1 Introduction

1.1 Motivation

According to the World Health Organisation (WHO), there are at least 2.2 bilions of people with some visual impairment degree (WORLD HEALTH ORGANIZATION AND OTHERS, 2019), hence there is a demand for assistive products in the world. This demand is driven on the unsatisfaction for the current products, since they are not practical, nor portable, invasive or demandful to learn (LOZANO *et al.*, 2009).

This difficulty to use or to learn could be avoided if concepts from human factors, or ergonomics, were analysed during the product's development, and these could be done using the proper methods. The early application of these methods and tests could be a game changer for the success of the product's user experience (WOLF *et al.*, 2019).

Another tool that helps training and user efficiency is the Virtual Reality (VR). VR can be used to create specific, immersive and interactive situations that could help the user to learn and train (FARRELL, 2018) and the developers to create more efficient products.

Another strategy to improve the user experience is to bring the user closer to the development team *Adicionar mais coisa*.

As for beginning of February, 2022, about 400 million people had been diagnosed with COVID-19 around the world (RITCHIE *et al.*, 2020). Purposing to try to slow the rate in which the virus spread, WHO recommended strategies like wearing face masks, washing hands regularly, social distancing, avoiding touching surfaces and staying at home (WORLD HEALTH ORGANIZATION, 2020).

Besides not having a desirable or easily adaptable guidance method, now BVI users' must avoid touching surfaces, an action that they depend in order to perceive the environment, and keep distance from other people, a task that, besides being difficult to maintain, a BVI user is not used to since he/she depends on others to do their daily activities, like to cross the street (JONDANI, 2021).

1.2 Objectives

The objectives of this master's thesis are to assess BVI users' using different guidance methods inside a Virtual Environment (VE) and to verify if non-BVI users have the same mental demand and situation awareness as BVI users when using assistive products as in order to improve the development of new assistive solutions for BVI users.

To reach this goal, the following questions must be answered:

1. Do BVI users feel present in the VE as if they were in the real world?

2. BVI users rely on audio cues and haptic feedback to guide. But does it rely more on a type of information than the other?

3. Do non BVI users have the same demands and skill as BVI users when designing assistive products?

1.3 Resources and methods

In order to answer all the questions and reach the goal mentioned above, the following resources were allocated:

• To answer about the feeling of presence from BVI users in VE:

– HTC VIVE VR Head Mounted Device (HMD), as show in Figure 1.1;

– A guidance method evaluation questionnaires (See Appendix A.4) . • To answer if BVI rely more in one type of information than the other and if non BVI can undergo the same situations as BVI users when using assistive products:

– Mental workload assessment, using:

∗ Physiological sensors (INSERIR FOTO); ∗ NASA-TLX questionnaire (See Appendix A.2).

– Situation awareness assessment, using:

∗ SAGAT questionnaire (Adapted for this experiment. See Appendix A.3).

1.4 Research boundaries

This experiment is not testing the usability of the guidance tools developed for it. This tools are only used here to help users and researchers compare the different feelings provoked by the information transmitted by it.

FIGURE 1.1 – VIVE HTC TOBII Virtual Reality Headset.

1.5 Structure

This master's thesis is organized in 8 different chapters and they the following:

- Introduction

  It's the current chapter of this master's thesis

- Theoretical Foundation

  This chapter explores the mains concepts that are needed to fully understand this experiment. These concepts are:

  – Human Factor or Ergonomics;

  – Mental Workload (MWL);

  – Task Performance;

  – Physiological measures; – Subjective measures.

  – Situation Awareness (SA);

  – Extended Reality (XR);

  – Virtual Reality (VR); – Co-Design.

- Literature review

  During this chapter, related articles, i.e articles that involve applications of:

  – VR;

  – BVI users;

  – Human factors.

  All these article have some relevance to the current experiment.

- Proposal description

  Within this chapter, the method will be explained used to reach the goals presented above.

- Virtual environment development

  This chapter is dedicated to explained the steps that was taken in order to design the scene used during the experiment

- Haptic belt development

  In this chapter, the process of coding and assembly of the haptic belt is explained.

- Results' analysis and discussion

  One of the mains chapters of this work. Here is presented and discussed all the gathered results and data

- Conclusion

  Finally, which goals were reached and which were not and why they were not.

2 Theoretical Foundation

This work use concepts from Human Factors and Co-design and is supported by tools such as Extended Reality (XR), more precisely VR, and some specific assessment methods using task performance, physiological measures and subjective measures. This chapter introduces the need-to-know of each of these to help to better understand this Master's thesis. Each subject is introduced in the following 5 sections

2.1 Human Factor or Ergonomics

Studies started at the Second World War because of the perfomance shortfalls and failures noted in manned equipment. These studies showed that these problems could diminish when Engineering, Psychology and Physiology were gathered when designing a system that was to be handled by a human being (SANDOM; HARVEY, 2004).

This area of study was named "Human Factors" in United States an "Ergonomics" in Europe. Despite this difference in the names, today they are considered the same field of study. The International Ergonomics Association (IEA) defines Human Factors, and Ergonomics, as the following:

> Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans 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. Human Factors professionals contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people (KARWOWSKI, 2012).

Besides being synonyms, this definition shows that humans is a variable inside a system and their interactions should be studied and that is the focus of Human Factors (SANDOM; HARVEY, 2004; SANDERS; MCCORMICK, 1998; DUL; WEERDMEESTER, 2003).

Humans handle with devices, machines and equipment during their daily activities and all of these manipulations are susceptible to accidents or failures that can happen because of the interaction between operator, equipment and environment. Each interface with the operator can be a factor, for example:

- The operator's body position during an activity;

The position can impact on the comfort felled by the operator and this impacts on its concentration throughout the activity therefore impact on the success rate or in the chance of some accident happen (SANDERS; MCCORMICK, 1998).

- The environment's lighting;

  The illumination can make details easier to be noted without provoking discomfort or distraction to the user and even increase productivity (SANDERS; MCCORMICK, 1998).

- The information displayed and manipulation of the device.

  The way an information is displayed on a screen, figure or text impact on how efficient it will be understand by the operator. If this take too long it can draw the operator attention for too long and compromise his/her reaction time.

To take human into account when designing a product or a system is one of the principles for human factors (SANDOM; HARVEY, 2004) and the results of this humancentred-design is already a ISO Standard (BS EN ISO 13407 'Human-centred design processes for interactive systems'). This standard was originally written for computerbased-system, but easy applicable in other scenarios and areas (SANDOM; HARVEY,
2004).

It is important to say that when it is said ”User”, it doesn't mean that one need to design a product specifically for an individual. The design has to be suited to everyone (DUL; WEERDMEESTER, 2003).

”Human-Machine systems” (on this thesis, for now on, called simply ”Systems”), are interactions between humans and machines. These systems are designed to have an input, or demand, and an output, or product. Here, ”machine” can be any manipulated object, from a simple screwdriver until a car, or some machine operated by more than one human, like a cargo ship for example. The Figure 2.1 represent a general human-system machine interaction.

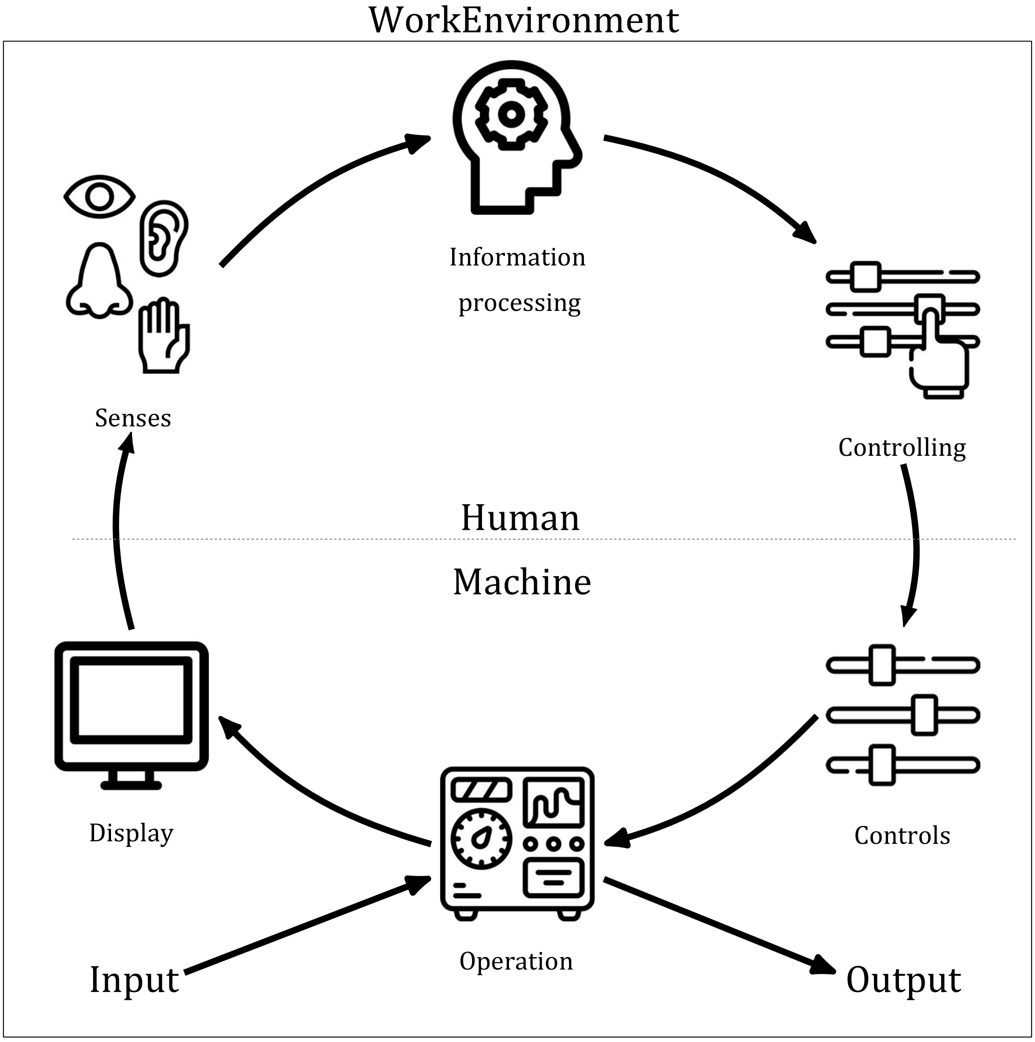


FIGURE 2.1 – Human-Machine system representation (SANDERS; MCCORMICK, 1998).

2.2 Mental Workload (MWL)

Mental workload (MWL) is one of the main concepts studied in Human Factors and is not a familiar concept to the most people (STANTON *et al.*, 2004). A good way to explain it is with a analogy with physical workload (STANTON *et al.*, 2004). When a athlete must lift a dumbbell (one of those gym's weights bars). The strength's demand from the athlete will be proportional with the the dumbbell's mass he/she is lifting. If the dumbbell is lighter than the athlete's capability, then it will be easy enough for him/her to lift it. So if the athlete is strong enough to carry the dumbbell, he/she will not feel a physical demand bigger than his/her capabilities. So the physical workload of this activity is properly fitted for this athlete.

If the dumbbell is heavier than the athlete can lift then two things can happen:

- Or the athlete adapts to lift that dumbbell using tools (adjust the strategy)

- Or the athlete will not be able lift completely the dumbbell (performance degrades)

This is a scenario that represent an user, or operator, executing a task that is not fitted for their capabilities.

It is the same with MWL. Each human being has a finite mental capacity and can only use it with a limited number of tasks at the same time. If the sum of these mental demands are higher than the user's capacity, the user will need to adapt in order to finish those task, otherwise he/she will compromise the overall performance of those tasks.

Although, if the workload is too low, the same operator may get bored and easily distracted and so could also fail or not process the task's information.

It's important to say that MWL is unique within each individual and is influenced by his/her perception of the task's workspace but is also impacted by other factors outside the task itself and more related to the operator (like it's skill, age, education, training) or to the environment (like noise, heat and toxicity) (CAIN, 2007; FALLAHI *et al.*, 2016; CARDOSO; GONTIJO, 2012).

MWL is not a quantitative resource or something that one can directly measure, but is has methods to infer it. The Figure 2.2 has an overview of MWL and its measureament methods.

2.2.1 Task Performance

If the MWL influences on the task perfomance, then it would be possible to infer it using the performance's variation of a task. Because there are cases that the user's mental capacity is too high for only one task, two tasks are designed. In these evaluations, the user is asked to maintain a good perfomance level and still try to execute both tasks. Both tasks are similar and use the same kind of skill. (STANTON *et al.*, 2004; SANDERS; MCCORMICK, 1998).

For example, an experiment to assess MWL in a flight simulator that uses two tasks:

- Fly a fighter aircraft and maintain a good performance level;
- Mentally sum two random numbers that appear on the screen. If the numbers' sum is odd, then the pilot should press left on the keyboard, if the result is even the he/she should press right.

If the pilot's performance at the second task is too low, it means that the demand from the first task is too high for him/her to be able to pay attention on it, than it means that the MWL at the flight was high (MOHANAVELU *et al.*, 2020).

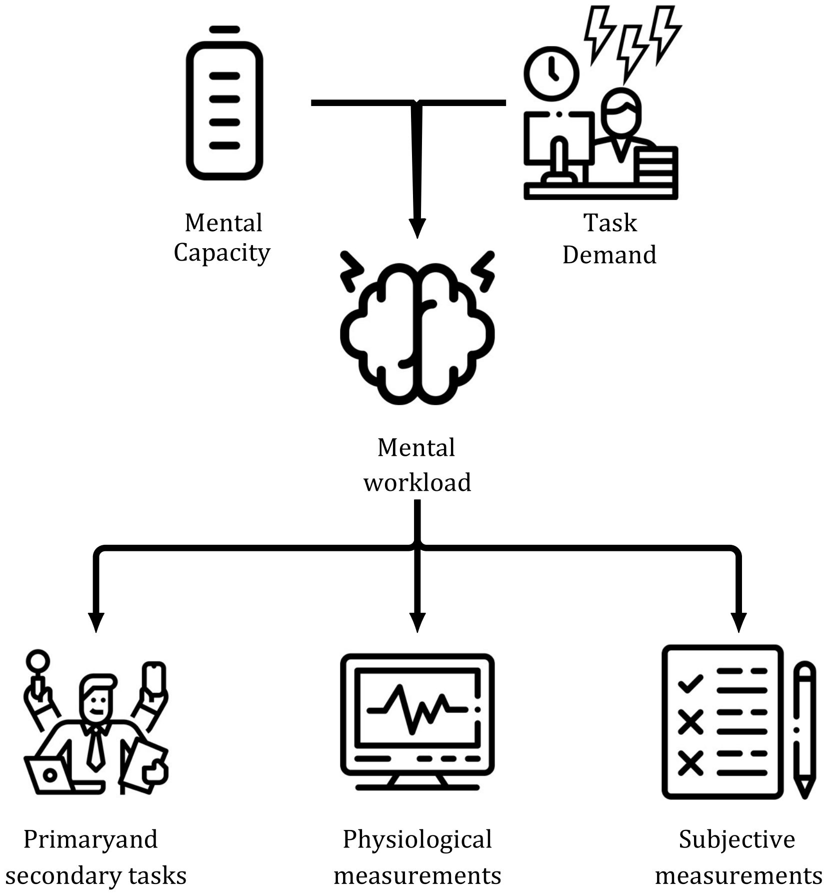


FIGURE 2.2 – A overview of mental workload and the methods to infer it.

2.2.2 Physiological measures

There are many physiological reflexes that one can use to assess MWL. These measures are a good, unbiased method to assess MWL (FALLAHI *et al.*, 2016), but, still, it is recommended that they are evaluated alongside other method. It is possible to extract MWL information from the heart and brain activity (CHAKLADAR *et al.*, 2020; ORLANDI; BROOKS, 2018), skin conductance, eye movement, pupillary contraction (STANTON *et al.*, 2004; RODR´IGUEZ *et al.*, 2015) This master's thesis it is used heart activity and skin conductance.

2.2.2.1 Heart rate and heart variability with electrocardiogram (ECG)

Electrocardiogram is a recording of the heart's electrical activity. With this recording one can verify the heart's interval between heartbeats and frequency (heart rate, HR), and other statistical parameters such as the standard deviation and the mean error (heart rate variability, HRV) and these are a good way to assess MWL (CAIN, 2007). This is a simple and non-invasive method used in many human factors' experiments (MOHANAVELU *et al.*, 2020; MANSIKKA *et al.*, 2016; ZHANG *et al.*, 2014).

The heart activity is controlled by the sympathetic and parasympathetic nervous systems. These systems are responsible to control many of the body's autonomous activities (STANTON *et al.*, 2004). (DEFINIR MELHOR)

During a task that has a mental demand the user's heart activity changes with MWL. The higher the MWL, higher the HR and lower the HRV. This happens because of the mechanism that controls our heart activity. These are consequences of two reactions in our system when in a mental demand situation (STANTON *et al.*, 2004).:

- A decreased parasympathetic nervous system activity and;
- An increase sympathetic nervous system activity.

2.2.2.2 Electrodermal response with galvanic skin reaction (GSR)

One of the electrodermal activity that can happen in our skin is controlled by the the sweating and the moisture level and both can be used to reveal changes in our sympathetic system (NOURBAKHSH *et al.*, 2012; SHI *et al.*, 2007). So its origin lies solely in the sympathetic branch of the autonomic nervous system as is MWL (STANTON *et al.*, 2004). EDA is being used to assess stress, emotion, arousal, mental strain and cognitive activity (NOURBAKHSH *et al.*, 2012; STANTON *et al.*, 2004; SHI *et al.*, 2007)m also used to evaluate the usability of HCI systems (SHI *et al.*, 2007) and some are to assess the mental workload (ZHANG *et al.*, 2014; BORGHINI *et al.*, 2014).

2.2.3 Subjective measures

It is discussed if one should only use subjective measures to measure MWL (SANDERS; MCCORMICK, 1998; STANTON *et al.*, 2004). They are sensitive to perceived difficulty, automation, concurrent activities and demand for multiple resources. These test can be unidimensional, that are simplier but has only a general workload score (STANTON *et al.*, 2004), or multidimensional. Some example of the latter is the Subjective Workload Assessment Technique (SWAT) and the NASA Task Load Index (NASA-TLX), both multidimensional tests. SWAT treats MWL as a load defined by three dimensions: time load; mental effort load; and psychological stress. In this test the user score each of these dimensions based on a 3-point scale while NASA-TLX uses 6 different dimensions.

2.2.3.1 NASA-TLX

NASA-TLX is a questionnaire created by Hart e Staveland (1988). It is answered by an user who has just completed a task/activity that someone wish to infer its MWL. This questionnaire will assess the task's MWL felt by that user with 6 rating scales and each of these is explained, ideally, at the experiment's briefing. The Table 2.1 presents each scale with a description of it.

TABLE 2.1 – NASA-TLX dimensions and the description of each dimension. (STANTON *et al.*, 2004).

Dimension	Explanation
Mental demand (MD)	The mental and perceptive activity demanded by the task (chose, decide, think, calculate, search, etc.).
Physical demand (PD)	The physical activity demanded by the task (pull, lift, spin, drag, etc.).
Temporal demand (TD)	The time pressure felt by the user. A rating the leverages the time available and the time necessary to completed the task.
Performance (PE)	The user's satisfaction with it's perfomance or result the task.
Effort (EF)	A rating of the effort necessary to achieve that perfomance felt by the user.
Frustration (FR)	A rating of stress, annoy or irritation felt by the user throughout the task.

This questionnaires evaluate only one task/activity. So if the user executed two tasks (like a primary and secondary tasks), he/she should be oriented to answer about primary task only, not a combination of both of them (SANDERS; MCCORMICK, 1998).

To measure mental workload, it is recommended not to chose only one measuring method, but more. MWL is multidimensional and can reflect partially or differently in each of the methods (SANDERS; MCCORMICK, 1998).

2.3 Situation Awareness (SA)

Situation awareness (SA) can be defined as ”the perception of the elements within a volume of time and space (Level 1), the comprehension of their meaning (Level 2), and the projection of their status in the near future (Level 3)”. The term was first written in the aeronautic sector. Today is key factor when designing complex and dynamic system's, i.e the aeronautic and automotive, medical and nuclear power plants systems (ENDSLEY, 1995). It is an important factor to make sure that the user will be capable to take important decisions correctly and achieve high performance (ENDSLEY, 1988a; ENDSLEY, 2018).

For example, when an air traffic controller looks at a radar display, he/she seeks to understand the aircraft's position and speed and then predict their position in the near future (5, 10 or 15 minutes after) (SANDERS; MCCORMICK, 1998), or when a pilot reads the cockpit panel, understands their data then he/she is able to predict the next reading of that same instrument or some other status of the aircraft after a couple of minutes.

As is with MWL, SA is not a quantitative subject. The most common way to to measure SA is by subjective methods, like for example the Situation Awareness Rating Technique, but is not reliable since it can distort the participant's answer (STANTON *et al.*, 2004), and the Situation Awareness Global Assessment Technique (SAGAT). The Figure 2.3 represents an overview of SA.

