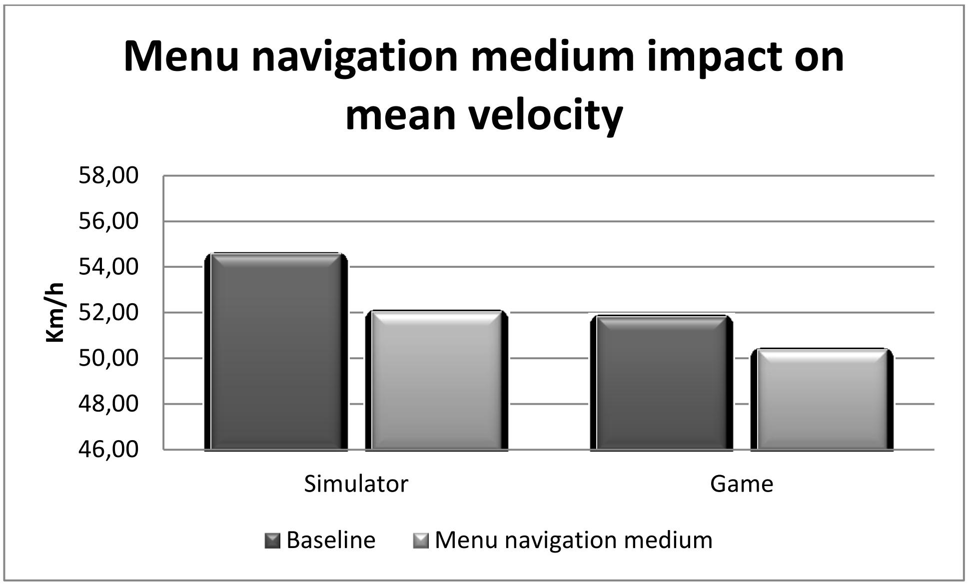

Figure 64: Menu navigation task's impact on mean velocity at medium level.

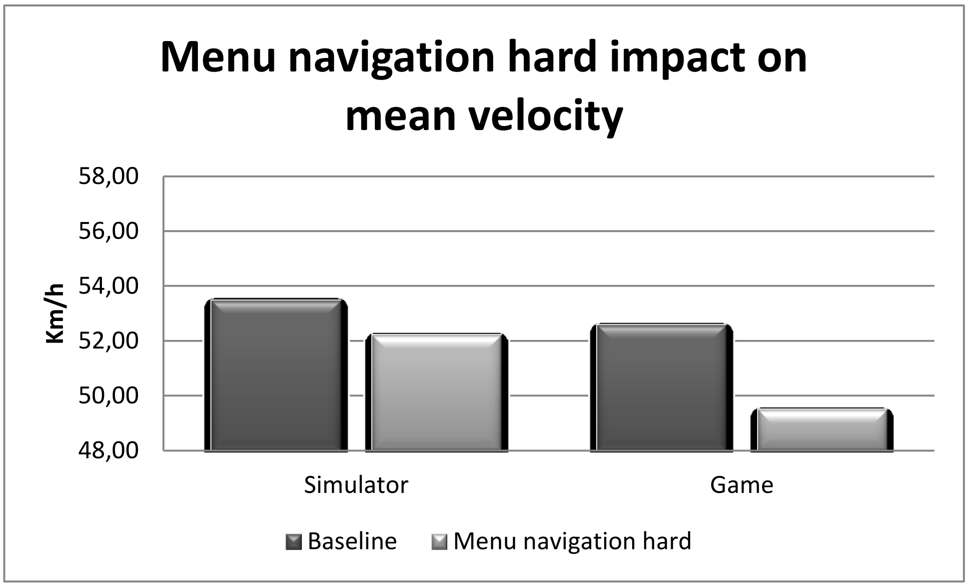

Figure 65: Menu navigation task's impact on mean velocity at hard level.

Table 38: Detailed menu navigation task impact on mean velocity.