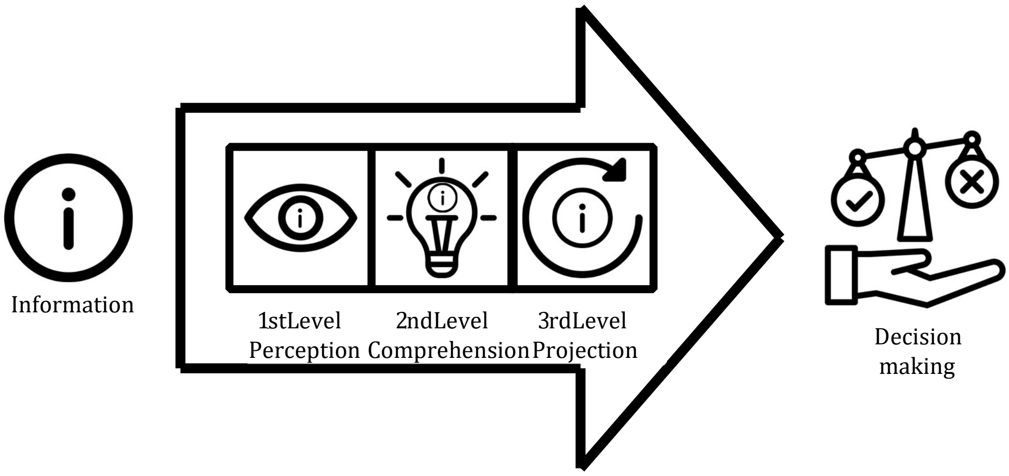


FIGURE 2.3 – A overview of situation awareness and the SAGAT.

2.3.1 SAGAT

The Situation Awareness Global Assessment Technique is a method developed by ENDSLEY in 1988b. It is based on how the information is processed inside the user's mind. The test application is made by stopping the operator activity, usually made in a simulation, then asking the user an amount of questions that were previously created based on the user's activity. These questions should be as similar as possible to how the person thinks when thinking about that information in order to avoid extra effort in understanding it (STANTON *et al.*, 2004).

Although the stopping during the activity may sound troublesome for the testing, empirical work shown that that doesn't interfere with the the user performance and the user memory can withstand a break as long as 5 to 6 min ENDSLEY

2.4 Extended Reality (XR)

Extended reality refers to the interaction of a Human-Machine system with a real and virtual interface together. It has four differents forms:

- Augmented Reality;
- Augmented Virtuality;
- Mixed Reality;
- Virtual Reality.

These forms differs from one another based on a leverage of reality and virtuality involved on the system. To help to visualise these differences, Milgram e Kishino (1994) created the concept of ”virtuality continuum” and is presented on Figure 2.4.

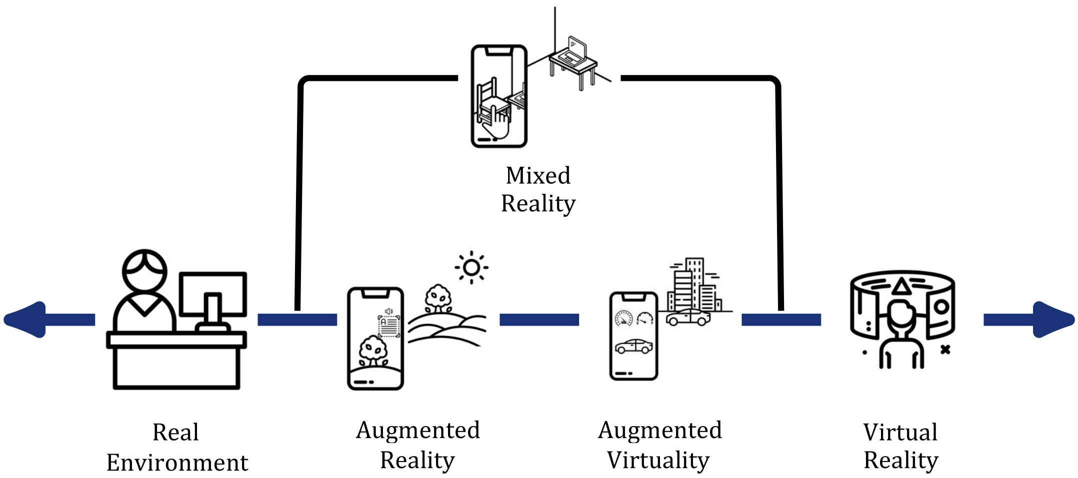


FIGURE 2.4 – The Virtuality Continuum concept (MILGRAM; KISHINO, 1994)

The extreme left means full reality, where the stimuli does not come, or is not produced, from any computer or any other digital system. Along the path to the right, the environment starts to have some digital elements until it reaches the far right, where all the elements in the environment have a digital origin (NIJHOLT; TRAUM, 2005; DOOLANI *et al.*, 2020). The first step from the Real Environment towards Virtual Reality is the Augmented Reality.

2.4.1 Augmented Reality (AR)

In augmented reality, the user can see some digital elements, that could be text, images, video, etc, that are laid in a real environment without the user losing the sense of presence in the real world. Some uses for AR are to assist workers in the manufacturing, assembly tasks and in training (DOOLANI *et al.*, 2020; FARRELL, 2018; MA; CHOI, 2007).

2.4.2 Augmented Virtuality (AV)

While AR brings digital elements inside a real environment, Augmented Virtuality creates an environment that could only exist with a digital origin, like a fantasy world from games or movies. This scenario is the background of some other activity that is being done in a real environment. An example could be using a virtual environment during the a pilot or driver training or an engineer visualizing a real-time model of an aircraft in flight (FARSHID *et al.*, 2018). Other example could be playing sports the use an equipment to play it, like tennis, golf or baseball but the arena is completely digital. The user can use the real equipment with a tracker, but, besides that, the rest would be all digital.

2.4.3 Mixed Reality (MR)

Mixed Reality stay in between Real and Virtual Environment. But what is the difference between MR and AR or AV? In MR the user can manipulated the digital element, as if it where inside the real world (DOOLANI *et al.*, 2020). For example, a client from a furniture store could use MR to see what product fit inside his/her room. He/she can move the furniture inside the room and see if the colors, size and shape fit before buying or even going to the shop.

2.4.4 Virtual Reality (VR)

Resting in the far right of the virtuality continuum, the Virtual Reality has its user as the only element that hasn't a digital origin, making he/she totally immersed in a virtual environment, but, of course, inside the physical limits of a real environment (MA; CHOI, 2007). If the feeling of presence of that environment is well done, the user can momentarily forget about the real environment and act and react accordingly to the virtual environment (FARRELL, 2018).

VR is a powerful tool that allow an user to be transported to a tridimensional environment that could be out of reach or that doesn't exist but is perfect to test or train some situation. Inside this virtual environment the user can walk and look around and interact with the many elements as if they were real (MUJBER *et al.*, 2004) and this technique becomes more effective and valuable when one can simulate a real situation and use it for training (SALAH *et al.*, 2019).

The Figure 2.5 shows the representations of each of these Extended Reality subsections.

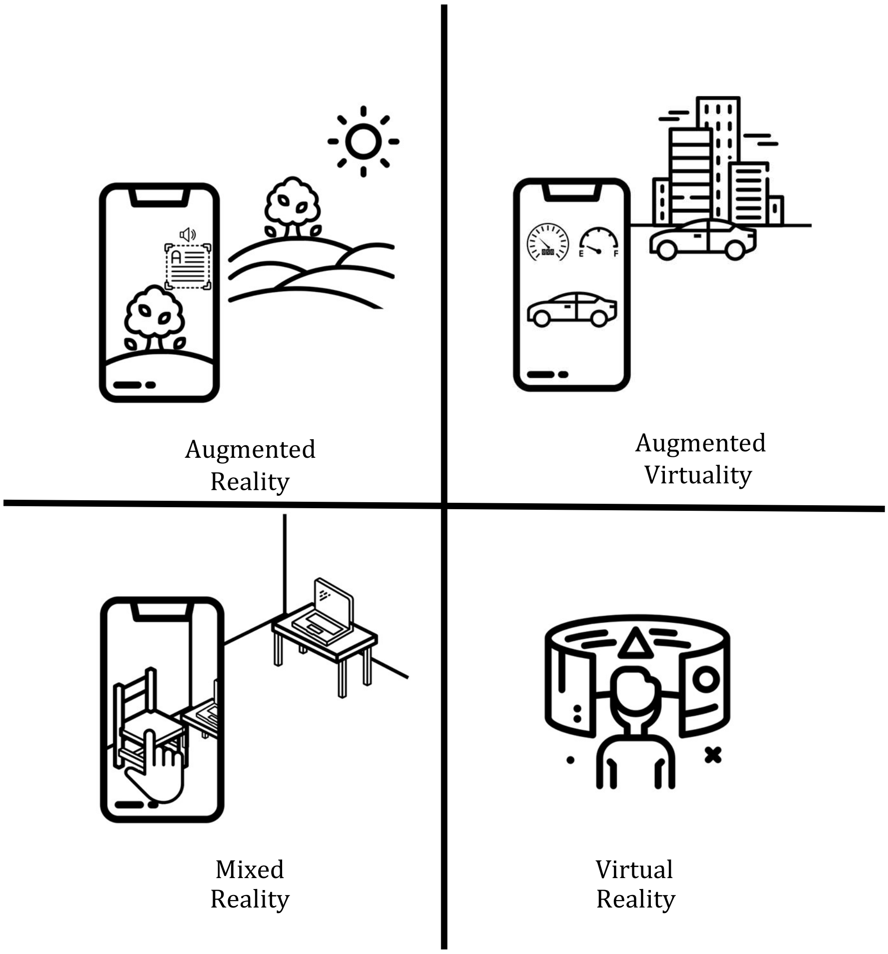


FIGURE 2.5 – A represantion of the differences between AR, AV, MR and VR

2.5 Co-Design

Collaborative design is a way to design that each element inside the design team has a different experience, resourcers, ideas or formation that is important for the product effectiveness. It is based on a good communication and in the information sharing (CHIU, 2002). Still, it is common to say ”collaboration” interchangibly with ”interaction” and ”cooperation”. Some authors define those words differently. ”Interaction”is a more formal relationship between the elements (KAHN, 1996) and ”cooperation” focus more on the coordination and the mutual gain or benefit between the elements (SMITH *et al.*, 1996).

For collaborations, the shared vision and the process to be followed are imporant (KLEINSMANN, 2006).

> Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed (KLEINSMANN, 2006).

According to Kleinsmann (2006) there are two aspects that are important for Collaborative Design:

Information is a data after the receiver understanding, or translating, process. Knowledge is the data in a state that is possible record, register to remember later inside the individual's memory. This can be ideas, facts or concepts. During the collaborative design, these ideas, facts or concepts are exchanged between the actors. This exchange is a fundamental part of this method since it is responsible for the growth of each individuals's knowledge and this is used to perform their individual tasks. This brings us to the second aspect, the knowledge integration (KLEINSMANN, 2006).

With both of these aspects in mind, Kleinsmann (2006) defines Collaborative design as "the process in which actors from different disciplines share their knowledge about both the design process and the design content". This happens to increase the team understanding to help them to design a new product based on all of their knowledge and experience.

3 Literature review

For the literature review of this work the following steps were taken in order to gather the used information.

- Search through the Scopus and Web of Science platforms;
  - Search the Scopus plaform:
    - Filter articles using the keywords ”Human Factors”, ”Virtual Reality”; ∗ Filter articles from 2019 until 2022 and related to engineering or social science;
    - Read the title and abstract and select the more relevant of them; ∗ Read the selected articles.
  - Search the Web of Science:
    - Filter articles using the keywords ”Human Factors”, ”Virtual Reality”, ”Covid-19” and ”Blindness”;
    - Read the title and abstract and select the more relevant of them; ∗ Read the selected articles.

After following these steps, 344 abstracts were read and from these the following articles were selected as the most relevant for the research.

3.1 Virtual Reality Without Vision

SIU *et al.*, also motivated by the popularization of the VR technology, developed a White Cane to be used by BVI users in virtual environments and to make virtual reality application useful for these users as well. The traditional white cane transmits three sources of information to the user: Detection of obstacles, surface topography and footplacement preview and these information are transmitted through sounds or haptics (SIU *et al.*, 2020) and the developed cane would simulate that in the virtual environment.

For the obstacle detection, the new cane was build with a three degree-of-freedom brake mechanism that would stop the movement when the cane hit an obstacle. It was installed a voice coil actuator that was used to detect surface properties or other information that had a higher frequency than the capacity of the brake mechanism. Lastly, a wave-based acoustic simulation was used to render geometry-aware sound effects in other to enable the user a sense the surroundings using the sounds (Echolocalisation).

The experiment's participants were meant to play a "Scavenger Hunt" using a HTC Vive. During the experiment each participant had two tasks:

- Collect targets along the way;

  The main task. Five targets appeared, one at a time, once the previous target was collected, and they emitted a sound that acted as an audio beacon for the participant. The experiment was concluded when the participant collected all of them.

- Avoid virtual obstacles and walls.

  The secondary task. These obstacles didn't emit any sound as a beacon, but the participant could detect it by the shape and by the noise it emits when in contact with the cane. All the obstacles had the same geometry and material, a cube shaped metal. When tapped by the cane, this object emitted a metal clinking sound.

Besides the audio beacon and the metal sound, there were also a sound when a target was collected, when colliding with a wall and with an obstacle. Figure 3.1 shows the targets obstacles and the starting point location.

The experiment was performed with 8 blind users (4 female, 4 male) from 25 to 70 years old. All of them did a training section where it was presented to them the mechanics of the virtual environment and how to detect walls, doors and obstacles. Figure 3.2 shows both the training and the game rooms.

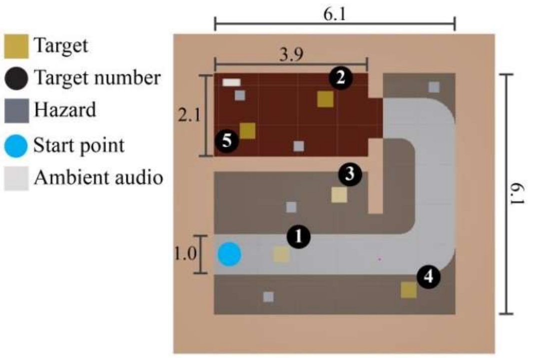


FIGURE 3.1 – Siu et al. key locations. Distances are in meters (SIU *et al.*, 2020).

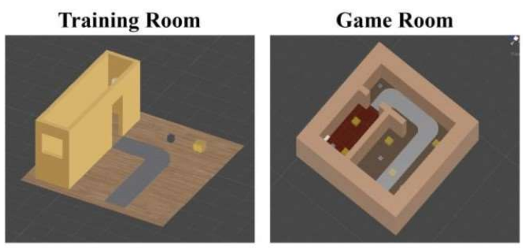


FIGURE 3.2 – Siu et al. training and game rooms layout (SIU *et al.*, 2020).

The researcher found out that the simulated vibration of the cane confused part of the participants, while other part were familiar with that vibration of the cane. This was reflected in the performance of this participants. The ones that were already used with this vibration performed better. This shows that user preferences can impact their perfomance and experience in the VE.

Another point taken by the researcher was about navigating in tight spaces. Is was easier for the participants to navigate in larger areas, similar as it is said in real world.

The final conclusion was about the exploration of the environment. The participants were focused in finding all of the target and did not explore the environment. This might have caused a bias in the low time and low obstacle hits. So it not sure that the tool could help a BVI user to freely explore a VE.

The authors noted some limitation. The cane, even though it had a good brake system, it didn't stop the participant when he/she walked forwards towards a wall. The lack of variation in the cane material and in the feedback possibilities (i.e when the obstacle contact a point along the cane, not the tip of it).

The present experiment has similar motivations, to study or improve BVI users' navigation, but in different environments. While the work from SIU *et al.* was focused in the navigation of BVI users inside a VE, this experiment uses VE to assess BVI navigation in a simulated real environment. SIU *et al.* commented the importance of the sound in the guidance of the BVI and used spatialized audio to increase the realism and received a positive feedback by the participants as this experiment also did.

One big difference between the two works is the cane. SIU *et al.* used a cane controller that represented a virtual cane inside the VE, as was made in this work with the *Virtual Cane*, but the feedback from the *Virtual Cane* interaction on the VE was only a vibration, whilst the cane controller, besides using a high frequency response that could be said to be similar to a vibration, used a brake system to simulate the contact with the wall or obstacle. This experiment couldn't apply this resource for financial and time reasons.

3.2 Effects of Emotion and Agency on Presence in Virtual Reality

One of the many feelings that flourish during the use of a VR is the feeling of presence. This feeling, inside the virtuality context, is when someone feels draw into a VE and starts to occupy the VE instead of the real one (CUMMINGS; BAILENSON, 2016).

Jicol *et al.* (2021) explores this feeling in its work. The authors aim to correlate the feeling of presence with one's agency (which is the self perception that the user is in control of a situation or some actions (FARRER; FRITH, 2002)) and emotion, both of these in a VE context. Besides assessing this correlation, the author also did a structural equation model (SEM) based on their findings. The author did this by creating two different VE, one that would trigger happy emotions, and another that would trigger fear. For each VE there was two different variations of it, one that the user could interact with it's elements and another that it could not. So at the end, four different VE were designed as the Figures 3.3a to 3.4b show.

(a) Without agency. (b) With agency.

FIGURE 3.3 – Happy environment (JICOL *et al.*, 2021).

(a) Without agency. (b) With agency.

FIGURE 3.4 – Fear environment (JICOL *et al.*, 2021).

This experiment had 121 participants and they were randomly assigned to one of the four VE. Participants with a neurological disease, fear of dogs, psychological or emotional issues, epilepsy or use of medical device were excluded.

The authors had three hypothesis about their experiment:

1. The intensity of the dominant emotion in each VE will correlate positively with the presence

2. Presence will be significantly higher in environments where participants have agency

3. Agency will moderate the effect of the emotion on the presence

The first hypothesis was confirmed. No matter if the feeling is positive (happiness) or negative (fear), the users did felt a stronger presence when the positive or negative feeling were more intense.

The second hypothesis was partially correct. In the VE that provoked fear, agency did make a difference and induced a higher feeling of presence, whilst in the VE that provoked happiness, agency did not affected the presence. The same could be said about the third hypothesis.

This is an important work for its findings about the user's presence feeling. Inside a VE, users that have a direct interaction inside it do find a bigger feeling of presence. This is important for this master's thesis experiment. It is possible that, if the participant did not feel ”present” inside the VE, the gathered data could be less sensitive to the experiment's goals.

This experiment did not assess directly the feeling of presence, but the feeling of presence inside a VE with BVI users could be a suggestion for future works or even a base study.

3.3 Bradley and Dunlop research about BVI navigation

Bradley and Dunlop written two works about BVI navigation, one in 2002 and the last in 2005.

3.3.1 The 2002 investigation

On 2002 they studied which information BVI users used throughout their navigation and compared the data collected with another similar data, but instead it was answered by sighted users. This second data was also collected by the same researchers in a prior investigation, made also in 2002, and both of the data were collected using the same interview's structure.

This investigation was made by analysing the answers from a interview with the participants. In this interview, the participants had to explain how to arrive to two different location as if they were talking to someone with the same condition. The answer were than classified in 11 different categories:

- Directional (e.g. left/right, north/south)
- Structural (e.g. road, monument, church)
- Environmental (e.g. hill, river, tree)
- Textual-structural (e.g. name of shops, places, restaurants)
- Textual-area/street based (e.g. name of street, neighborhoods, squares)
- Numerical (e.g. first, second, 100m)
- Descriptive (e.g. steep, tall)

- Temporal/Distance based (e.g. *"walk until you reach..."* or *"before you get to"*)
- Sensory (e.g. sound of engines, smell of bread from a bakery)
- Motion (e.g. cars passing by, doors opening)
- Social Contact (e.g. asking people or using a guide dog for help)

The motion and the social contact was added in the interview with the BVI users, so the researches re-analysed the sighted answers to fill this classification as well. The Figures 3.5 and 3.6 show their findings.

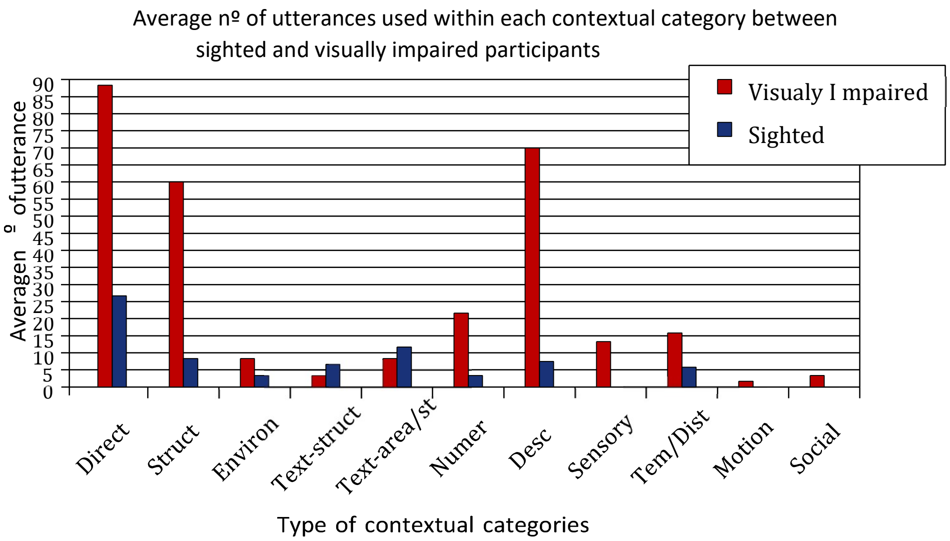


FIGURE 3.5 – Comparison between sighted participants with BVI participants (BRADLEY; DUNLOP, 2002).

In conclusion the researches realised that BVI participants use less text-based information than the sighted participants, but BVI participants used more words to describe a path than the sighted participants.

Besides describing the paths to reach the destinations, the researches also asked the BVI participants their "opinions on the importance of different types of contextual information for route navigation, design issues relating to usability and their mobile needs/requirements"(BRADLEY; DUNLOP, 2002). Many participants said that white canes and guide dogs had limitations and also commented that sensory information are very important when different types were used together in order to confirm one information.