SIMULATOR						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline Mean Velocity	Mean Velocity	Baseline Mean Velocity	Mean Velocity	Baseline Mean Velocity	Mean Velocity
User 1	59,21	56,88	48,01	50,90	57,94	56,64
User 2	78,96	65,49	66,65	53,99	56,62	54,45
User 3	56,06	57,00	54,06	57,78	54,30	47,42
User 4	51,88	59,38	48,89	47,87	48,63	50,14
User 5	49,88	48,13	51,51	43,00	48,25	44,68
User 6	57,18	40,66	61,42	58,31	56,34	50,65
User 7	52,21	51,20	52,92	49,42	52,94	57,77
User 8	53,55	51,39	52,58	54,29	51,76	54,97
User 9	57,95	53,82	54,81	52,15	53,69	52,91
User 10	58,17	54,58	54,53	52,51	54,31	52,37
Average	57,50	53,85	54,54	52,02	53,48	52,20

GAME						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline Mean Velocity	Mean Velocity	Baseline Mean Velocity	Mean Velocity	Baseline Mean Velocity	Mean Velocity
User 1	67,48	64,86	58,23	61,39	54,47	51,97
User 2	57,22	62,66	52,65	48,30	55,79	55,22
User 3	53,43	52,18	54,78	50,70	53,34	48,16
User 4	50,43	48,50	49,54	49,15	49,20	50,06
User 5	51,16	39,67	47,77	42,09	51,04	42,93
User 6	51,35	49,23	50,09	48,42	53,66	48,61
User 7	54,60	51,63	54,22	52,74	52,99	52,89
User 8	48,76	44,85	46,45	49,03	49,23	45,18
User 9	54,65	52,66	51,97	51,16	53,09	50,20
User 10	54,42	52,31	52,27	50,51	52,88	49,66
Average	54,35	51,86	51,80	50,35	52,57	49,49

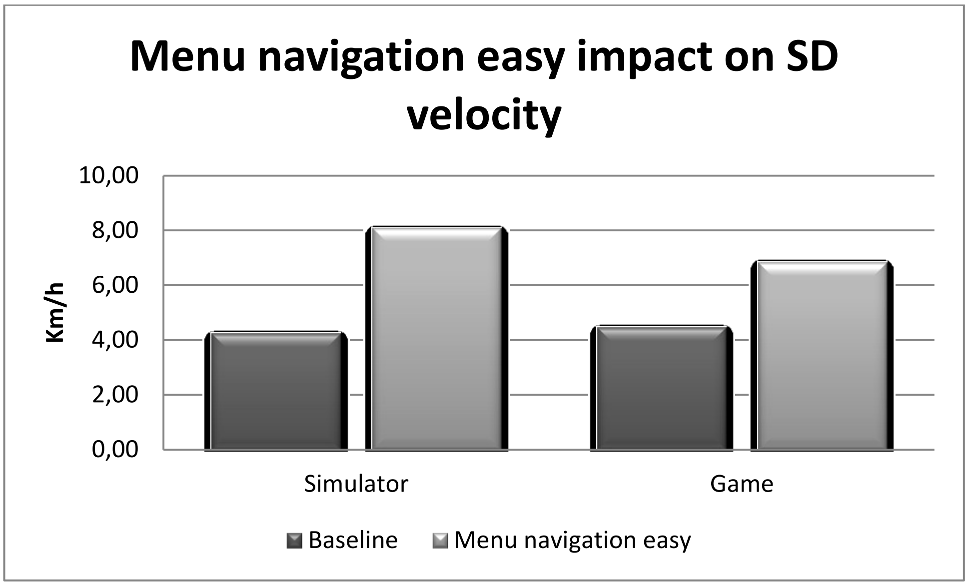

Figure 66: Menu navigation task's impact on SD velocity at easy level.

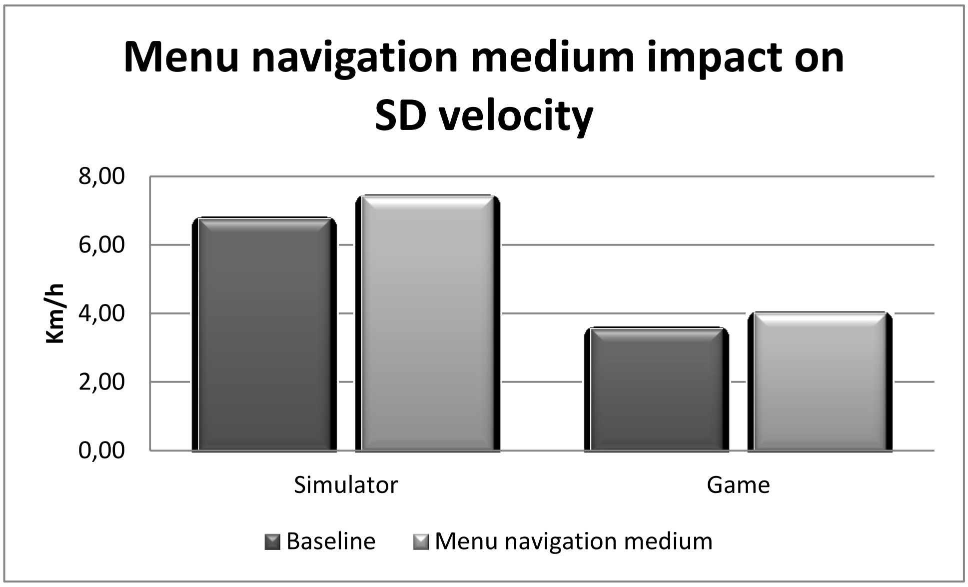

Figure 67: Menu navigation task's impact on SD velocity at medium level.