Average nº of contextual categories used per participant

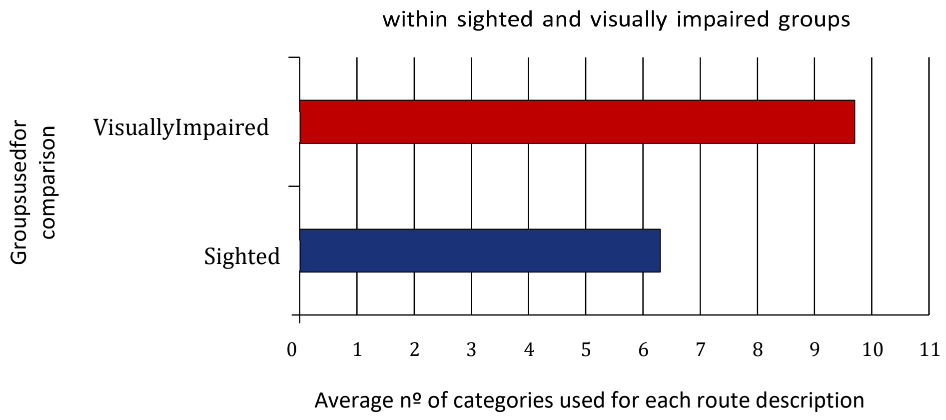


FIGURE 3.6 – Number of categories used by each group (BRADLEY; DUNLOP, 2002).

3.3.2 The 2005 experiment

Based on the findings from 2002, Bradley and Dunlop designed an experiment to investigate if there is a difference between the perceived workload of both BVI participant and sighted participants when then navigate using a user-tailored information created with the results of both previous experiments.

16 participants, 8 sighted and 8 BVI, were recruited to walk to four pre-determined landmarks at the centre of Glasgow. They followed the same orientations that were pre-recorded and given to the participants. For each participant, orientations for 2 of these 4 landmarks, that were made using based on the proportions of the results of the sighted users' interview, were randomly given. Similar was made with the remaining 2 landmarks, but with orientations made with the findings of the BVI users' interview. These proportions are presented at the Table 3.1

TABLE 3.1 – Proportion of each type of information used by sighted and BVI participants (BRADLEY; DUNLOP, 2005)

Class of contextual information	% Used Sighted	% Used BVI
1. Directional	37.4	30.1
2. Structural	11.5	20.1
3. Environmental	1.6	2.9
4. Textual-structural	9.9	1.2
5. Textual-area/street	15.6	2.7
6. Numerical	5.0	7.5
7. Descriptive	10.8	23.8
8. Temporal/distance	8.2	5.1
9. Sensory	0	4.4
10. Motion	0	0.8
11. Social contact	0	1.4

Their results found out that BVI users reached landmarks significantly quicker when given the information that were made for that group, but still longer than sighted users. This comparison is show in the Figure 3.7 and 3.8. Condition 1 is the verbal orientation made for sighted users and condition 2 is the verbal orientation made for BVI users

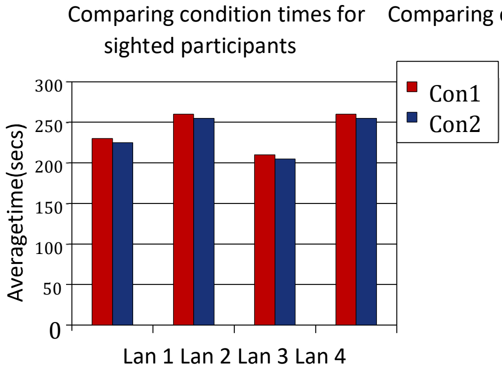


FIGURE 3.7 – Mean times for each landmark performed by the sighted participants (BRADLEY; DUNLOP, 2005).

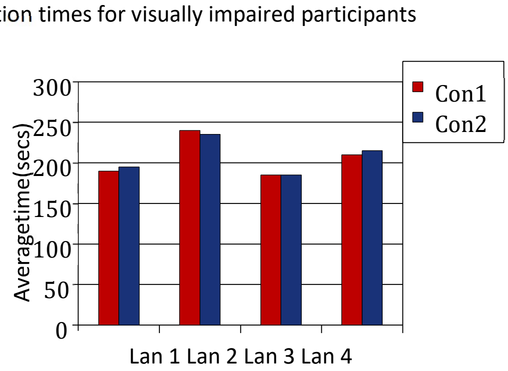
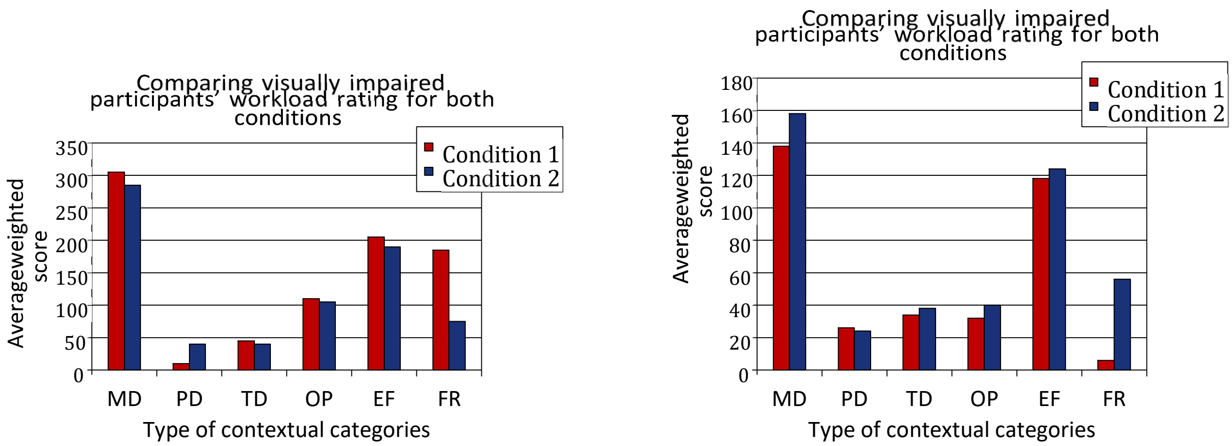


FIGURE 3.8 – Mean times for each landmark performed by the BVI participants (BRADLEY; DUNLOP, 2005).

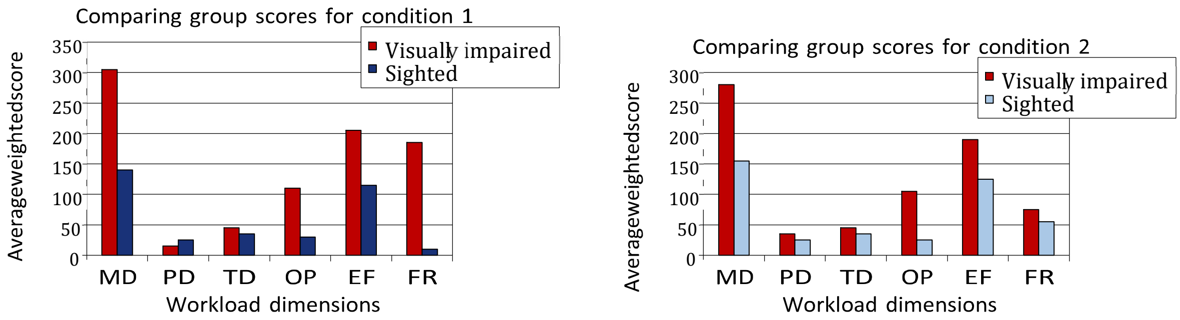
After the experiment a NASA-TLX was completed by each participant. The score for each dimensions is show in the Figures 3.9 and 3.10. These scores show that BVI participants did had higher workload when guided by the condition 1 as well as the sighted participants did with the condition 2.



(a) BVI participants.

(b) Sighted participants

FIGURE 3.9 – Comparison of the NASA-TLX between the conditions (BRADLEY; DUNLOP, 2005).



(a)Condition 1. (b)Condition 2.

FIGURE 3.10 – Comparison of the NASA-TLX between the participants (BRADLEY; DUNLOP, 2005).

This current experiment used their conclusion in order to create proper navigation commands used in the experiment. Another difference between this experiment and the one written by the duo is the inclusion haptics information in the scope of studied guidance commands.

3.4 Evaluation of spatial display for navigation without sight

In the work of (MARSTON *et al.*, 2006), the author wanted to test a prototype developed in previous researches on the street and in a park with a blind user. This experiment would also compare two differente guidance display, one based on haptics transmission and another based on sounds.

8 BVI participants attended the experiment, that was divided in one training set and two test sites. The first was in a busy block which had a variety of street furniture, parked bicycles and people and the participant need to pass through 4 waypoints for a total of 244m. The second site was inside a park, with paths made of concrete, crushed gravel and paver blocks, with 7 waypoint for a total of 187m. Each participant did each route with both guidances displays.

The researches collected the time to collect all waypoints, the errors made, the distance travelled and the percentage of the total time that the users accessed the guidance device. All participants were able to complete all routes and collect all waypoints with both devices. This shows that they were able to be guided by new sound or haptic devices. The mean time to collect all he waypoints using the sound device was lower than with the haptic device, as show in the Figure 3.11. This Figure shows a standardize time made based on the time that two researchers took to complete the route, both of them blindfolded and with a cane, but already had made the same route many times before and during the experiment.

Another finding from this work is about the use haptic device the cause some strain

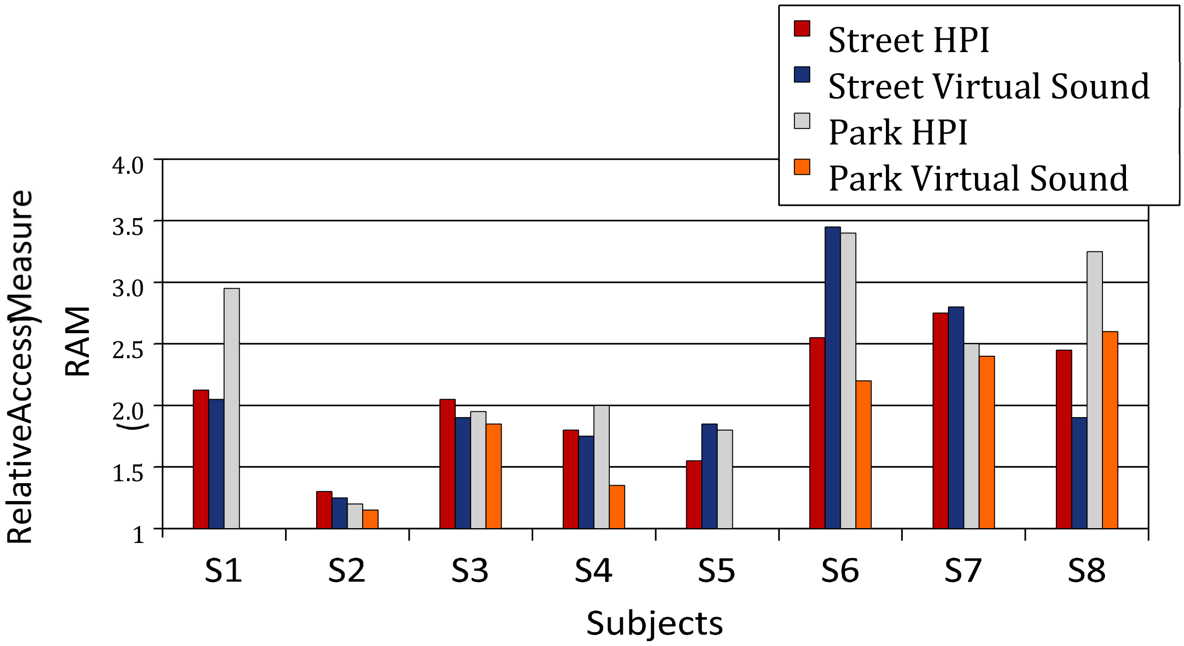


FIGURE 3.11 – Standardize mean completion time for each subject with each device in each route (MARSTON *et al.*, 2006).

at the arm and was less acceptable as compaired to the sound device, that required no use of the arms.

This study was relevant for current work because it also compares the same types of guidance devices. The participants were asked to score both devices in three questions from 1 = very unacceptable to 5 = very acceptable. These scores are presented in the Table 3.2. As said above, the participants were able to perform the full experiment with both devices, but there seems to be a preference for the sound-based device.

TABLE 3.2 – Scores of the device

Statement	Haptic device's mean score	SD	Sound device's mean score	SD
Precision of the directiona information	4.0	0	4.1	0.83
Personal safety while using the device	4.1	0.35	4.0	0.76
Ease of use	3.5	0.53	4.6	0.52

But what about being able to use both devices? That's one of the questions that the experiment of this master's thesis aims to answer.

3.5 Use of VR in the aircraft cabin design process

VR is also being studied by aeronautics and aerospace industries. MOERLANDMASIC *et al.* proposed the use of the VR during the aircraft cabin's design procedure. The idea is to create a easy communication between the development actors and it's clients.

The cabin design procedure is often said to be a complex product because it involves a lot of users and stakeholder and each of them have their own set of preferences and requirements MOERLAND-MASIC *et al.*. The time needed to attend all of these demands tend to be long and expensive. In order to understand better the design process of an aircraft cabin, MOERLAND-MASIC *et al.* interviewed an cabin designer and the conclusion of this interview was that the cabin design needed in general 2 years to be concluded. As an example, the interviewed cited a design that multiples mock-ups and more than ten meetings with the stakeholder were needed while designing the cabin. The Figure 3.12 illustrates a simplified cabin design process and shows that the traditional process has a high chance to return to initials phases even at final phases.

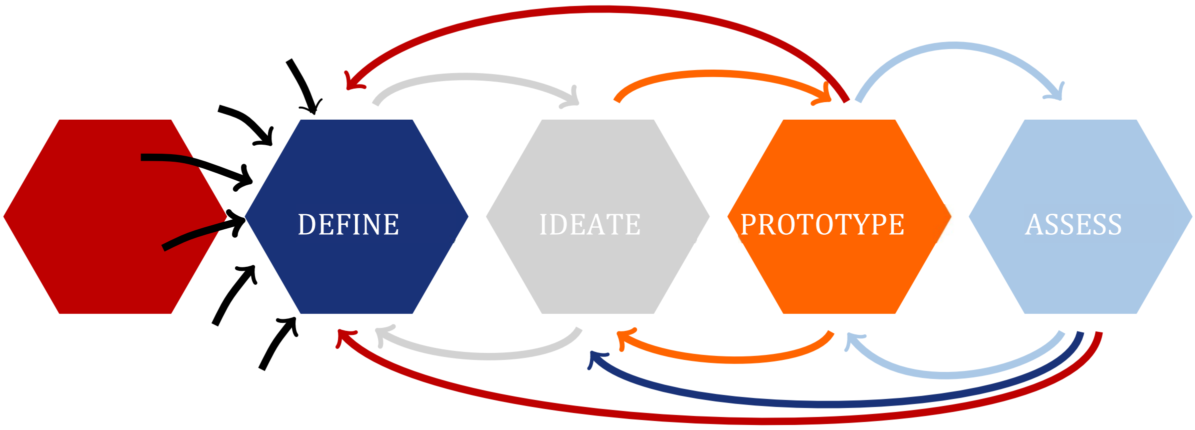


FIGURE 3.12 – Simplified cabin design process (MOERLAND-MASIC *et al.*, 2021).

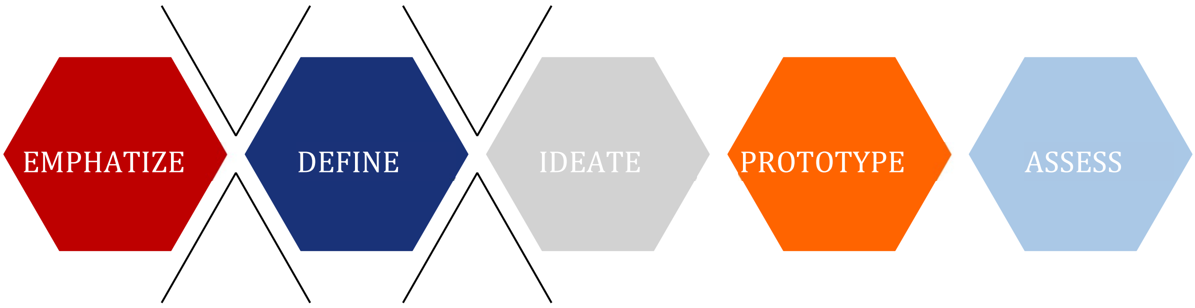


FIGURE 3.13 – Best moments for user involvement (MOERLAND-MASIC *et al.*, 2021).

MOERLAND-MASIC *et al.* are inside the German Aerospace Center (DLR, *Deutsch Zentrum fur Luft- Raumfahrt¨*) and decided to study a new procedure that could bring the involvement from the final users in the design process. This procedure is based on codesign, where the users can influence the product's development from the beginning until the end. The Figure 3.13 shows the best moments to bring the users to the process. But for the involvement to happen, a communication channel needed to be established. The authors choose to use *Reality Works* and test on a DLR's inside project. This project's goal was to design a new cabin that would be incorporated in a large workflow, but the design process was to be completely made in an digital environment. This was the perfect test case for the VR use in the cabin's design procedure.

A pilot use case was made with the members from this project. Three different designers (two with around 5 years of experience and other more than 35 years of experience) initiated a cabin design. The Figures 3.14 and 3.15 show the results using the traditional method. The sketch can only present a glance of what the cabin will be. The 3D model has more details, but any change on this representation needs a new rendering session and this can take hours, or even days, to be made.

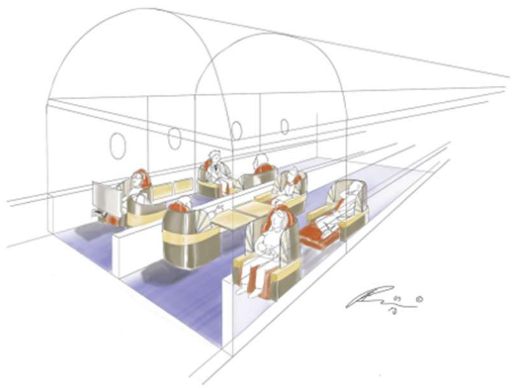


FIGURE 3.14 – Cabin sketch made with Adobe Photoshop (MOERLAND-MASIC *et al.*, 2021).

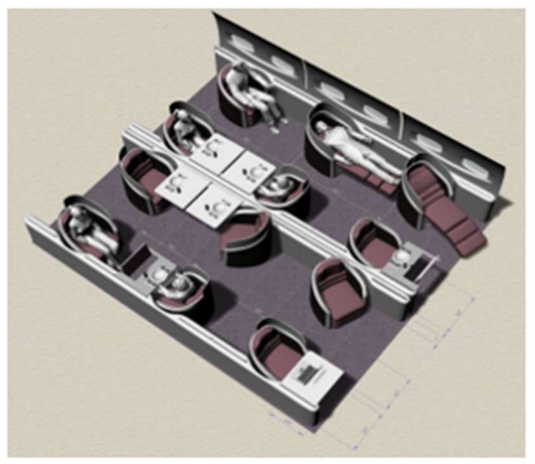
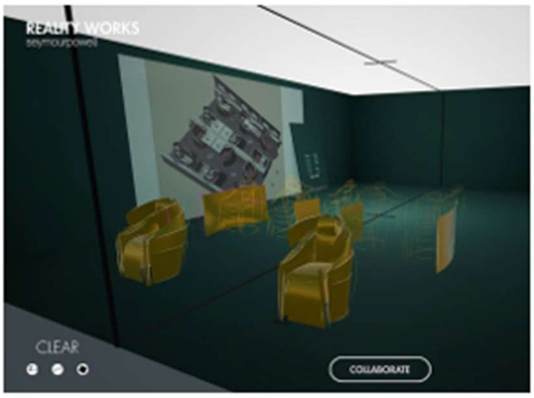


FIGURE 3.15 – Cabin 3D model made with Rhyno (MOERLAND-MASIC *et al.*, 2021).

The Figures 3.16 and 3.17 show the same representation but made in a VR environment. The sketch was made inside the aircraft cabin and this could have been done with a client or a stakeholder and they could also draw and give their opinions from the beginning. The 3D models can be imported to increase the sketch's level of detail.

FIGURE 3.16 – VR navigation with sketching



(MOERLAND-MASIC *et al.*, 2021). FIGURE 3.17 – VR navigation with imported 3D models (MOERLAND-MASIC *et al.*, 2021).

This case was well received by the design team and they chosen to continue to use the VR tool. The benefits disadvantages pointed by MOERLAND-MASIC *et al.* are listed in the Table 3.3. The VR definitely helps to brings the clients closer to the design team, allows to draw quick sketches in brainstorming gatherings and has a steep learning curve for the designers. On the other hand, is its a high cost tool, the use during a long time can cause nausea and maybe other health implications and, even though the learning curve is steep, there is still a learning curve and the user needs to get used with the exposure to others that can see the user from outside the virtual environment (some find this situation uncomfortable).

TABLE 3.3 – The benefits and disadvantages noted by the authors MOERLAND-MASIC *et al.*.

Benefits	Disadvantages
Bottleneck at early concept design stages	High cost
Quick sketchs during brainstorming	Nausea and other health implacations
Steep learning curve	There is a learning and personal adaptation to exposure

The current master's thesis isn't about designing or aicraft cabin's, but this research shows that VR is being studied to be implemented inside industries. The current research could be done by any product industry that wanted to create a test environment for their clients in order to increase the user's approval or to bring other teams close to reduce the full design time.

4 Proposal description

This chapter is about the proposed methodology of this master thesis experiments. The Figure 4.1 shows the phases and the tasks inside each phase. This chapter will explain each phase and task presented in the Figure 4.1.

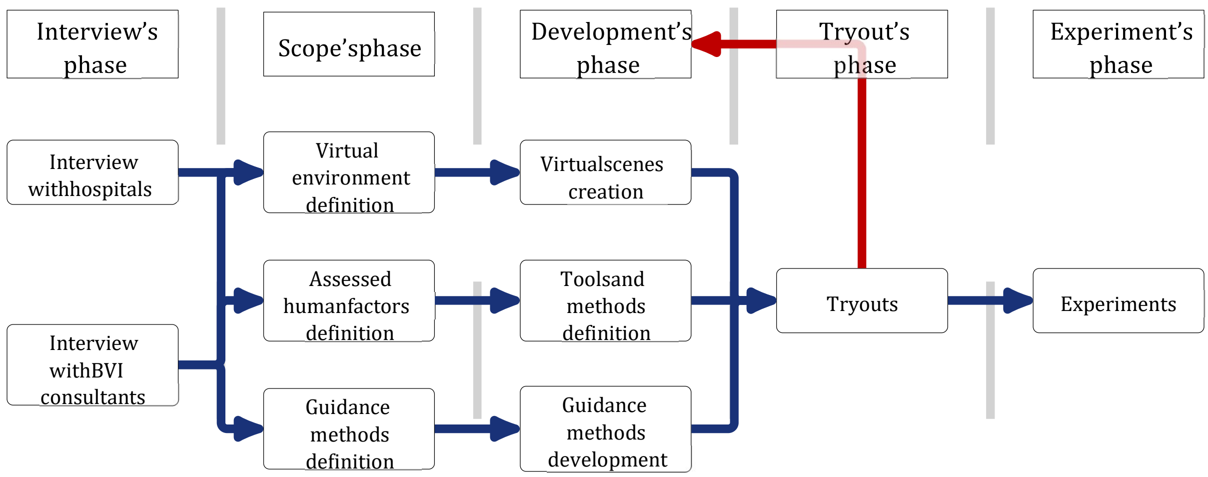


FIGURE 4.1 – Methodology's diagram

4.1 Interviews' phase

The first phase of this project was the Interviews' phase. In these phase, the researchers' main goal was to gather information, especially those related to the COVID-19 pandemic, about the main procedures that happen inside a hospital and about the daily life of BVI people.

4.1.1 Interview with the hospital

To understand the procedures that hospital and medical clinics followed during their day to day activities and during the COVID-19 pandemic, two hospitals were interviewed.

The interview was aimed to find out how a new patient does a check-in and the following steps until he/she get in the proper medic's office.

At the project start, the scenario was supposed to be a reception inside a hospital, but, because of the physical space needed to simulate that virtual environment, the scenario changed along the project several times.

4.1.2 Interview with the BVI consultants

One of the motivations of this master thesis is that the current BVI guidance products are not effective enough and one of the likely reasons is that the BVI users were not consulted during the products development process.

With that though in mind, BVI users were consulted in order to design a virtual environment that would be familiar to their reality. Two users with different visual impairments were interviewed, one person that became blind with 13 years old, and other that with Usher's disease. These were critical to understand how they perceive a medical clinic as they walk in and how they interact with the environment and these notes were used in the next phase.

4.2 Experiment idealization's phase

At this phase, the proceedings and the interview notes are used to take key decisions about the virtual environment used in the experiment, about which human factors are going to be assessed and which guidance methods are going to be used

4.2.1 Experiment's virtual world definition

As said before, the original idea was to use a hospital reception as model to the virtual environment for the experiment, however the physical space needed to fit the hospital was to big. So instead of a whole hospital reception, it was decided to use it a medical clinic reception but still with the same proceedings.

4.2.2 Assessed human factors definition

In order to reach the experiment's objective, a set of human factors had to be choose. The objectives 2 and 3 could be reach if the assessed human factor represented the user's workload and the developed mental map. Both these could be evaluated using:

- Mental workload
- Situation awareness

The details about each method are explained in the sections 2.2 and 2.3.

4.2.3 Guidance methods definition

The variety of BVI users is wide, as is the variety of assistive products. All of these products must communicate with the users and they use sound, vibration or both to transmit these information. With this though in mind, it was decided that that would be used at least two methods: one that rely only in audio and another that transmits only vibration. Of course, the interaction between those two methods would be also evaluated. This interaction became the third method.

Another interesting property that could be evaluated in those products is the effect of a information being transmitted with and without the user's command. This evaluation split the vibration method in two: one that worked *without* the user's command and another the worked *with* the user's command.

At the end, the following methods were chosen to be analysed:

- A usual guidance method;
- Audio guidance;
- Vibration guidance without command;
- Vibration guidance with command;
- Mixture of audio and vibration.

4.3 Development and creation's phase

With the decision of the previous phase it is possible to start the development of the virtual environment, the guidance methods and the tools for the assessment of the human factors.

4.3.1 Virtual world creation

The virtual reality application was made using the software Unity3D, which is a famous tool for virtual reality applications and game development. It has some built-in tools but is also possible to customize functions for more specific use (WANG *et al.*, 2010). The virtual environments, or scenes (as it is called inside the Unity3D), were made with the dimensions to fit in the CCM entry hall, that has a flat area of 8x4m. Inside the environment there was some typical furniture or devices found in hospital reception, a reception desk and a waiting area, composed of 2-3 chairs. The participant had 4 tasks at the scene and they are displayed at Figure 4.2. More details ahead at Chapter 5.

1. Clean the hands at the sanitizer totem (COVID-19 procedures);
2. Go to the reception desk to receive a queue number;
3. Go to the waiting area and wait for the number calling;
4. Leave the room when called

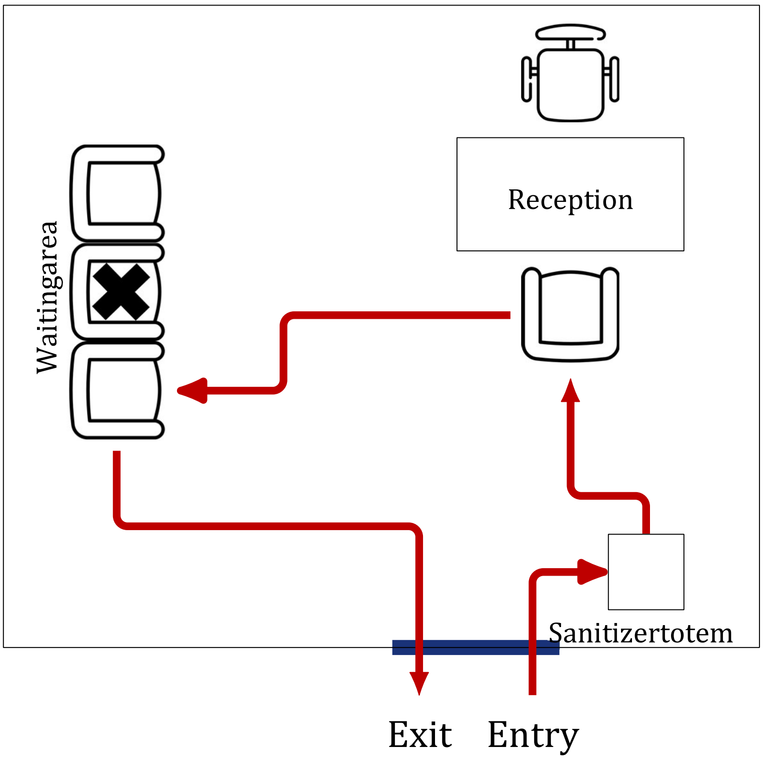


FIGURE 4.2 – Scheduled task of the experiment and their order.

The goal of these tasks is to engage the user to navigate through the room and see if it is able to draw a mental map of the scene as well as use the information of the obstacles in order to avoid them when needed. Beside theses mains components, there are also some minor distractions that is common to hear at a clinical, such as telephone ringing, keyboard typing, people taking and others. These were put to increase the immersion and to be a distraction as well, otherwise it wouldn't simulate the reality of these scenarios.

4.3.2 Tools and methods definition

There were three types of human factors' assessment tools that were applied at the experiment:

- Task performance;

Measured using the time and the number contacts between the user and the furniture throughout the experiment. • Physiological measures;

Measured using and ECG sensor, a GSR sensor and a temperature sensor. •

Subjective measures.

Measured using a NASA-TLX, a SAGAT Adapted questionnaire and a guidance method evaluation questionnaire.

The details about each method are explained in the sections 2.2.1, 2.2.2 and 2.2.3.

4.3.3 Guidance methods development

As said in the last section, three different guidance methods were established to be used in the experiment besides the White Cane:, a haptic belt and a virtual cane.

- A audio guidance method;

  The audio only guidance method will be straight simple. In the course of the experiment the participant could give two different voice commands:

  - ”What is around me?”;

    The answer of this command was a quickly description of the closest furniture around the user.

  - ”Where is (something)?”.

    The answer of this command was the direction and distance of something asked by the user.

  Each command was answered by a member of the experiment team accordingly.

- The haptic belt;

  That is a belt that had appended 8 vibration devices that vibrate accordingly to the direction and distance of the closest object around the user. More information on the Haptic Belt ahead at Chapter 6.

- The virtual cane.

  This was based on the white cane mechanics, that the user ”points”the cane to check near obstacles in the direction of the cane. The virtual cane has a similar function, but instead of connecting the user to the object through the cane, it vibrates when it detects an obstacle in the direction pointed by the user. A VR hand-control was used as canes and the user point's it to where he/she wanted. The algorithm used on the Virtual Cane is in the Appendix B

4.4 Tryouts and tests' phase

At this phase a few tests were performed to evaluate if the experiment was going as planned and to avoid any unfortunate events or errors during the real experiment. It was expected that changes could be needed to be made before the real experiment and there were a few. It was at this phase that the final dimension of the virtual environment and the physical space were defined.

4.5 Experiment

As the proper section name says, this phase is were the proper experiment was made.

After all these phases were completed, the next step was to analyze all the data and elaborate their conclusions. Instead of going to the results and discussions, the next Chapters 5 and 6 will deepen in the virtual environment development and in the haptic belt development in these order.

5 Virtual environment development

The main background and the source of the sensorial input was the virtual environment. Its development can be divided in 5 steps. The hole procedure is represented in the Figure 5.1.

1. Procedures
2. City Hospital
3. Medical Clinic
4. Adjustments
5. Final clinic

5.1 Procedures

The first step of the research was to learn how hospitals operate, especially throughout the COVID-19 pandemic. Two hospitals from the city of S˜ao Jos´e dos Campos - S˜ao Paulo were interviewed on how does the reception procedure worked and both of them had a similar operation:

1. Patient enters the hospital
2. Uses the sanitizer to clean their hands
3. Take a queue number and wait the calling of the receptionist
4. Go to the receptionist and does his/her check-in
5. Sits on the waiting area and wait until it's name is called

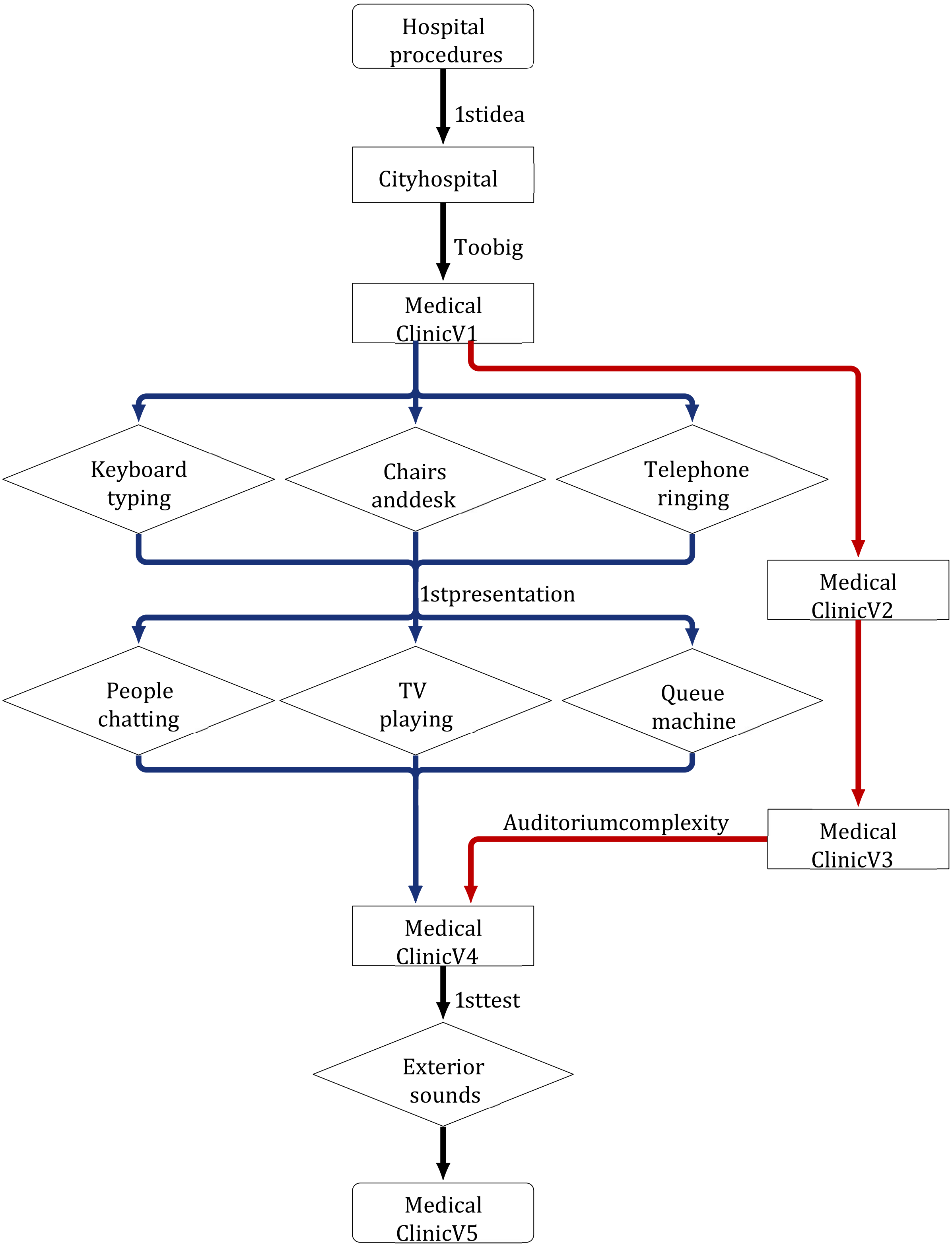


FIGURE 5.1 – Virtual environment development process

The tasks in the experiment were to be similar as these procedures. The only exception was the name calling, step 5, because of the complexity of create a routine inside the virtual environment that could call the participant's name. One possible solution was to use an actor, but because of the COVID-19 procedures that limits the number of people inside a room, this solution was discarded.

Since the procedures was from hospitals, the first idea of a virtual environment was to build a virtual hospital reception.

5.2 City Hospital

If the virtual environment was a hospital reception, it would be possible to include a lot of artifacts that could increase the participant's sense of presence, such as people walking and the sound of elevators, and that was very appealing.

One problem with that idea was the physical space needed to simulate that. It would be needed a closed quarters space with enough area to allow the participant to walk through the hole reception. The original space was approximately 15x20m and the laboratory, or the university, didn't had somewhere like that.

So the solution for that was to shrink down the area to fit inside the laboratory, so it was decided not to simulate a hospital reception, but a medical clinic reception

5.3 Medical Clinic

The laboratory didn't had a room that could fit a hospital reception, but it did had a plenty of space that could fit a medical clinic reception, especially at the laboratory's auditorium. The laboratory has 7x10m and that was the dimension of the first version of the virtual medical clinic. At the first moment, it was decided that this would be the setting for the experiment and its development went towards the definition of the interior details (blue path on the Figure 5.1), but other problems appeared along the development that the room dimensions needed to be redefined (red path on the Figure 5.1). Both of these modification are going to be detailed in the following Interior and Exterior subsections.

5.3.1 Interior

The goal of the interior was to increase the presence feeling of the participant inside the virtual environment. The inspiration was on the typical objects and furniture that a patient notices when waiting in a reception. The first objects positioned inside the reception was the desk, chairs (both normal and some with ”X” in the seats to represent a COVID-19 procedure), a telephone and a laptop. The last two also emitted sounds to increase the feeling of presence and to point to the BVI participant where the reception desk was located. The telephone and the laptop had a C# script to play their sounds randomly.

This virtual environment was presented to two BVI members of the research team and they pointed that it needed to have more noise, in order to increase even more the feeling of presence. They felt the lack of people chattering and the noise that came from a TV show, both were included in the virtual environment. To simulate the people chattering, dialogues from video or series between two people were used. The TV noise was made in a similar way, but with audio from famous Brazilian tv programs. Another missing artifact noticed by the team was the queue machine that was also included. All these added object also had a script that played a specific dialoque/program/queue order for each created scene, never repeating once, to increase the sensation of a different day [1].

After all of these objects were included, the interior was ready for a trial.

5.3.2 Exterior

The first version of the clinic had 7x10m, that was the exact dimension of the *Audit´orio Romi*, the room that was selected to be the physical space for the experiment. Since it was the exact dimension, it became the first change, since an extra space is needed to place the two VR Stations, that in the experiment was assembled in tripod basis. That modification became the second version of the clinic, with 5x7m.

The second modification came from the maximum distance between the VR Stations. Accordingly with "SteamVR" (the software that was the interface between the computer and the VR) the maximum distance was 5m, besides that it could not guarantee the correct operation of the device. Besides that, the auditorium was filled with chairs and without a computer. Every time an experiment was going to be realized, it would be needed to rearrange the entire room, costing almost half a hour to clear the space and another half a hour to return to their place. The solution was to reduce, once more, the virtual environment dimensions to 4x4 and that was the third version of the medical clinic.

The forth version was reached because, even though smaller, the rearrangement of the auditorium was still a nuisance. The answer to that was to do the experiment in the entry hall. This was a empty space, just in front of the room where the computer with all the files was stationed. The only problem was that people passed by until 17h, but since the chosen of auditorium to be the physical space, it was scheduled that the experiment was going to be performed only at non-working hours.

With these Exterior and Interior modification, the environment was ready to receive its first BVI participant.

[1] During one of the experiments, a BVI participant commented that he/she felt different day times for each time he/she did the scene

5.4 Adjustments

The first BVI participant was the blind member of the research team and he enjoyed the final result, but still found a thing that could help to increase the feeling of presence. He pointed that BVI people normally find the exit of a room by searching the following sounds in sequence and repeatedly:

1. Sound of a door opening;

2. Noise from a exterior space (like people walking, cars passing by, horns, etc.);

3. Sound of a door closing.

After that note, a sound emitting point was added in each environment. This point played this sequence of sounds, but in a random interval.

5.5 Final Clinic

After that last addition, the clinic reached its final version.

6 Haptic belt development

Since haptic is one of the type of information that a BVI user can rely on, it was a good idea to test haptic devices in the experiment. This haptic devices would not detect the real object per se, but would receive the information from Unity3D based on the positon of the user inside the virutal environment.

The virtual cane was a simple development, since the controller already had a vibration motor inside of it. Knowing that, was only a matter to find the right commands and write a algorithm that worked. A pseudo-code is presented at Appendix B. The two differences between the virtual cane and the haptic belt are the command to check distance and the fact the with the cane the user must point to the direction where he/she wants to investigate if there is an obstacle whilst the belt indicates to the user the direction of the closest object.

The idea to design a haptic belt came as a suggestion from one of the research members. It was possible to buy one directly from the internet but the cost was too high, so it was decided to assemble one from scratch. The project was based on a haptic compass (KYLECORRY31, 2020), but instead of have the input being made by a magnetometer, it was made by the Unity3D.

The first prototype was made using a Arduino Mega 2560, LEDs and a protoboard. If Unity3D could send a command to turn the LED on, then the software would be able to do the same with a coin vibrator. After checking the communication between Unity3D and Arduino, it was time to build the proper belt.

The materials used were:

- DOIT ESP32 DevKit v1. (Datasheet in the Annex A);
- A printed circuit board (PCB)
- A leather belt;
- 8 Coin Vibrator 1027;
- 16 female P2 jacks or PJ-320B;

- 16 P2 male or PJ cable connectors;
- 8 straps;
- Duct tape;

- A 3D printed case.

The first step was to correct adapt the algorithm used on the Arduino to be used on ESP32 also using the LEDs. After it was made sure that it would also work with a ESP32, the system was designed in the EasyEDA website (EASY...,) them a PCB was order with the schematic presented in the Appendix C. While the PCB didn't arrive the coin vibrator and the cables were being soldered. When the PCB arrived, it was time to solder the board P2 jacks and design a case for it, represented in the Figure 6.1. After everything was soldered, printed, connected it was ready, as is represented in the Figure 6.2.

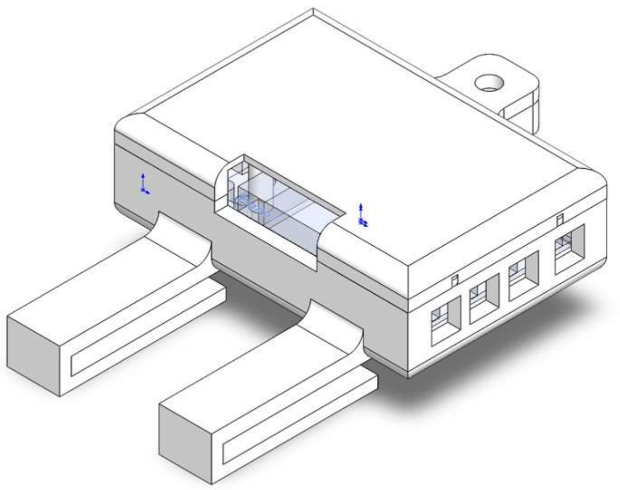


FIGURE 6.1 – CAD model of the designed case

Until these moment the belt was working cabled, but since the participant could walk great distances it was decided that the correct way to connect Unity3D with the ESP32 would be by wireless and it was decided to use a Bluetooth connection. The pseudo-code used in the development are in the Appendix C.