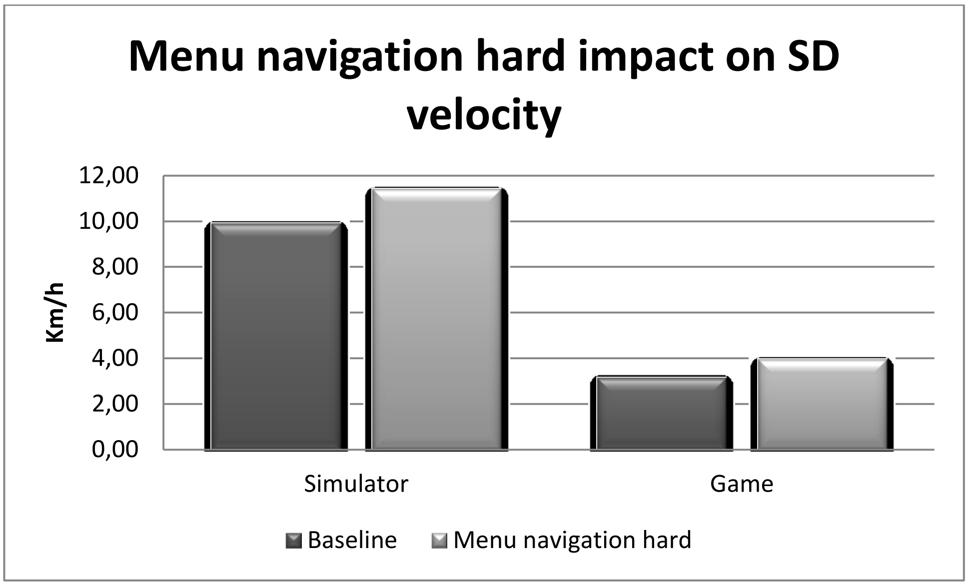

Figure 68: Menu navigation task's impact on SD velocity at hard level.

Table 39: Detailed menu navigation task impact on SD velocity.

SIMULATOR						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity
User 1	4,20	10,53	14,39	16,77	15,11	13,35
User 2	7,99	12,63	16,08	8,91	17,44	23,11
User 3	3,10	8,06	4,24	7,81	3,98	16,02
User 4	2,70	7,91	4,21	4,11	7,63	5,55
User 5	2,96	7,51	2,34	4,52	9,64	5,92
User 6	6,79	5,55	7,25	7,06	15,34	6,45
User 7	3,65	6,16	2,80	6,76	3,85	15,68
User 8	2,50	6,18	2,90	2,93	6,17	5,01
User 9	3,96	7,58	5,85	6,91	8,99	10,73
User 10	4,54	8,71	7,50	8,25	10,83	12,27
Average	4,24	8,09	6,75	7,40	9,90	11,41
GAME						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity	Baseline SD Velocity	SD Velocity
User 1	5,93	11,91	5,43	9,31	2,56	3,93
User 2	4,56	7,69	6,18	5,15	6,57	2,13
User 3	0,88	7,51	1,97	1,08	0,55	1,14
User 4	0,04	2,39	1,97	2,48	0,83	6,01
User 5	11,45	10,74	4,66	6,21	1,85	7,12
User 6	10,04	7,06	2,78	3,71	6,40	7,61
User 7	0,91	0,67	2,20	1,63	3,05	2,17
User 8	2,28	7,39	3,19	2,48	3,75	1,11
User 9	3,64	5,96	3,30	3,47	2,65	3,83
User 10	4,89	7,05	3,73	4,41	3,26	4,44
Average	4,46	6,84	3,54	3,99	3,15	3,95

Table 40: Correlation matrix for menu navigation easy mean velocity.

Correlation matrix for menu navigation easy mean velocity						
	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,398447	1				
simulator_task	0,590934	0,377434	1			
game_task	0,720707	0,852877	0,598394	1		
simulator sensibility	-0,44198	-0,01518	0,453948	-0,15293	1	
game sensibility	0,713518	0,320123	0,561475	0,758868	-0,22249	1

Table 41: Correlation matrix for menu navigation medium mean velocity.