FIGURE 6.2 – Haptic belt

7 Results' analysis and discussion

Throughout the experiment, three data sources were gathered from the participants, and this chapter will show their values, will explain the process to analyze the data and will discuss their results. Each source will have its own section, making up to three sessions, and they are:

- Data collected from the simulation;
- Data collected from questionnaires;
- Data collected from physiological sensors.

From these point, the data' from the blind participants will be called "Blind" sample and the data' from the sighted participants will be called "Sight" sample.

The processing of each data collected is rather similar and follow these steps:

1. Separate the Blind sample and the Sight sample;

2. Check if the samples are normally distributed;

   If the data is normally distributed, than it is possible to use other statistical analysis and verify the results statistically.

3. Check if the "blind" sample is statistically different then the "sight" sample; This is one of the goals. To verify that the workload and the situation awareness from the blind participants are different from the sighted participants

4. Calculate the average of of each participant in each method;

5. Calculate the average of the participant group in each method.

7.1 Data from the simulation

Unity3D was programmed to record the time that each user spent in each scene. It expected that the the time analysis show the following observation:

- The scene made with the white cane would be the fastest and with the less number of impacts;

  Since the participant is already used with this method, it is safe to assume that with the others methods the participant would go slower and hit more furniture on the way.

- Comparing both scenes made with the same method, the second one would have the fastest and with less impact;

  Not only this is expected but also that is the intention on having two scenes with each method.

7.1.1 Time elapsed on each scene

The data collected from the participants are show in the Table 7.1.

TABLE 7.1 – Duration grouped by participant and guidance method (in minutes).

Participant	Visual Impairment	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	10:18	13:05	6:42	6:52	7:54
		Return	12:38	6:25	7:41	10:28	5:21
001C	Blind	First	2:11	6:00	10:41	9:02	7:42
		Return	11:21	7:41	6:06	5:36	6:10
002C	Blind	First	2:02	6:17	4:32	7:34	4:08
		Return	13:32	8:06	8:02	3:35	3:57
003	Sight	First	8:06	2:14	2:51	4:21	8:11
		Return	4:11	15:25	6:50	5:25	4:18
003C	Blind	First	2:40	11:16	8:04	5:20	5:42
		Return	6:38	4:59	4:00	8:52	5:32
004	Sight	First	2:40	11:16	8:04	5:20	5:42
		Return	6:38	4:59	4:00	8:52	5:32
004C	Blind	First	2:30	6:26	4:23	5:04	3:54
		Return	8:29	6:38	11:25	4:29	6:24
005	Sight	First	2:33	6:58	5:34	5:09	7:52
		Return	8:16	8:46	4:25	6:45	3:00

The Table 7.2 show the the average time of each participant on each method and they are plotted in the Figure 7.1 and 7.2. The Figure show that there is no pattern in the relationship between the difference of the rounds of each method with the visual condition of the users.

The Table 7.4 show the the average time grouped by visual condition and Figure 7.3

TABLE 7.2 – Average Duration grouped by participant and guidance method (in minutes).

Participant	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Impairment
001	11:28	9:45	7:12	8:40	6:38	Sight
001C	6:46	6:50	8:23	7:19	6:56	Blind
002C	7:47	7:11	6:17	5:34	4:02	Blind
003	6:09	8:50	4:51	4:53	6:14	Sight
003C	4:39	8:08	6:02	7:06	5:37	Blind
004	4:39	8:08	6:02	7:06	5:37	Sight
004C	5:30	6:16	7:54	4:46	5:09	Blind
005	5:25	7:52	4:59	5:57	5:26	Sight

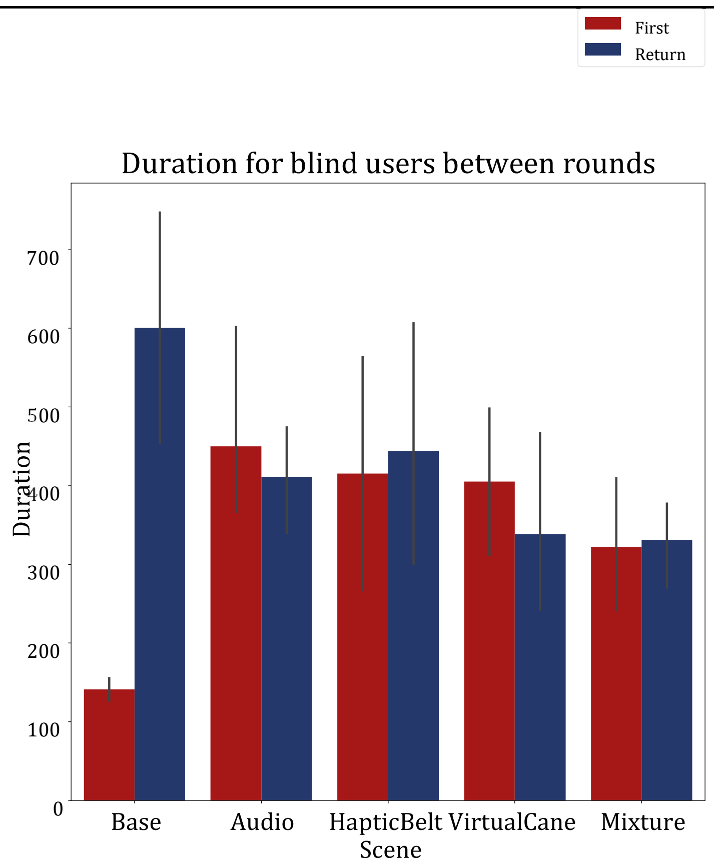


FIGURE 7.1 – Bar plot of the average time of the blind participants on each method.

these data is plotted. The Figure show that there could be some difference in the time between the methods, but that would only be assured with a hypothesis test.

The Table 7.4 show the the average time grouped by visual condition and Figure 7.4 these data is plotted. The table shows a noticible difference between the two groups. The Figure 7.4 show that the global average of the groups in all scenes were almost the same.

For a more correct analysis, one should use statistical methods to analyse. So hypothesis tests were used, but the first step in this analysese is to check the if the sample has

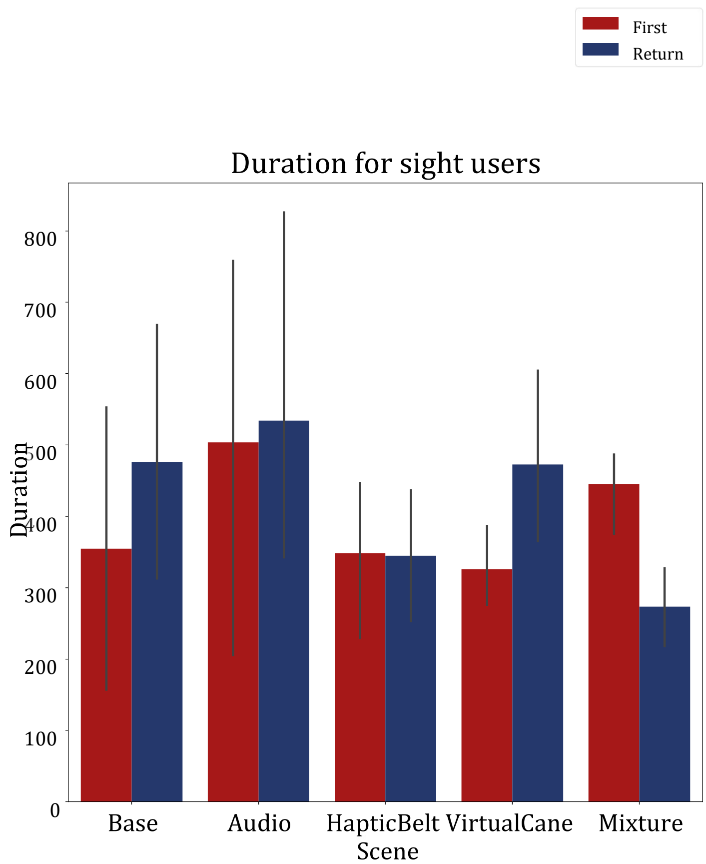


FIGURE 7.2 – Bar plot of the average time of sighted participants on each method.

TABLE 7.3 – Duration difference grouped by participant and visual Condition.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition					
Blind	342.329	1.082	36.139	-8.927	9.153
Sight	86.482	126.610	20.839	43.526	-36.075

TABLE 7.4 – Duration difference grouped by participant and visual Condition.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition					

Blind	342.329	1.082	36.139	-8.927	9.153
Sight	86.482	126.610	20.839	43.526	-36.075

a normal distribuition.

The Table 7.5 shows the Shapiro Wilk test p-value. If this value is higher than 0.05, then the sample is normally distributed. The table 7.5 indicates that the p-values of the time averages are normally distributed hence the steps that follow are allowed to be used.

The Table 7.6 shows the T test p-value between the time average of the blind sample and time average of the sight sample. If this value is higher than 0.05, it means that there

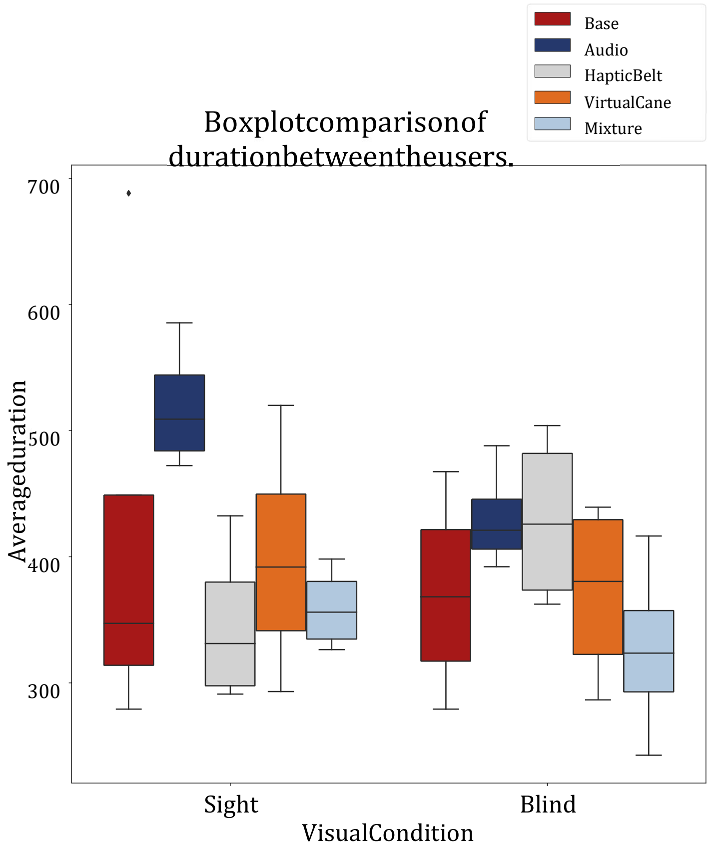


FIGURE 7.3 – Boxplot of the average time of each group on each method. TABLE 7.5 – Shapiro test p-value for the duration of participant in each method.

Method	Shapiro P-Value
Audio blinded users	0.596
Audio sighted users	0.623
Haptic Belt blinded users	0.296
Haptic Belt sighted users	0.420
Virtual Cane blinded users	0.402
Virtual Cane sighted users	0.954
Mixture blinded users	0.966

Mixture sighted users	0.619

are no statistically difference between the samples and that both samples had the same time performance. The table 7.6 indicates the time of both the blind and the sight user are statistically the same, with an exception of the "Audio" method.

The Table 7.8 shows the Anova test p-value of the blind time averages between the guidance methods presented in tha Table 7.7. If this value is higher than 0.05, there is at least one method that has no statistically difference between one of the other methods. The table 7.8 indicates that there are no similar variation between the methods, that means that all of the time differences noticed on the methods are relevant.

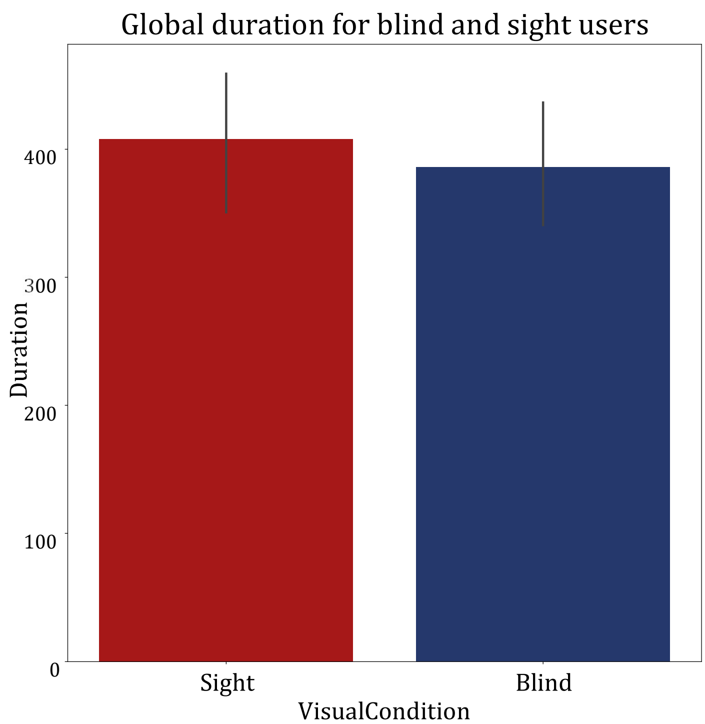


FIGURE 7.4 – Barplot of the average time of each group.

TABLE 7.6 – T test p-value for the duration for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.675
Audio	0.035
Haptic Belt	0.134
Virtual Cane	0.667
Mixture	0.442

TABLE 7.7 – Duration variation grouped by participant and guidance method.

Participant	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Impairment
001	22.5%	-50.8%	14.6%	52.4%	-32.1%	Sight
001C	419.5%	28.1%	-42.9%	-37.8%	-20.0%	Blind
002C	563.3%	28.8%	77.3%	-52.6%	-4.2%	Blind
003	-48.3%	587.1%	139.5%	24.4%	-47.4%	Sight
003C	148.9%	-55.7%	-50.3%	66.2%	-2.8%	Blind
004	148.9%	-55.7%	-50.3%	66.2%	-2.8%	Sight
004C	237.4%	3.0%	160.4%	-11.5%	63.6%	Blind
005	222.7%	25.9%	-20.5%	30.9%	-61.8%	Sight

TABLE 7.8 – Anova p-value for the duration of each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	359255.115	4	89813.779	8.898	0.001
Inside factors	151413.334	15	10094.222		
Total	510668.449	19			

Considering the on Table 7.6, the duration of the "sight" sample is similar to the "blind" sample and considering the conclusion from the ANOVA test and the Figure 7.3, the method that had the better time efficiency was the one mixing all of the methods together, and the least one was the "Audio" method.

Despite all these results above, it is noticible some outliers in the data, specially in the first participants, when the most minor procedure errors, such as the one to stop the simulation, hence stoping the timer, had happened.

7.2 Data from questionnaires

There were 3 different questionnaires in this experiment. Each of these questionnaires were meant to verify one of the experiment goals:

- NASA-TLX;

  Meant to verify the mental workload of the user. Is expected that after each "First" round, the mental workload would decrease and that one of the methods would have the least mental workload. Also that there is a noticible difference between the sight sample mental workload and the blind sample mental workload.

- Adapted SAGAT;

Meant to verify the situation awareness and the mental map of the user. Is expected to notice an increase from the "First" round to the "Return" round at each method and a difference between the "blind" sample and the "sight" sample.

- Guidance method's questionnaire.

  Meant to assess the user experience with each method.

7.2.1 NASA-TLX

It is possible to analyze the mental workload using NASA-TLX two different ways. The first is to by analyzing only the mental demand scale and the second is by analyzing the NASA-TLX score, which is a average of the scales' rating.

7.2.1.1 Analysis of the mental demand scale

The Table 7.9 presents the mental demand averages by each participant on each scenes and they are plotted in the Figures 7.5 and 7.6.

TABLE 7.9 – Mental demand felled by the participants.

Participant	Visual Impairment	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	6.000	12.000	11.000	5.000	9.000
		Return	6.000	13.000	13.000	5.000	10.000
001C	Blind	First	3.000	1.000	14.000	3.000	6.000
		Return	1.000	1.000	10.000	2.000	6.000
002C	Blind	First	5.000	1.000	1.000	10.000	12.000
		Return	1.000	1.000	1.000	10.000	3.000
003	Sight	First	2.000	18.000	18.000	16.000	10.000
		Return	1.000	12.000	15.000	11.000	8.000
003C	Blind	First	5.000	5.000	5.000	8.000	1.000
		Return	3.000	1.000	1.000	2.000	1.000
004	Sight	First	8.000	17.000	20.000	12.000	20.000
		Return	5.000	12.000	15.000	10.000	15.000
004C	Blind	First	9.000	10.000	15.000	10.000	10.000
		Return	7.000	10.000	14.000	8.000	10.000
005	Sight	First	2.000	4.000	12.000	10.000	13.000

Return	2.000	6.000	10.000	6.000	12.000

The Table 7.10 show the the average mental demand between the rounds of each participant and the Figure 7.7 these data is plotted. The figure shows a noticible difference between the two groups. The Figure 7.7 indicates a visual difference between the mental demmand feeled by the sighted participants and the mental demand feeled by the blind participants. Inside the blind participants groups is also noticible a difference between the methods, but the ones that are different does not show a better performance, instead a higher mental demand than the one feeled during the "Base" method.

The Table 7.11 show the the average mental demand grouped by visual condition and these data is plotted in Figure 7.8. Both the table and the figure also show the difference between the mental demand of the "sight" sample and the "blind" sample.

The Shapiro–Wilk normality test on the Table 7.12 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the "blind" sample is different then the "sight" sample.

Acording to the T-Test presented on the Table 7.13, the only method that showed a difference on the mental demand between the "sight"sample and the "blind"sample is the

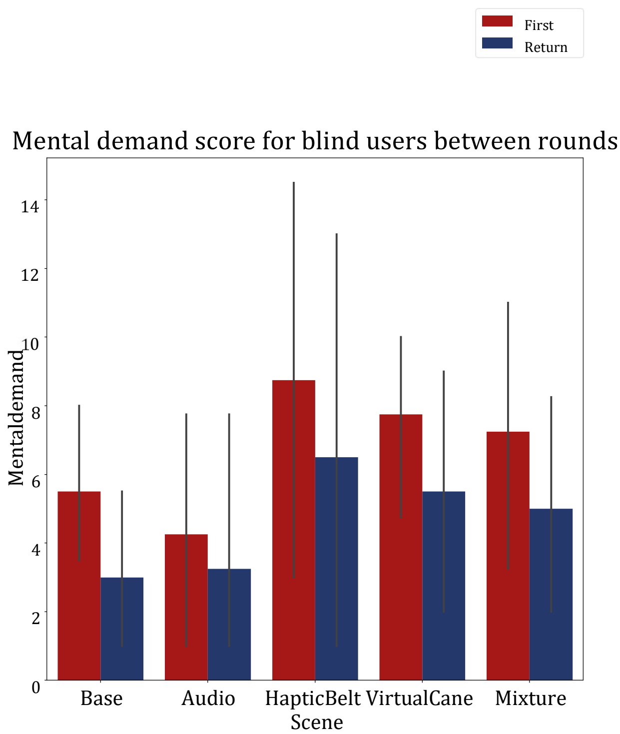
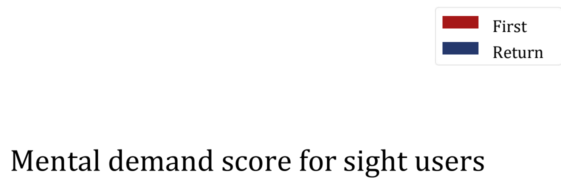


FIGURE 7.5 – Bar plot of the average mental demand of the blind participants on each method.



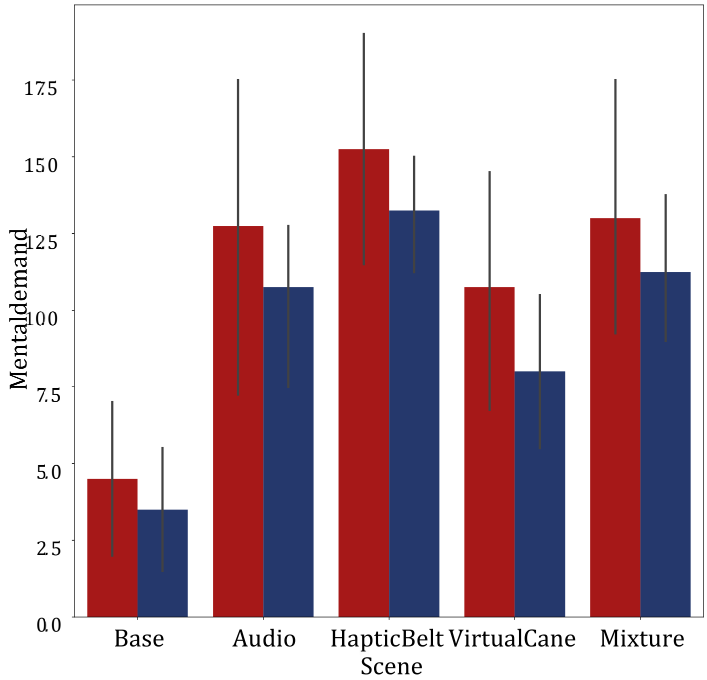


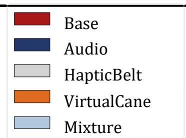
FIGURE 7.6 – Bar plot of the average mental demand of the sighted participants on each method.

audio method. The other methods both samples had a similar mental demand.