Correlation matrix for menu navigation medium mean velocity

	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	-0,07518	1				
simulator_task	0,52758	0,195962	1			
game_task	-0,32895	0,812334	0,22154	1		
simulator sensibility	-0,56899	0,295076	0,394681	0,615352	1	
game sensibility	-0,41733	0,142275	0,209758	0,688657	0,702976	1

Table 42: Correlation matrix for menu navigation hard mean velocity.

Correlation matrix for menu navigation hard mean velocity

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,848791	1				
simulator_task	0,509102	0,278827	1			
game_task	0,605343	0,658006	0,661886	1		
simulator sensibility	-0,27417	-0,41148	0,686346	0,239449	1	
game sensibility	0,202827	0,130837	0,675769	0,830862	0,603039	1

Table 43: Correlation matrix for menu navigation easy SD velocity.

Correlation matrix for menu navigation easy SD velocity

	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,465379	1				
simulator_task	0,530947	-0,03055	1			
game_task	0,496152	0,642922	0,392093	1		
simulator sensibility	-0,84377	-0,58807	-0,00981	-0,39727	1	
game sensibility	0,015574	-0,59941	0,368465	0,07656	0,17807	1

Table 44: Correlation matrix for menu navigation medium SD velocity.

Correlation matrix for menu navigation medium SD velocity

	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,763432	1				
simulator_task	0,672249	0,44497	1			
game_task	0,643781	0,826546	0,705581	1		
simulator sensibility	-0,73163	-0,58064	0,007726	-0,18835	1	
game sensibility	0,273895	0,38777	0,34449	0,719687	-0,03916	1

Table 45: Correlation matrix for menu navigation hard SD velocity.

Correlation matrix for menu navigation hard SD velocity						
	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,689325	1				
simulator_task	0,225592	0,254637	1			
game_task	0,381453	0,06013	-0,57234	1		
simulator sensibility	-0,49858	-0,34902	0,697661	-0,82913	1	
game sensibility	-0,14401	-0,60957	-0,30095	0,607345	-0,19103	1

Appendix N

Driving while navigating menu: Lateral control

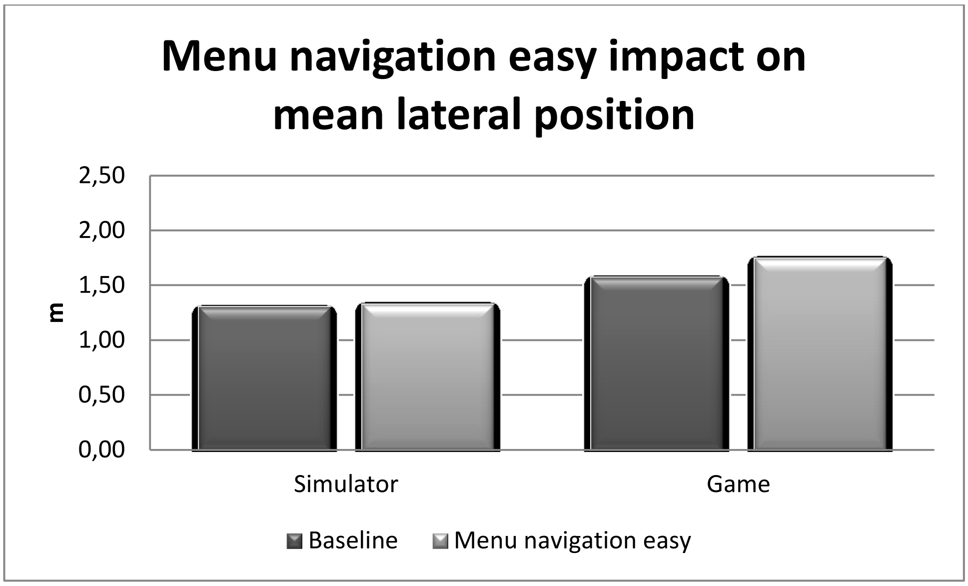

Figure 69: Menu navigation task's impact on mean lateral position at easy level.

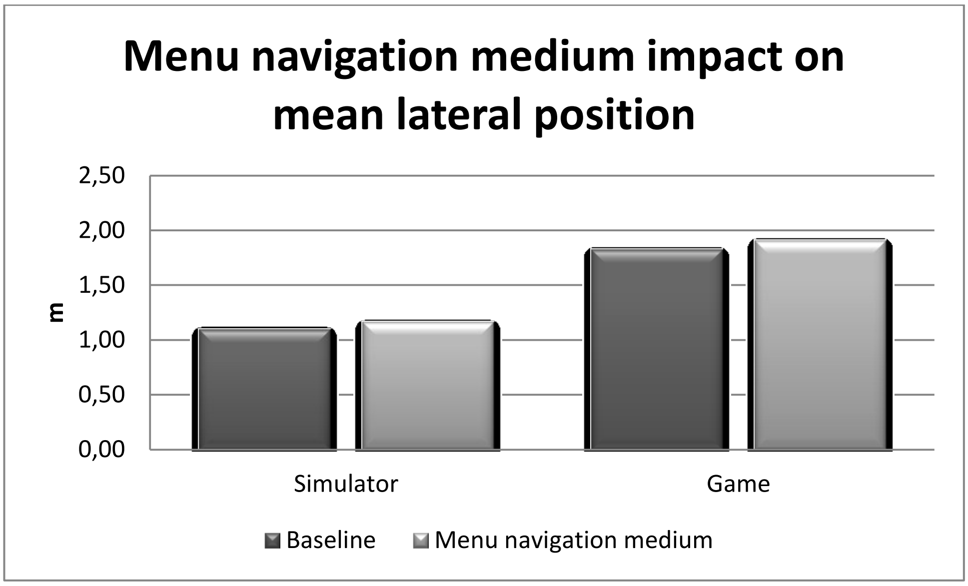

Figure 70: Menu navigation task's impact on mean lateral position at medium level.

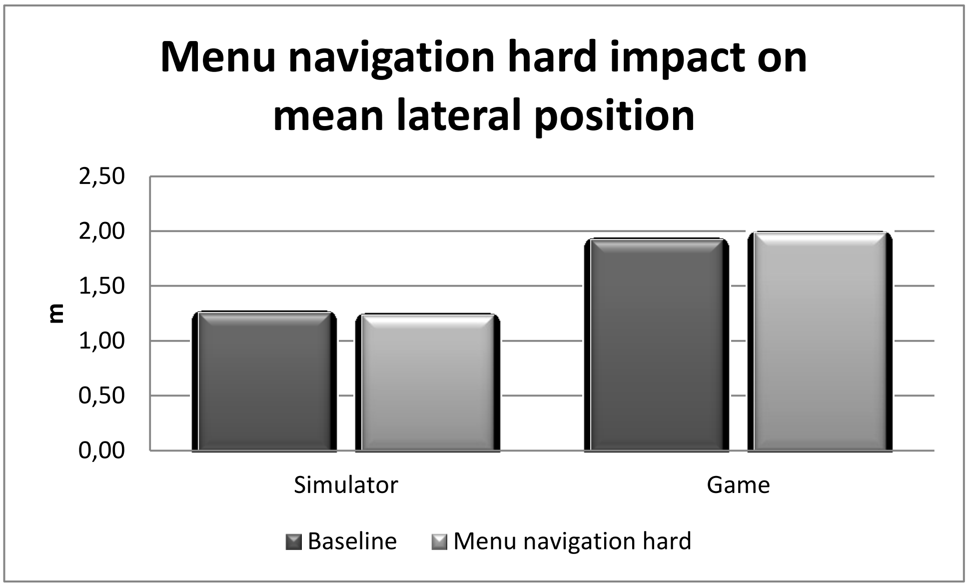

Figure 71: Menu navigation task's impact on mean lateral position at hard level.

Table 46: Detailed menu navigation task impact on mean lateral position.

SIMULATOR						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position
User 1	0,96	1,39	0,85	0,97	1,06	1,24
User 2	1,11	1,39	1,05	1,18	0,99	1,32
User 3	1,08	1,33	1,11	1,12	1,18	1,26
User 4	1,69	1,41	1,41	1,26	1,47	1,38
User 5	1,59	1,62	1,46	1,41	1,91	1,62
User 6	1,05	0,78	1,09	1,16	1,23	1,09
User 7	1,40	1,22	0,93	1,14	1,12	0,99
User 8	1,32	1,37	1,07	1,16	1,25	0,87
User 9	1,15	1,12	0,67	0,96	0,88	0,82
User 10	1,65	1,61	1,35	1,27	1,44	1,71
Average	1,30	1,32	1,10	1,16	1,25	1,23