The Table 7.14 shows the Anova test p-value of the mental demand average of the

TABLE 7.10 – Mental demand average by participant and method.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Impairment
Participant						
001	6.000	12.500	12.000	5.000	9.500	Sight
001C	2.000	1.000	12.000	2.500	6.000	Blind
002C	3.000	1.000	1.000	10.000	7.500	Blind
003	1.500	15.000	16.500	13.500	9.000	Sight
003C	4.000	3.000	3.000	5.000	1.000	Blind
004	6.500	14.500	17.500	11.000	17.500	Sight
004C	8.000	10.000	14.500	9.000	10.000	Blind
005	2.000	5.000	11.000	8.000	12.500	Sight



Box plot comparison of
mental demand between the users.

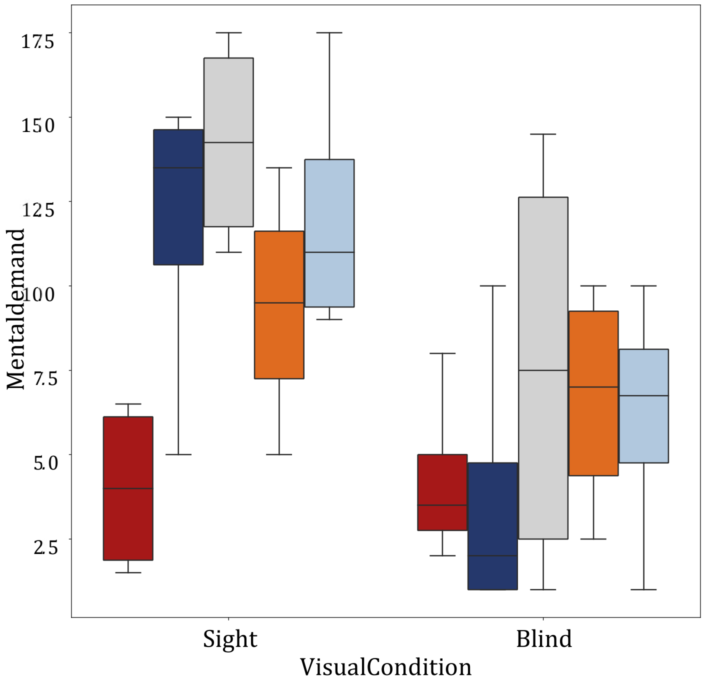


FIGURE 7.7 – Boxplot of the average mental demand of participant.

TABLE 7.11 – Mental demand average grouped by participant and visual Condition

	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition					
Blind	4.250	3.750	7.625	6.625	6.125
Sight	4.000	11.750	14.250	9.375	12.125

"blind" sample between the guidance methods presented on the Table 7.10. The p-value indicates that there is at least one method that is statistically equal to one of the other

Global mental demand score for blind and sight users

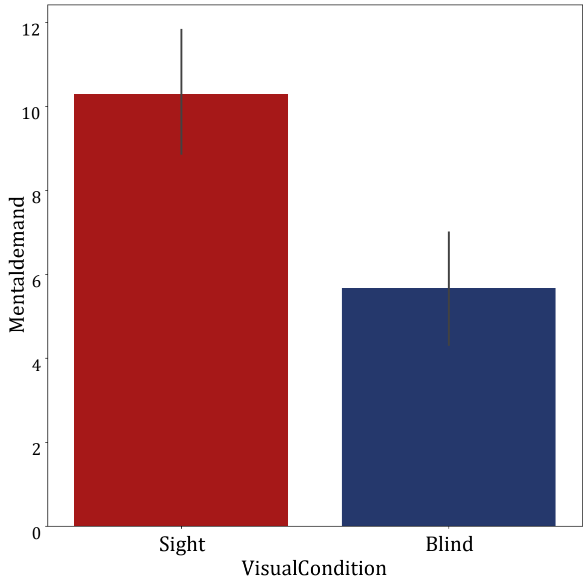


FIGURE 7.8 – Barplot of the average mental demand of each group.

TABLE 7.12 – Shapiro test p-value for the mental demand for each method and visual condition.

Method	Shapiro P-Value
Base blinded users	0.369
Base sighted users	0.145
Audio blinded users	0.066
Audio sighted users	0.117
Haptic Belt blinded users	0.346
Haptic Belt sighted users	0.300
Virtual Cane blinded users	0.555
Virtual Cane sighted users	0.948
Mixture blinded users	0.771
Mixture sighted users	0.339

TABLE 7.13 – T test p-value for the mental demand on each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.897
Audio	0.044
Haptic Belt	0.122
Virtual Cane	0.320
Mixture	0.070

methods.

The Table 7.15 presents the conclusion of a pairwise Fisher LSD test of the blind

TABLE 7.14 – Anova p-value for the average mental demand on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	42.575	4	10.644	0.556	0.698

Inside factors	287.062	15	19.137
Total	329.637	19	

mental demand average between all the guidance methods. The results show that only ”Haptic Belt”caused a different mental demand average than the one notice on the ”Base” Method.

TABLE 7.15 – Cross validation p-value for the average mental demand on each method for blinded users.

Method	Analysis
Base versus Audio	$H_0 : \mu_{Base} = \mu_{Audio}$
Base versus Haptic Belt	$\ast\ast H_1 : \mu_{Base} \neq \mu_{HapticBelt} \ast\ast$
Base versus Virtual Cane	$H_0 : \mu_{Base} = \mu_{VirtualCane}$
Base versus Mixture	$H_0 : \mu_{Base} = \mu_{Mixture}$
Audio versus Haptic Belt	$\ast\ast H_1 : \mu_{Audio} \neq \mu_{HapticBelt} \ast\ast$
Audio versus Virtual Cane	$\ast\ast H_1 : \mu_{Audio} \neq \mu_{VirtualCane} \ast\ast$
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

The Table 7.17 shows the Anova test p-value of the mental demand variation of the ”blind” sample between the guidance methods presented on the Table 7.16. The p-value indicates that there is at least one method that is statistically equal to one of the other methods so its recommended to do a pairwise analyses between all the methods.

TABLE 7.16 – Mental demand variation by participant and method.

Participant	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Impairment
001	0.0%	8.3%	18.1%	0.0%	11.1%	Sight
001C	-66.6%	0.0%	-28.5%	-33.3%	0.0%	Blind
002C	-80.0%	0.0%	0.0%	0.0%	-75.0%	Blind
003	-50.0%	-33.3%	-16.6%	-31.2%	-20.0%	Sight
003C	-40.0%	-80.0%	-80.0%	-75.0%	0.0%	Blind
004	-37.5%	-29.4%	-25.0%	-16.6%	-25.0%	Sight
004C	-22.2%	0.0%	-6.6%	-20.0%	0.0%	Blind
005	0.0%	50.0%	-16.6%	-40.0%	-7.6%	Sight

The Table 7.18 presents the conclusion of a pairwise Fisher LSD test of the blind mental demand variation between all the guidance methods. The results show that the

TABLE 7.17 – Anova p-value for the mental demand variation on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	2901.806	4	725.451	0.604	0.666
Inside factors	18007.946	15	1200.530		
Total	20909.752	19			

"Virtual Cane" method has a similar mental demand variation with the "Base" method. All other methods have a different variation. This can be seen at the Table 7.19 and in the Figure 7.9 compiles the mental demand average of the methods observed on all of the participants.

TABLE 7.18 – Cross validation p-value for the mental demand variation on each method for blinded users.

Method	Analysis
Base versus Audio	$**H_1 : \mu_{Base} \neq \mu_{Audio} **$
Base versus Haptic Belt	$**H_1 : \mu_{Base} \neq \mu_{HapticBelt} **$
Base versus Virtual Cane	$H_0 : \mu_{Base} = \mu_{VirtualCane}$
Base versus Mixture	$**H_1 : \mu_{Base} \neq \mu_{Mixture} **$
Audio versus Haptic Belt	$H_0 : \mu_{Audio} = \mu_{HapticBelt}$
Audio versus Virtual Cane	$H_0 : \mu_{Audio} = \mu_{VirtualCane}$
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

TABLE 7.19 – Mental demand variation grouped by participant and visual Condition

	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition					
Blind	-52.2%	-20.0%	-28.8%	-32.0%	-18.7%
Sight	-21.8%	-1.1%	-10.0%	-21.9%	-10.3%

According to T-Test on Table 7.13, the mental demand of the "sight"sample is similar to the "blind" sample, excluding only on the "Audio" method.

According to both Anova test at Table 7.14 and 7.17, Tables 7.10 and 7.16 and Figure 7.9, none of the methods did provoke a higher mental demand variation than the one notice on the "Base" method on the participants and the only different mental demand average was noticed on the "Haptic Belt"method, and is higher mental demand than the "Base" method.

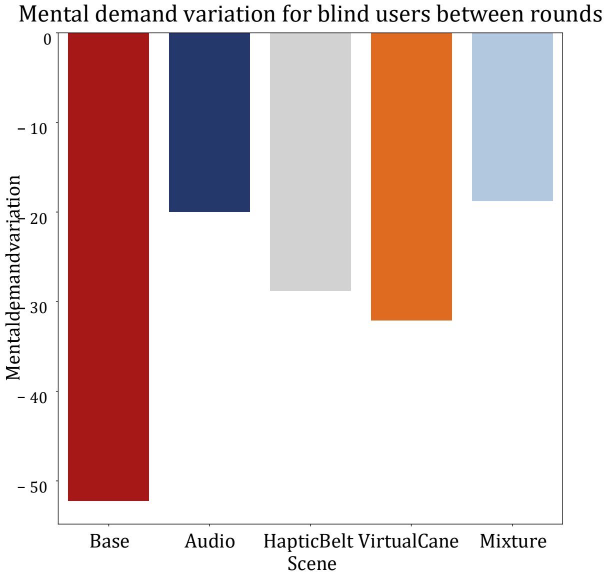


FIGURE 7.9 – Barplot of the average mental demand variation from the blind participants of each method.

7.2.1.2 Analysis of the NASA-TLX score

The Table 7.20 presents the Nasa score averages by each participant on each scenes and they are plotted in the Figures 7.10 and 7.11. It is notible that after each "First" round the Nasa score diminishes for both "sight" and "blind" participants.

The Table 7.21 show the the average Nasa score between the rounds of each participant and in the Figure 7.12 these data is plotted. The table and the figure also shows a noticible difference between the two groups, meaning that problably the Nasa score from the "sight" sample higher then the one of the "blind" sample.

The Table 7.22 show the the average Nasa score grouped by visual condition and these data is plotted in Figure 7.13. Both the table and the figure also show the difference between the mental demand of the "sight" sample and the "blind" sample.

The Shapiro–Wilk normality test on the Table 7.23 shows that these data are normally distributed, with an exception of the "Audio" Nasa score. This means that the further analysis cannot be applied for this method.

Acording to the T-Test presented on the Table 7.24 it cannot be verified that the average Nasa score are different between the "sight" and the "blind" samples.

The Table 7.25 shows the Anova test p-value of the average Nasa score, presented on the Table 7.21, of the "blind" sample between the guidance methods. The p-value indicates that there is at least one method that is statistically equal to one of the other

TABLE 7.20 – NASA score felled by the participants.

Participant	Visual Impairment	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	7.833	10.167	9.833	7.000	9.000
		Return	8.000	11.000	10.833	6.167	9.333
001C	Blind	First	4.833	4.000	8.833	5.167	6.333
		Return	4.167	4.000	6.667	4.500	6.167
002C	Blind	First	6.333	4.833	4.833	9.000	7.000
		Return	4.500	4.833	4.833	7.000	5.167
003	Sight	First	4.833	9.833	10.167	9.500	6.500
		Return	4.333	6.667	9.667	7.833	4.833
003C	Blind	First	4.000	4.000	5.333	6.667	3.500
		Return	4.000	3.833	3.667	3.500	3.500
004	Sight	First	6.667	14.833	13.667	11.500	15.833
		Return	6.833	11.833	11.833	10.833	12.167
004C	Blind	First	9.833	10.000	12.667	9.667	11.000
		Return	8.667	9.167	11.667	9.333	10.833
005	Sight	First	5.000	7.667	9.000	8.000	9.667
		Return	5.000	7.667	8.667	7.667	6.000

Nasa score for blind users between rounds

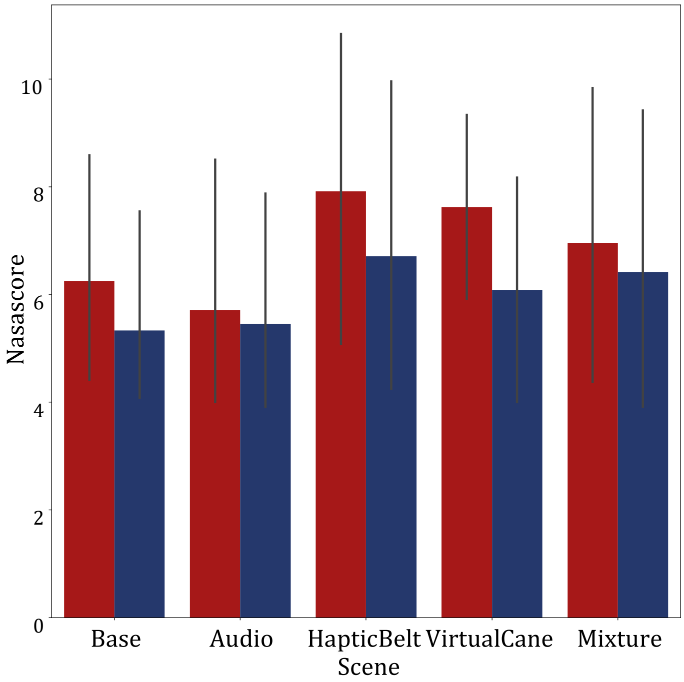


FIGURE 7.10 – Bar plot of the average Nasa-TLX score of the blind participants on each method.

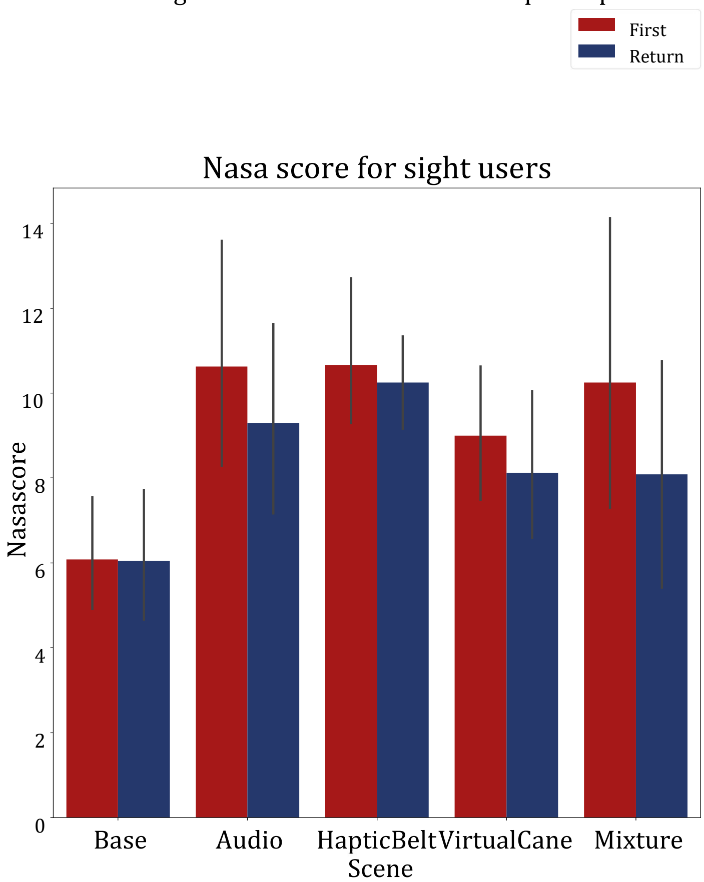


FIGURE 7.11 – Bar plot of the average Nasa-TLX score of the sighted participants on each method.

TABLE 7.21 – NASA-TLX score grouped by participant and method.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Condition
Participant						

001	7.917	10.583	10.333	6.583	9.167	Sight
001C	4.500	4.000	7.750	4.833	6.250	Blind
002C	5.417	4.833	4.833	8.000	6.083	Blind
003	4.583	8.250	9.917	8.667	5.667	Sight
003C	4.000	3.917	4.500	5.083	3.500	Blind
004	6.750	13.333	12.750	11.167	14.000	Sight
004C	9.250	9.583	12.167	9.500	10.917	Blind
005	5.000	7.667	8.833	7.833	7.833	Sight

TABLE 7.22 – NASA-TLX score grouped by participant and visual Condition

Visual Condition	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Blind	5.792	5.583	7.312	6.854	6.688
Sight	6.062	9.958	10.458	8.562	9.167

methods so its recommended to do a pairwise analyses between all the methods.

The Table 7.18 presents the results of a pairwise Fisher LSD test of the blind Nasa

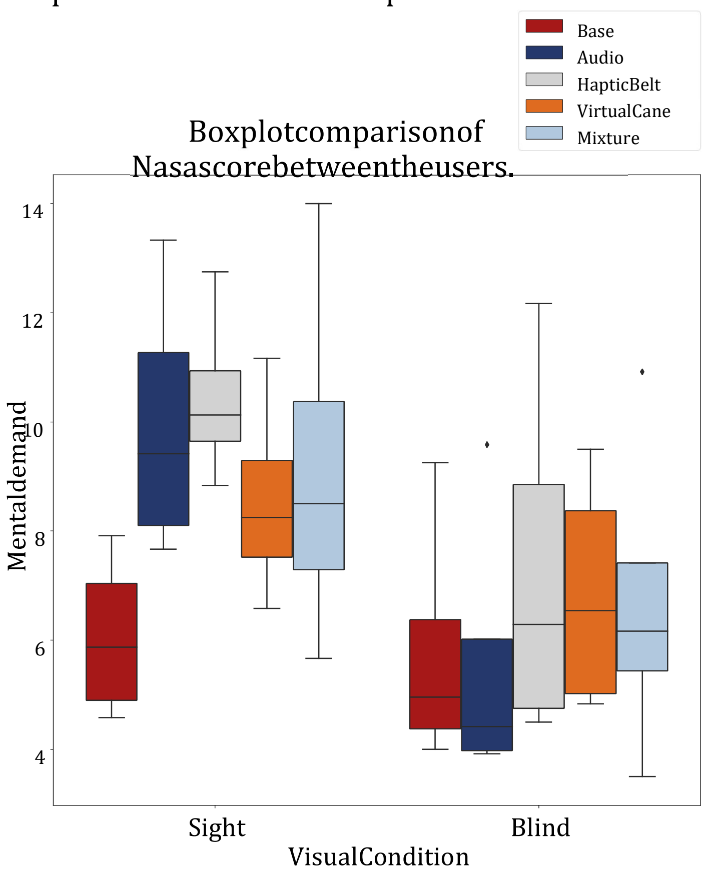


FIGURE 7.12 – Boxplot of the average Nasa-TLX score of the participants.

TABLE 7.23 – Shapiro test p-value for the NASA score for each method and visual condition.

Method	Shapiro P-Value

Base blinded users	0.176
Base sighted users	0.550
Audio blinded users	0.034
Audio sighted users	0.533
Haptic Belt blinded users	0.321
Haptic Belt sighted users	0.592
Virtual Cane blinded users	0.329
Virtual Cane sighted users	0.792
Mixture blinded users	0.527
Mixture sighted users	0.695

score average between all the guidance methods. The results show that all of the averages are statistically the same. That means that there are no difference on the Nasa score feelt by the "blind" sample between the methods.

The Table 7.27 shows the Anova test p-value of the mental demand average of the "blind" sample between the guidance methods presented on the Table 7.30. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

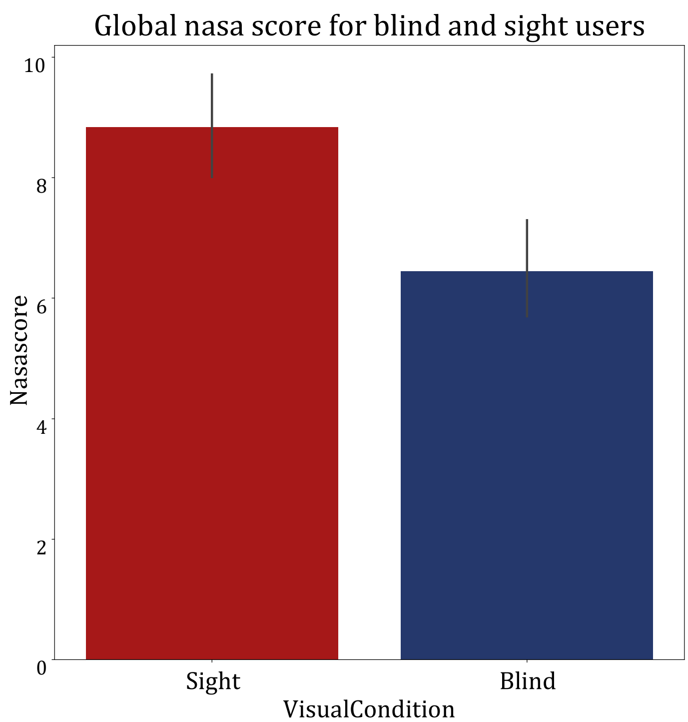


FIGURE 7.13 – Barplot of the average nasa score of each group.