GAME						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position	Baseline Mean Lateral Position	Mean Lateral Position
User 1	1,27	1,79	1,87	2,15	1,69	2,15
User 2	1,71	1,72	1,95	1,92	2,04	2,00
User 3	1,78	1,70	1,69	2,17	1,91	1,85
User 4	1,90	1,84	1,95	2,05	2,08	1,77
User 5	1,78	2,07	2,17	1,52	1,87	2,12
User 6	1,82	1,79	1,73	1,84	2,17	1,32
User 7	0,88	1,61	1,56	2,14	1,68	2,48
User 8	1,50	1,57	1,66	1,72	1,68	1,85
User 9	1,41	1,52	1,71	1,48	1,74	1,86
User 10	1,62	1,80	1,98	2,09	2,33	2,38
Average	1,57	1,74	1,83	1,91	1,92	1,98

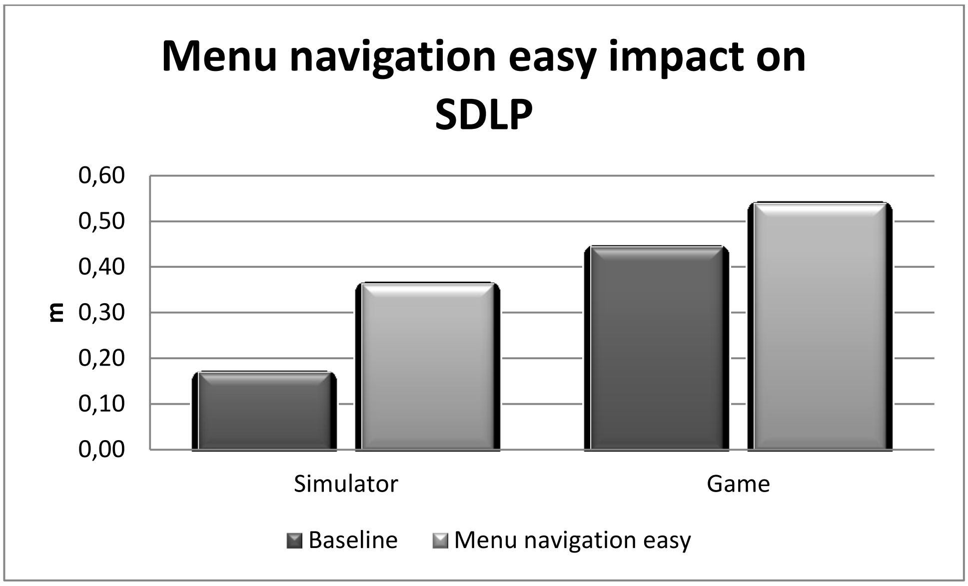

Figure 72: Menu navigation task's impact on SDLP at easy level.

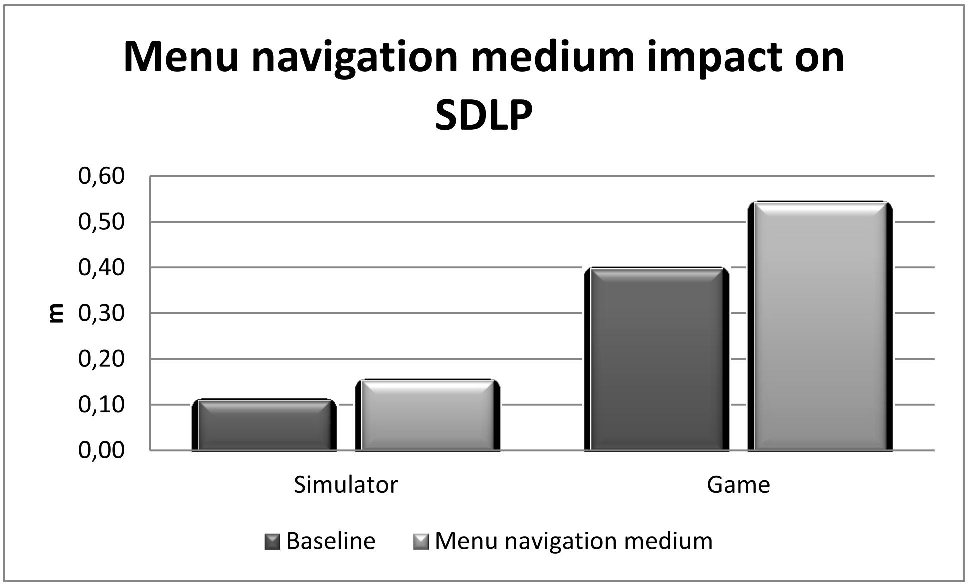

Figure 73: Menu navigation task's impact on SDLP at medium level.

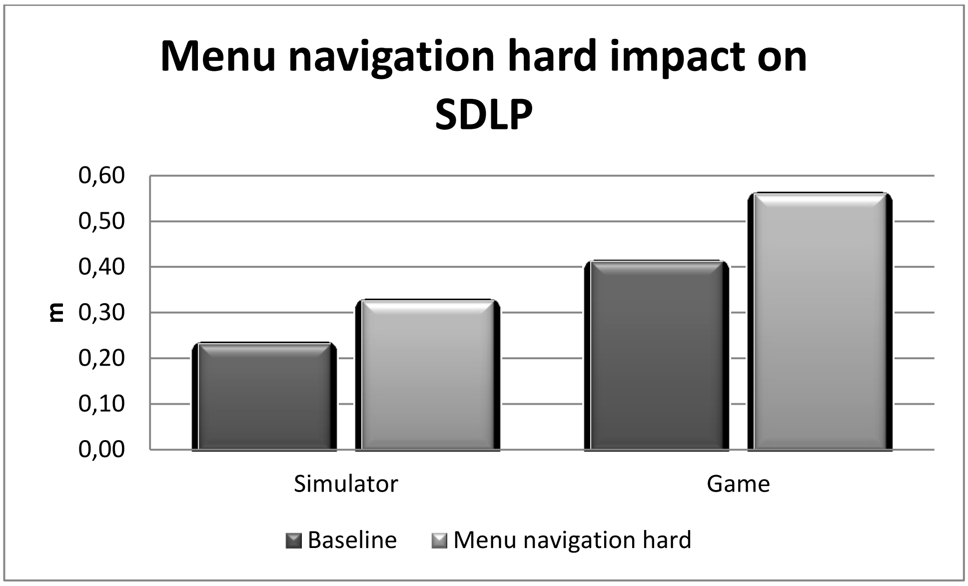

Figure 74: Menu navigation task's impact on SDLP at hard level.

Table 47: Detailed menu navigation task impact on SDLP.

SIMULATOR						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline SDLP	SDLP	Baseline SDLP	SDLP	Baseline SDLP	SDLP
User 1	0,16	0,48	0,10	0,16	0,21	0,16
User 2	0,17	0,39	0,17	0,16	0,27	0,32
User 3	0,16	0,50	0,07	0,19	0,19	0,50
User 4	0,14	0,12	0,11	0,08	0,13	0,21
User 5	0,20	0,12	0,12	0,13	0,21	0,24
User 6	0,21	0,45	0,14	0,19	0,36	0,54
User 7	0,17	0,68	0,09	0,19	0,25	0,39
User 8	0,16	0,23	0,07	0,15	0,26	0,28
User 9	0,12	0,27	0,10	0,11	0,15	0,23
User 10	0,19	0,38	0,11	0,16	0,28	0,37
Average	0,17	0,36	0,11	0,15	0,23	0,32

GAME						
	Navigation Easy		Navigation Medium		Navigation Hard	
Users	Baseline SDLP	SDLP	Baseline SDLP	SDLP	Baseline SDLP	SDLP
User 1	0,41	0,61	0,33	0,45	0,41	0,45
User 2	0,53	0,60	0,49	0,54	0,50	0,67
User 3	0,56	0,67	0,33	0,54	0,50	0,75
User 4	0,31	0,35	0,29	0,31	0,26	0,25
User 5	0,51	0,36	0,26	0,45	0,48	0,42
User 6	0,48	0,74	0,74	0,99	0,41	0,69
User 7	0,42	0,66	0,34	0,62	0,33	0,74
User 8	0,28	0,30	0,37	0,40	0,41	0,45
User 9	0,43	0,48	0,32	0,54	0,33	0,53
User 10	0,49	0,61	0,49	0,58	0,48	0,62
Average	0,44	0,54	0,40	0,54	0,41	0,56

Table 48: Correlation matrix for menu navigation easy mean lateral position.

Correlation matrix for menu navigation easy mean lateral position

	Simulator free	Game free	Simulator task	Game task	simulator sensitivity	game sensitivity
simulator_free	1					
game_free	0,137418	1				
simulator_task	0,450536	0,032051	1			
game_task	0,361005	0,509692	0,327002	1		
simulator sensitivity	-0,42963	-0,13138	0,607822	-0,06675	1	
game sensitivity	0,025357	-0,92457	0,088024	-0,14641	0,0823	1

Table 49: Correlation matrix for menu navigation medium mean lateral position.