TABLE 7.24 – T test p-value for the NASA score on each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.855
Audio	0.058
Haptic Belt	0.159
Virtual Cane	0.296
Mixture	0.331

TABLE 7.25 – Anova p-value for the average Nasa score on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	8.592	4	2.148	0.267	0.895
Inside factors	120.773	15	8.052		
Total	129.365	19			

The Table 7.29 presents the conclusion of a pairwise Fisher LSD test of the blind Nasa score variation between all the guidance methods. The results show that only "Audio" method caused a different variation than the one notice on the "Base"Method. The Figure 7.14 shows the variation of the Nasa score and one can notice that the variation provoked on the "Audio" method" is a lot lesser than the other ones.

TABLE 7.26 – Cross validation p-value for the average Nasa score on each method for blinded users.

Method	Analysis
Base versus Audio	$H_0 : \mu_{Base} = \mu_{Audio}$
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$H_0 : \mu_{Base} = \mu_{VirtualCane}$
Base versus Mixture	$H_0 : \mu_{Base} = \mu_{Mixture}$
Audio versus Haptic Belt	$H_0 : \mu_{Audio} = \mu_{HapticBelt}$
Audio versus Virtual Cane	$H_0 : \mu_{Audio} = \mu_{VirtualCane}$
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

TABLE 7.27 – Anova p-value for the variation Nasa score on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	825.191	4	206.298	1.172	0.362
Inside factors	2639.612	15	175.974		
Total	3464.803	19			

TABLE 7.28 – NASA-TLX score variation grouped by participant and method.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Condition
Participant						

001	2.128	8.197	10.169	-11.905	3.704	Sight
001C	-13.793	0.000	-24.528	-12.903	-2.632	Blind
002C	-28.947	0.000	0.000	-22.222	-26.190	Blind
003	-10.345	-32.203	-4.918	-17.544	-25.641	Sight
003C	0.000	-4.167	-31.250	-47.500	0.000	Blind
004	2.500	-20.225	-13.415	-5.797	-23.158	Sight
004C	-11.864	-8.333	-7.895	-3.448	-1.515	Blind
005	0.000	0.000	-3.704	-4.167	-37.931	Sight

According to T-Test on Table 7.24 all of the Nasa score are similar between the both groups.

According to both Anova test at Table 7.25 and 7.25, Table 7.30 7.21 and Figure 7.14, all of the methods have a similar Nasa score average, and the only different variation is provoked by the "Audio" method, and is a smaller variation.

TABLE 7.29 – Cross validation p-value for the variation Nasa score on each method for blinded users.

Method	Analysis
Base versus Audio	$\ast\ast H_1 : \mu_{Base} \neq \mu_{Audio} \ast\ast$
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$H_0 : \mu_{Base} = \mu_{VirtualCane}$
Base versus Mixture	$H_0 : \mu_{Base} = \mu_{Mixture}$
Audio versus Haptic Belt	$\ast\ast H_1 : \mu_{Audio} \neq \mu_{HapticBelt} \ast\ast$
Audio versus Virtual Cane	$\ast\ast H_1 : \mu_{Audio} \neq \mu_{VirtualCane} \ast\ast$
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$\ast\ast H_1 : \mu_{HapticBelt} \neq \mu_{Mixture} \ast\ast$
Virtual Cane versus Mixture	$\ast\ast H_1 : \mu_{VirtualCane} \neq \mu_{Mixture} \ast\ast$

TABLE 7.30 – NASA-TLX score variation grouped by participant and method.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Condition
Participant						
001	2.128	8.197	10.169	-11.905	3.704	Sight
001C	-13.793	0.000	-24.528	-12.903	-2.632	Blind
002C	-28.947	0.000	0.000	-22.222	-26.190	Blind
003	-10.345	-32.203	-4.918	-17.544	-25.641	Sight
003C	0.000	-4.167	-31.250	-47.500	0.000	Blind
004	2.500	-20.225	-13.415	-5.797	-23.158	Sight
004C	-11.864	-8.333	-7.895	-3.448	-1.515	Blind
005	0.000	0.000	-3.704	-4.167	-37.931	Sight

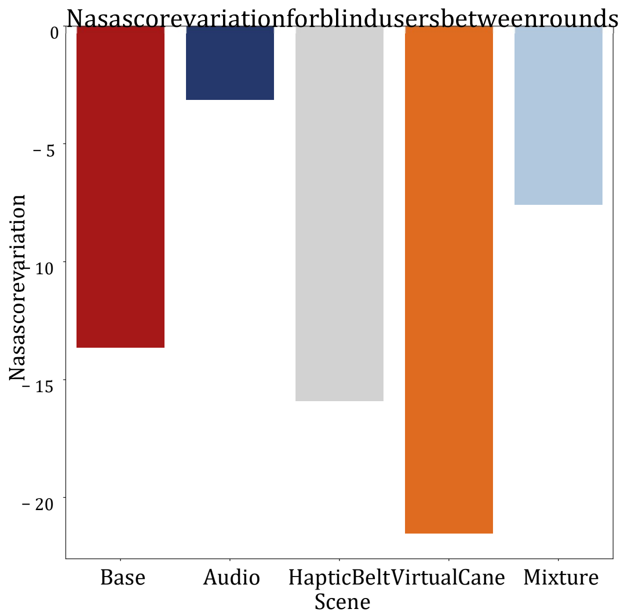


FIGURE 7.14 – Barplot of the Nasa score variation from the blind participants of each method.

7.2.2 Adapted SAGAT

In this subsection the Sagat questionnaire is analyzed. Its result's may give an ideia of the mental map the participant is drawing. For each question a participant could score 1 point or a fraction of it. The total score of each participant is presented on the Table 7.31 and they are plotted in the Figures 7.15 and 7.16. It visually noticible that both of the groups perform better in the second time they visit the room.

TABLE 7.31 – Adapted Sagat global score by participant and guidance method.

Participant	Visual Impairment	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	1.000	0.450	0.433	0.266	0.650
		Return	1.000	0.600	0.500	0.500	0.450
001C	Blind	First	0.625	0.550	0.533	0.583	0.350
		Return	0.625	0.650	0.850	0.550	0.550
002C	Blind	First	0.675	0.450	0.399	0.450	0.625
		Return	0.525	0.500	0.400	0.650	0.850
003	Sight	First	1.000	0.675	0.599	0.399	0.675
		Return	1.000	0.600	0.725	0.625	0.750

003C	Blind	First	0.725	0.750	0.749	0.466	0.900
		Return	1.000	1.000	0.850	0.900	0.900
004	Sight	First	1.000	0.725	0.799	0.599	0.825
		Return	1.000	0.775	0.950	0.825	0.700
004C	Blind	First	0.750	0.600	0.766	0.499	0.650
		Return	0.900	0.600	0.925	0.725	0.900
005	Sight	First	1.000	0.300	0.316	0.399	0.400
		Return	1.000	0.375	0.300	0.200	0.600

The Table 7.32 show the the average Sagat score between the rounds of each participant and the Figure 7.17 these data is plotted. It is possible only to assume that some methods causes differente Sagat scores than other, but both groups performed rather similarly.

The Table 7.33 show the the average Sagat score grouped by visual condition and these data, without considering the "Base" method, is plotted in Figure 7.18. Both the table and the figure also show a slightly difference between the score in favor of the "blind" sample.

The Shapiro–Wilk normality test on the Table 7.34 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the "blind" sample is different then the "sight" sample.

Acording to the T-Test presented on the Table 7.35, the only method that showed a difference on the Sagat score between the "sight" sample and the "blind" sample is the

Sagat score for blind users between rounds

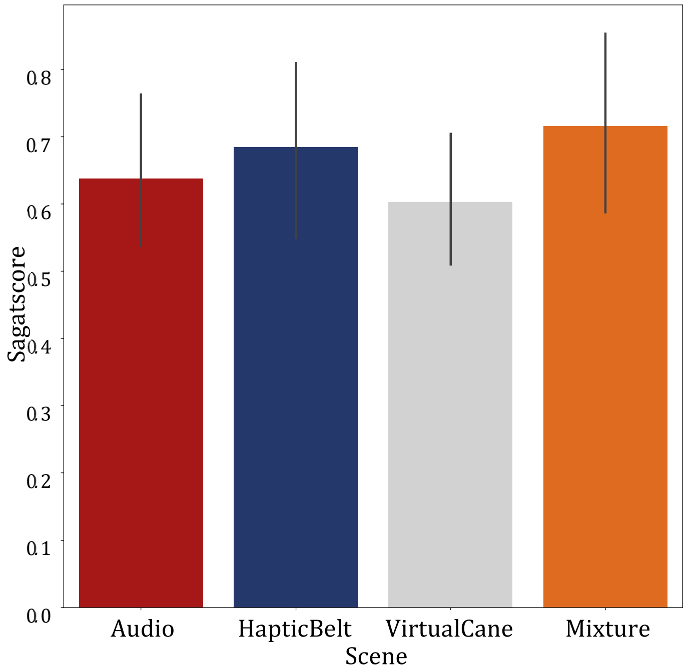


FIGURE 7.15 – Bar plot of the average Sagat score of the blind participants on each method.

TABLE 7.32 – Adapted Sagat average global score grouped by participant and guidance method.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Condition
Participant						
001	1.000	0.525	0.467	0.383	0.550	Sight
001C	0.625	0.600	0.692	0.567	0.450	Blind
002C	0.600	0.475	0.400	0.550	0.738	Blind
003	1.000	0.637	0.662	0.512	0.713	Sight
003C	0.863	0.875	0.799	0.683	0.900	Blind
004	1.000	0.750	0.875	0.712	0.762	Sight
004C	0.825	0.600	0.846	0.612	0.775	Blind
005	1.000	0.338	0.308	0.299	0.500	Sight

TABLE 7.33 – Adapted Sagat average global score grouped by participant and visual Condition.

	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition					
Blind	0.728	0.637	0.684	0.603	0.716
Sight	1.000	0.562	0.578	0.477	0.631

"Base" method. The other methods both samples had a similar Sagat score.

The Table 7.36 shows the Anova test p-value of the Sagat score average of the "blind"

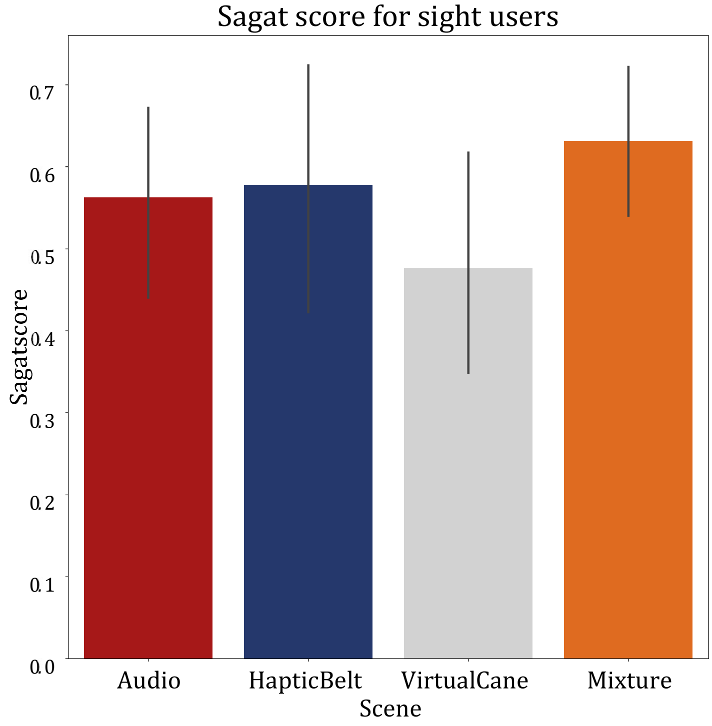


FIGURE 7.16 – Bar plot of the average Sagat score of the sighted participants on each method.

TABLE 7.34 – Shapiro test p-value for the Sagat score for each method and visual condition

Method	Shapiro P-Value
Base blinded users	0.189
Base sighted users	1.000
Audio blinded users	0.350
Audio sighted users	0.925
Haptic Belt blinded users	0.315
Haptic Belt sighted users	0.942
Virtual Cane blinded users	0.549
Virtual Cane sighted users	0.784
Mixture blinded users	0.520
Mixture sighted users	0.446

sample between the guidance methods presented on the Table 7.32. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

The Table 7.37 presents the analysis of a pairwise Fisher LSD test of the blind average Sagat score between all the guidance methods. The results show that only "Virtual Cane" caused a different average score than the one notice on the "Base" Method. The rest of the methods are did not signifcally chance it.

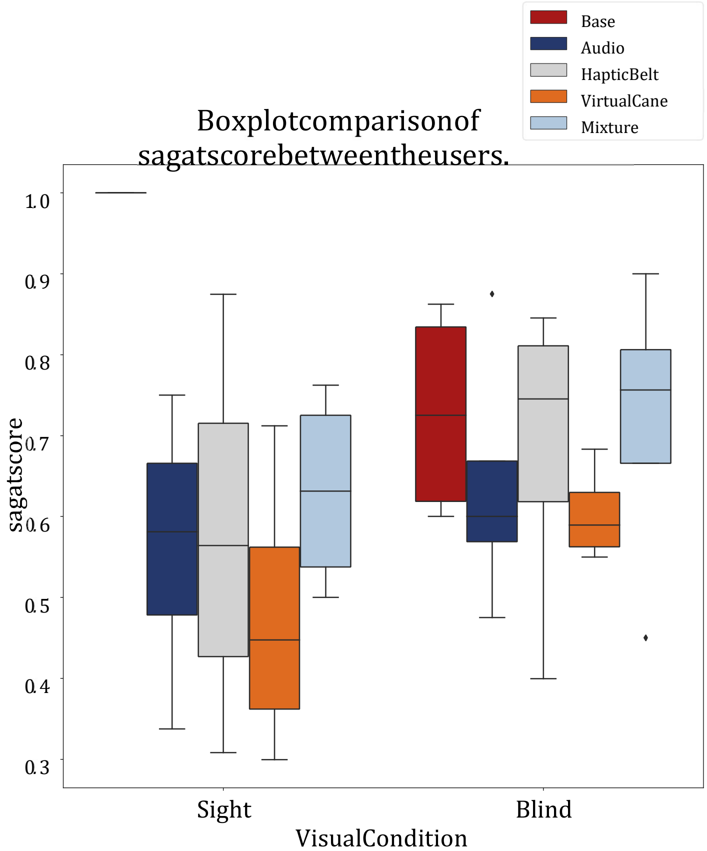


FIGURE 7.17 – Boxplot of the average Sagat score of participant.

TABLE 7.35 – T test p-value for the Sagat score on each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.007
Audio	0.561
Haptic Belt	0.527
Virtual Cane	0.230
Mixture	0.488

TABLE 7.36 – Anova p-value for the Sagat score on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	0.045	4	0.011	0.441	0.777
Inside factors	0.380	15	0.025		
Total	0.424	19			

The Table 7.39 shows the Anova test p-value of the Sagat score variation of the "blind" sample between the guidance methods presented on the Table 7.38. The p-value indicates that there is at least one method that is statistically equal to one of the other methods so its recommended to do a pairwise analyses between all the methods.

The Table 7.40 presents the conclusion of a pairwise Fisher LSD test of the blind Sagat

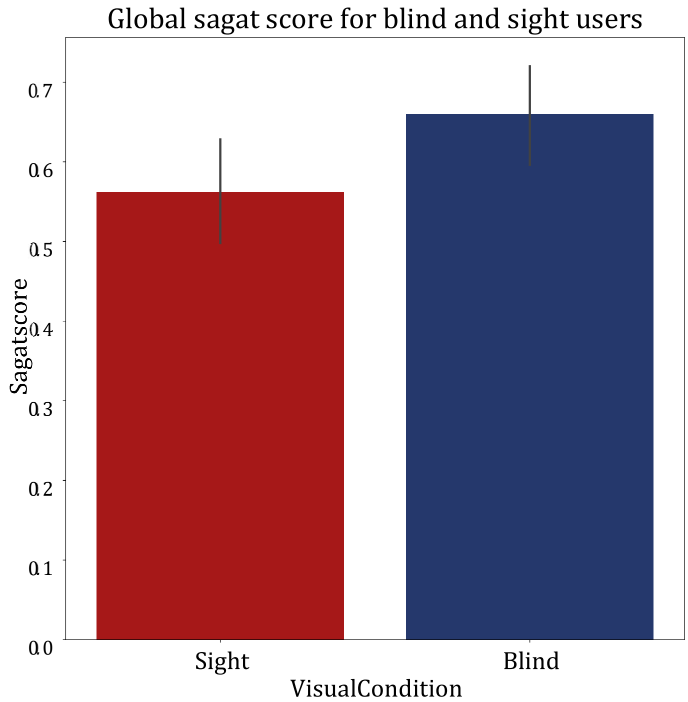


FIGURE 7.18 – Barplot of the average Sagat score of each group.

TABLE 7.37 – Cross validation p-value for the Sagat score on each method for blinded users.

Method	Analysis
Base versus Audio	$H_0 : \mu_{Base} = \mu_{Audio}$ **
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$ **
Base versus Virtual Cane	**$H_1 : \mu_{Base} \neq \mu_{VirtualCane}$ **
Base versus Mixture	$H_0 : \mu_{Base} = \mu_{Mixture}$ **
Audio versus Haptic Belt	$H_0 : \mu_{Audio} = \mu_{HapticBelt}$ **
Audio versus Virtual Cane	$H_0 : \mu_{Audio} = \mu_{VirtualCane}$ **
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$ **
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$ **
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$ **
Virtual Cane versus Mixture	**$H_1 : \mu_{VirtualCane} \neq \mu_{Mixture}$ **

score variation between all the guidance methods. The results show that the ""Haptic Belt" and the "Mixture"method have a different variation then the "Base"method and they are also different between each other. This can be seen at the Table 7.41 and in the Figure 7.19 compiles the Sagat score average of the methods observed on all of the participants.

According to T-Test on Table 7.35, there is no differecen in Sagat score between the ”sight” and the ”blind” sample.

According to both Anova test at Table 7.36 and LSD test at Table 7.37 only the

TABLE 7.38 – Adapted Sagat global score variation grouped by participant and guidance method.

Participant	Base	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Impairment
001	0.0%	33.3%	15.4%	87.9%	-30.7%	Sight
001C	0.0%	18.1%	59.4%	-5.6%	57.1%	Blind
002C	-22.2%	11.1%	0.2%	44.4%	36.0%	Blind
003	0.0%	-11.1%	21.0%	56.6%	11.1%	Sight
003C	37.9%	33.3%	13.4%	93.1%	0.0%	Blind
004	0.0%	6.8%	18.8%	37.7%	-15.1%	Sight
004C	20.0%	0.0%	20.7%	45.2%	38.4%	Blind
005	0.0%	25.0%	-5.0%	-49.8%	50.0%	Sight

TABLE 7.39 – Anova p-value for the variation Sagat score on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	3131.542	4	782.885	1.055	0.412
Inside factors	11133.360	15	742.224		
Total	14264.902	19			

TABLE 7.40 – Cross validation p-value for the variation Sagat score on each method for blinded users.

Method	Analysis
Base versus Audio	$H_0 : \mu_{Base} = \mu_{Audio}$
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$**H_1 : \mu_{Base} \neq \mu_{VirtualCane}**$
Base versus Mixture	$**H_1 : \mu_{Base} \neq \mu_{Mixture}**$
Audio versus Haptic Belt	$H_0 : \mu_{Audio} = \mu_{HapticBelt}$
Audio versus Virtual Cane	$**H_1 : \mu_{Audio} \neq \mu_{VirtualCane}**$
Audio versus Mixture	$**H_1 : \mu_{Audio} \neq \mu_{Mixture}**$
Haptic Belt versus Virtual Cane	$**H_1 : \mu_{HapticBelt} \neq \mu_{VirtualCane}**$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

TABLE 7.41 – Adapted Sagat global score variation grouped by participant and visual Condition

Visual Condition	Base	Audio	Haptic Belt	Virtual Cane	Mixture
Blind	8.9%	15.6%	23.4%	44.3%	32.9%

Sight	0.0%	13.5%	12.5%	33.1%	3.7%

"Virtual Cane" method has a different Sagat score average and according to the Anova test at Table 7.39 and the LSD test at Table ?? the "Virtual Cane" also has a different variation then the "Base"method, with the "Virtual Cane"having a higher, and positive, variation.

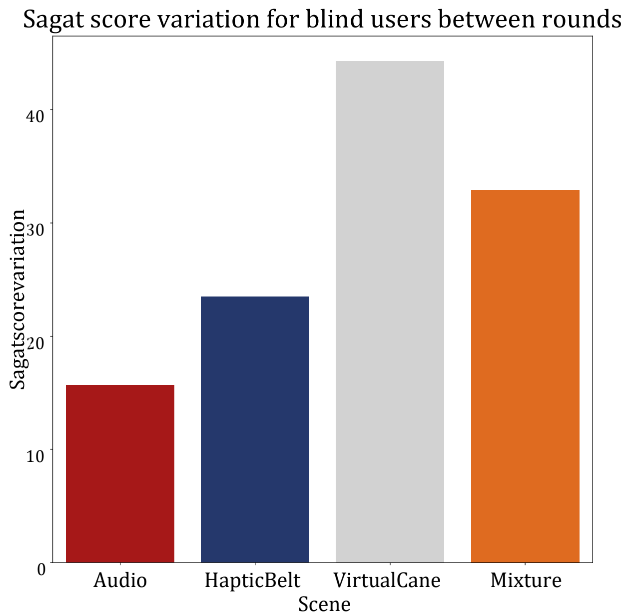


FIGURE 7.19 – Barplot of the average Sagat score variation from the blind participants of each method.