Correlation matrix for menu navigation medium mean lateral position

	Simulator free	Game free	Simulator task	Game task	Simulator sensitivity	Game sensitivity
simulator_free	1					
game_free	0,651019	1				
simulator_task	0,903757	0,610892	1			
game_task	-0,55625	-0,50345	-0,71557	1		
Simulator sensitivity	-0,89516	-0,52843	-0,62051	0,277297	1	
Game sensitivity	-0,70116	-0,84435	-0,79244	0,874886	0,443569	1

Table 50: Correlation matrix for menu navigation hard mean lateral position.

Correlation matrix for menu navigation hard mean lateral position

	Simulator free	Game free	Simulator task	Game task	simululator sensibility	game sensibility
simulator_free	1					
game_free	0,112355	1				
simulator_task	0,620722	0,370157	1			
game_task	-0,0439	-0,7338	0,05934	1		
simululator sensibility	-0,45063	0,298095	0,414358	0,128267	1	
game sensibility	-0,03362	-0,86401	-0,01259	0,942936	0,007902	1

Table 51: Correlation matrix for menu navigation easy SDLP.

Correlation matrix for menu navigation easy SDLP

	Simulator free	Game free	Simulator task	Game task	simulator sensibility	game sensibility
simulator_free	1					
game_free	0,437015	1				
simulator_task	0,041859	0,371654	1			
game_task	0,276063	0,630802	0,867047	1		
simulator sensibility	-0,18754	0,194502	0,882502	0,766592	1	
game sensibility	-0,21142	-0,11209	0,75679	0,683047	0,859645	1

Table 52: Correlation matrix for menu navigation medium SDLP.

Correlation matrix for menu navigation medium SDLP

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,513822	1				
simulator_task	-0,13082	0,442566	1			
game_task	0,353206	0,879984	0,678613	1		
simulator sensibility	-0,66362	0,017846	0,80063	0,258372	1	
game sensibility	-0,23132	-0,20005	0,525072	0,281154	0,489021	1

Table 53: Correlation matrix for menu navigation hard SDLP.

Correlation matrix for menu navigation hard SDLP

	Simulator free	*Game free*	*Simulator task*	*Game task*	*simulator sensibility*	*game sensibility*
simulator_free	1					
game_free	0,28376	1				
simulator_task	0,56955	0,26374	1			
game_task	0,564066	0,471649	0,811391	1		
simulator sensibility	-0,062	-0,0582	0,719034	0,420203	1	
game sensibility	0,537793	0,023841	0,758113	0,884529	0,425749	1

Appendix O

Performance Metrics

Table 54: Common longitudinal control metrics.

Control	*Metric*	*Units*
Longitudinal	Mean Speed	Km/h
	Speed Variation	Km/h
	Minimum Speed	Km/h
	Minimum TTC	s
	Mean TTC Minima	s
	Proportion TTC Minima < 4 s	%
	Proportion if time where TTC < 4 s	%
	Mean Distance headway	m
	Mean of distance headway minima	m
	proportion of distance headway minima	%
	proportion of distance headway minima < 20 m	%
	distance headway variation	m
	Minimum distance headway	m
	Mean time headway	s
	mean of time headway minima	s
	proportion of time headway minima	s
	proportion of time headway minima < 1 s	%
	time headway variation	s
	min time headway	s
	breake reaction time	s
	Travel proportion over the speed limits	%
	Travel proportion lower the speed limits	%

Table 55: Common lateral control metrics.

Control	Metric	Units
Lateral	Mean lateral position	m
	Lateral Position Variation	m
	Mean TLC minima	s
	Minimum TLC	s
	Proportion TLC minima < 1 s	%
	Proportion of time outside lane	%
	1 deg reversal rate	1/ Minute
	2 deg reversal rate	1/ Minute
	3 deg reversal rate	1/ Minute
	5 deg reversal rate	1/ Minute
	Observed lane exceedences	%

Appendix P

Interaction Metrics

Table 56: Common interaction metrics.

Usability factor	*Metric*
Effectiveness	Tasks completion
Efficiency	Task Completion time Error rate Proportion of high subtask time
Learnability	Time to Average Time to Expert
Memorability	Time from last use Initial Task completion Time Time to Average Time to Expert
Satisfaction	SUS Questionary

Appendix Q

System Usability Scale

Table 57: Example of SUS.

		Strongly disagree				Strongly agree
1	I think that I would like to use this system frequently	1	2	3	4	5
2	I found the system unnecessarily complex	1	2	3	4	5
3	I thought the system was easy to use	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5	I found the various functions in this system were well integrated	1	2	3	4	5
6	I thought there was too much inconsistency in this system	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8	I found the system very cumbersome to use	1	2	3	4	5
9	I felt very confident using the system	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system	1	2	3	4	5