Finally, also according with Anova tes at Anova test at Table 7.36 and LSD test at Table 7.37 the "Mixture" method also has a significant increase, different the the "Base" method. This increase is also bigger and higher.

7.2.3 Guidance method's questionnaire.

Finally, the Questionnaire is analyzed to give an idea about the impressions of the users with each device. This is an important avaliation to seek their personal impressions on each method. Each question was evaluated to favor with a higher score the methods that brought more satisfaction to the user. The Table 7.42 shows the average score of each method and they are plotted in the Figures 7.5 and 7.6

The Table 7.43 show the the average questionnaire score of each participant and the Figure 7.22 these data is plotted. It is possible only to assume that some methods causes differente Sagat scores than other, but both groups performed rather similarly.

The Shapiro–Wilk normality test on the Table 7.44 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a following test to check if there is a significant difference between the methods

The Table 7.45 shows the Anova test p-value of the Sagat score average of the "blind" sample between the guidance methods presented on the Table 7.42. The p-value indicates that all scores are signifcally different between each other. That means that the highest

TABLE 7.42 – Guidance method questionnaire average score grouped by participant.

Participant	Audio	Haptic Belt	Virtual Cane	Mixture	Visual Condition
001	0.464	0.600	0.500	0.557	Sight
001C	0.631	0.714	0.457	0.849	Blind
002C	0.857	0.914	0.486	0.720	Blind
003	0.762	0.714	0.679	0.866	Sight
003C	0.690	0.743	0.543	0.762	Blind
004	0.857	0.771	0.571	0.639	Sight
004C	0.595	0.657	0.400	0.611	Blind
005	0.613	0.743	0.536	0.731	Sight

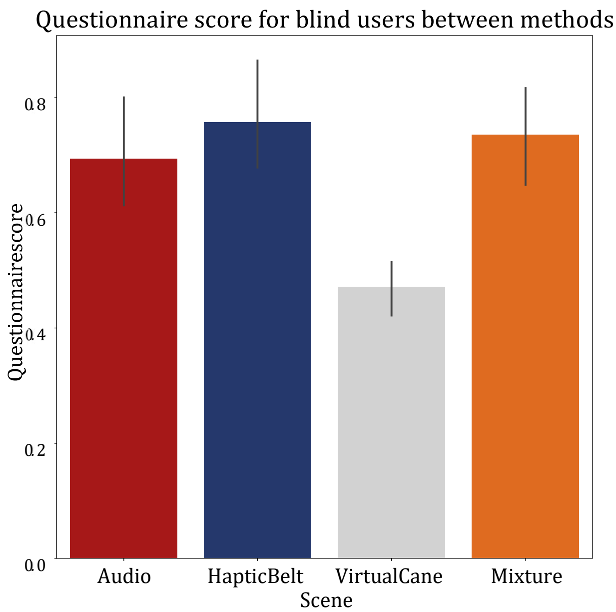


FIGURE 7.20 – Bar plot of the average mental demand of the blind participants on each method.

TABLE 7.43 – Guidance method questionnaire average score grouped by visual condition.

	Audio	Haptic Belt	Virtual Cane	Mixture
Visual Condition				
Blind	0.693	0.757	0.471	0.735
Sight	0.674	0.707	0.571	0.698

score show at Table 7.43, which are the "Haptic Belt" and the "Mixture" methods were the most favorate from the participant.

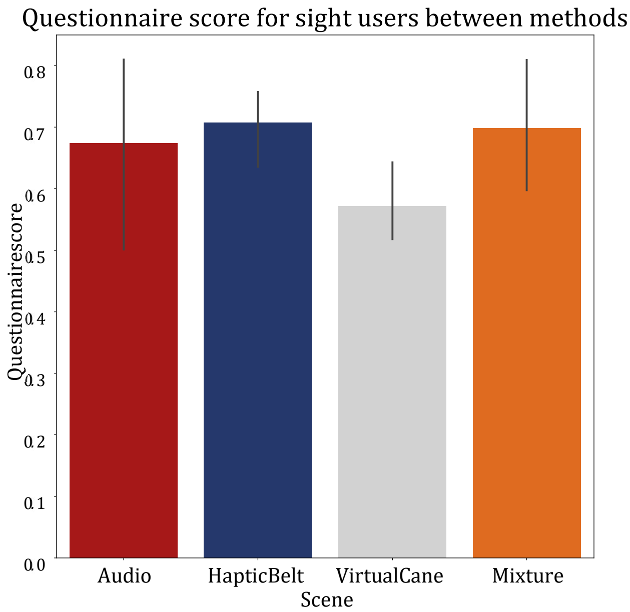


FIGURE 7.21 – Bar plot of the average mental demand of the sighted participants on each method.

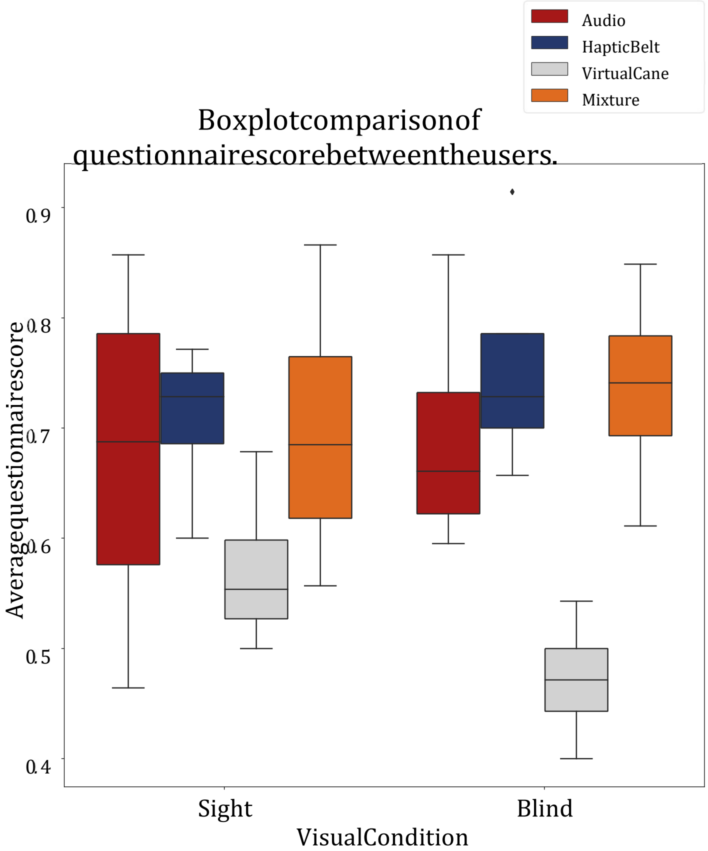


FIGURE 7.22 – Boxplot of the average questionnaire score of each group.

TABLE 7.44 – Shapiro test p-value for the questionnaires score for each method and visual condition.

Method	Shapiro P-Value
Audio blinded users	0.400
Audio sighted users	0.882
Haptic Belt blinded users	0.414
Haptic Belt sighted users	0.369
Virtual Cane blinded users	0.995
Virtual Cane sighted users	0.577
Mixture blinded users	0.966
Mixture sighted users	0.925

TABLE 7.45 – Anova p-value for the questionnaire score on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	0.207	3	0.069	7.080	0.005
Inside factors	0.117	12	0.010		
Total	0.324	15			

7.3 Data from physiological sensors

There were 3 different sensors in this experiment, 2 that collected physiological data and the one left collected temperature. The last one was used only the eliminate an possible increase at the GSR sensor caused by the increase of the temperature. These were all used to assess Mental Workload.

At the beggining of each experience, a baseline data was gathered to establish a comparison. All the following analysis is made in relation with the relative baseline data.

- Electrocardiogram (ECG) data;

  Is expected that the ECG frequency to increase at every "First" round and then a slight decrease in the next round. Also the variation is expected to decrease at the "First" round and a slight increase in the next round.

- Galvanic skin reaction and temperature data;;

  Is expected that the GSR average to increase at every "First" round and then a slight decrease in the next round.

7.3.1 Electrocardiogram (ECG) data

The ECG analysis is divided in two different types

- Heart rate;

  This analysis checks the heart beat frequency;

- Heart rate variancy.

  This analysis checks the heart beat frequency variance and it is done by analysing variation of the interval between beats.

7.3.1.1 Analysis of the heart beat frequency

The Table 7.46 presents the average heart rate by each participant on each scenes and they are plotted in the Figures 7.23 and 7.24. It is possible to see that there were no heart rate increase by any participant with exception only with the "sight" sample in the "First" round of the "Base" method

The Figure 7.25 shows a comparison between both groups

The Table 7.47 show the the variation of the heart beat in each the rounds of each participant. It is possible to notice that almost all of the variations were negative, meaning that the user decreased its workload between the "Baseline" and each method.

TABLE 7.46 – ECG average BPM felled by the participants.

	Baseline	Base	Audio	Haptic Belt	Virtual Cane	Mixture

Participant	Visual Condition	Round						
001	Sight	First	81.285	76.857	71.230	63.024	64.848	58.770
		Return	NaN	72.881	73.182	61.180	66.776	66.261
001C	Blind	First	78.333	75.754	60.708	71.167	59.066	68.241
		Return	NaN	71.052	58.613	66.223	64.198	70.764
002C	Blind	First	67.776	48.688	38.670	48.736	46.892	52.228
		Return	NaN	52.460	47.580	58.970	56.749	58.249
003	Sight	First	77.378	74.975	63.470	71.805	70.900	72.761
		Return	NaN	69.288	72.753	71.225	67.485	73.010
003C	Blind	First	63.449	68.372	69.891	70.954	69.408	66.942
		Return	NaN	67.337	67.437	69.683	68.823	67.372
004	Sight	First	65.323	72.971	66.851	62.450	65.939	67.858
		Return	NaN	76.853	69.476	65.650	64.576	71.860
004C	Blind	First	78.299	75.091	73.554	73.699	71.937	74.030
		Return	NaN	74.740	74.785	74.023	72.689	67.339
005	Sight	First	71.254	70.185	71.345	66.928	66.458	67.055
		Return	NaN	67.687	69.570	65.967	67.004	65.472

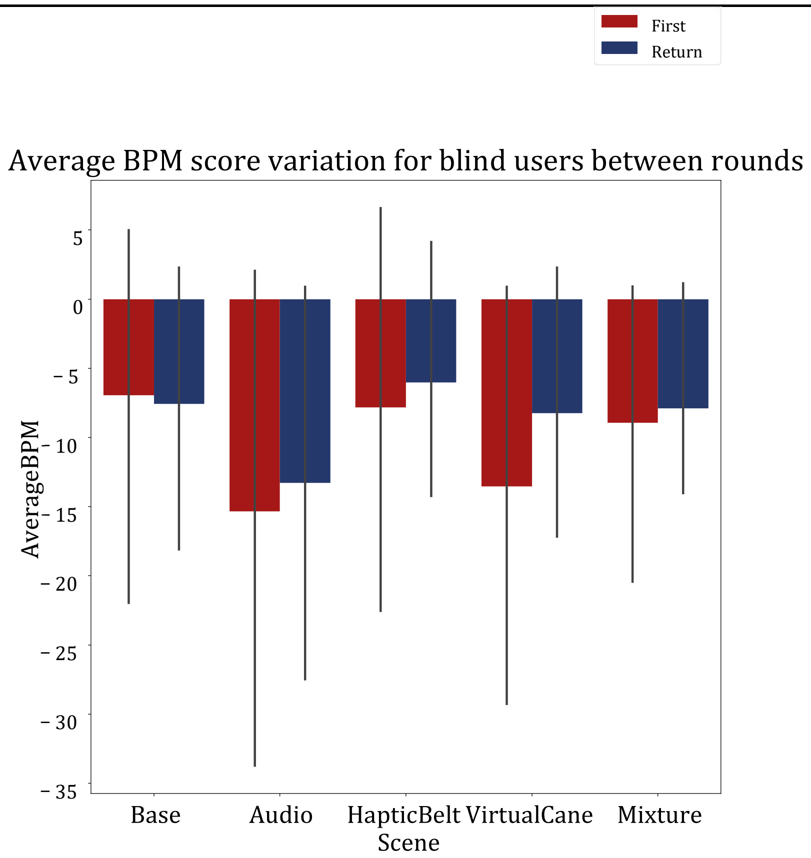


FIGURE 7.23 – Bar plot of the average heart rate of the blind participants on each method.

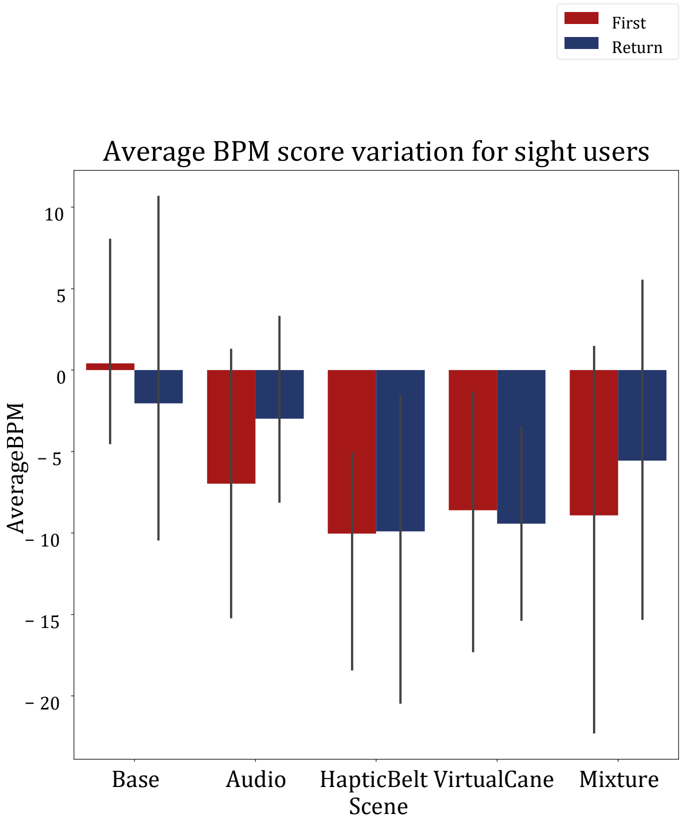


FIGURE 7.24 – Bar plot of the average heart rate of the sighted participants on each method.

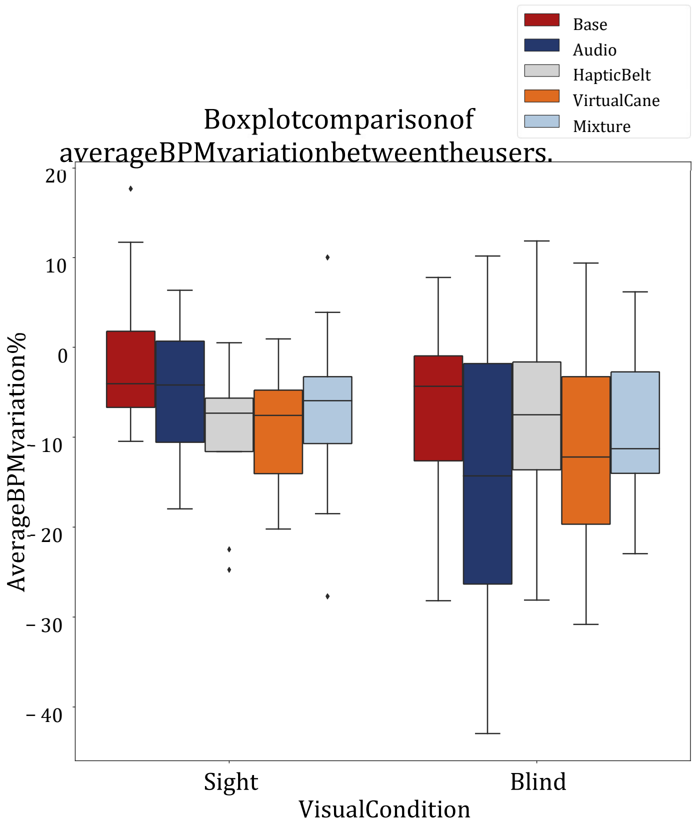


FIGURE 7.25 – Boxplot of the average heart rate of participants on each method.

TABLE 7.47 – ECG average BPM variation in relation to the baseline by participant and method.

Part	Visual Condition	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	-5.4%	-12.3%	-22.4%	-20.2%	-27.6%
		Return	-10.3%	-9.9%	-24.7%	-17.8%	-18.4%
001C	Blind	First	-3.2%	-22.5%	-9.1%	-24.5%	-12.8%
		Return	-9.2%	-25.1%	-15.4%	-18.0%	-9.6%
002C	Blind	First	-28.1%	-42.9%	-28.0%	-30.8%	-22.9%
		Return	-22.5%	-29.7%	-12.9%	-16.2%	-14.0%
003	Sight	First	-3.1%	-17.9%	-7.2%	-8.3%	-5.9%
		Return	-10.4%	-5.9%	-7.9%	-12.7%	-5.6%
003C	Blind	First	7.7%	10.1%	11.8%	9.3%	5.5%
		Return	6.1%	6.2%	9.8%	8.4%	6.1%
004	Sight	First	11.7%	2.3%	-4.3%	0.9%	3.8%
		Return	17.6%	6.3%	0.5%	-1.1%	10.0%
004C	Blind	First	-4.0%	-6.0%	-5.8%	-8.1%	-5.4%
		Return	-4.5%	-4.4%	-5.4%	-7.1%	-13.9%
005	Sight	First	-1.5%	0.1%	-6.0%	-6.7%	-5.8%
		Return	-5.0%	-2.3%	-7.4%	-5.9%	-8.1%

The Shapiro–Wilk normality test on the Table 7.48 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the "blind" sample is different then the "sight" sample.

TABLE 7.48 – Shapiro test p-value for the ecg average BPM for each method and visual condition

Method	Shapiro P-Value
Base blinded users	0.377
Base sighted users	0.086
Audio blinded users	0.721
Audio sighted users	0.969
Haptic Belt blinded users	0.665
Haptic Belt sighted users	0.059
Virtual Cane blinded users	0.584
Virtual Cane sighted users	0.743
Mixture blinded users	0.379
Mixture sighted users	0.663

Acording to the T-Test presented on the Table 7.49 there are no difference on the heart rate frequency variation between the sample groups.

The Table 7.50 shows the Anova test p-value of the heart rate frequency of the "blind" sample between the guidance methods presented on the Table 7.47. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

TABLE 7.49 – T test p-value for the ecg average BPM each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.279
Audio	0.215
Haptic Belt	0.594
Virtual Cane	0.750
Mixture	0.834

TABLE 7.50 – Anova p-value for the average BPM on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	303.579	4	75.895	0.383	0.819
Inside factors	6928.578	35	197.959		
Total	7232.157	39			

The Table 7.51 presents the conclusion of a pairwise Fisher LSD test of the blind heart rate frequency variation between all the guidance methods. The results show that only "Audio" caused a different variation than the one notice on the "Base" Method.

TABLE 7.51 – Cross validation p-value for the average BPM on each method for blinded users.

Method	Analysis
Base versus Audio	$**H_1 : \mu_{Base} \neq \mu_{Audio}**$
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$H_0 : \mu_{Base} = \mu_{VirtualCane}$
Base versus Mixture	$H_0 : \mu_{Base} = \mu_{Mixture}$
Audio versus Haptic Belt	$**H_1 : \mu_{Audio} \neq \mu_{HapticBelt}**$
Audio versus Virtual Cane	$H_0 : \mu_{Audio} = \mu_{VirtualCane}$
Audio versus Mixture	$H_0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

According to the Anova test at Table 7.50 and the LSD test at 7.51 only the "Audio" method provoked a different reaction than the "Base" method. Besides that, all methods decreased their frequency, going against the original expectations.

7.3.1.2 Analysis of the heart beat frequency

The Table 7.52 presents the standar deviation of the interbeat interval by each participant on each scenes and they are plotted in the Figures 7.26 and 7.27. It is possible to see that there were all of the users feelt an increase of the heart beat variancy.

TABLE 7.52 – ECG Average SDNN felled by the participants.

Part	Visual Condition	Round	Baseline	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	37.524	82.734	82.185	134.530	134.773	225.408
		Return	NaN	84.959	69.479	318.747	116.003	136.507
001C	Blind	First	78.548	81.292	107.061	124.737	163.968	129.054
		Return	NaN	120.719	130.885	131.590	157.589	124.786
002C	Blind	First	93.769	73.761	98.863	81.140	33.977	79.289
		Return	NaN	108.940	49.627	42.815	114.057	107.545
003	Sight	First	45.398	58.072	79.600	51.782	68.676	60.842
		Return	NaN	21.302	45.709	40.927	66.323	47.823
003C	Blind	First	26.140	36.870	38.325	35.101	42.392	43.692
		Return	NaN	52.750	41.196	44.256	42.602	46.145
004	Sight	First	91.787	120.512	121.130	154.718	128.477	125.947
		Return	NaN	139.858	100.366	122.563	140.115	119.260
004C	Blind	First	20.978	70.728	86.827	62.560	85.900	70.472
		Return	NaN	71.950	74.895	70.017	66.089	104.040
005	Sight	First	80.608	44.497	87.686	120.522	88.591	102.796
		Return	NaN	59.771	93.207	122.839	141.305	96.035

Average SDNN score variation for blind users between rounds

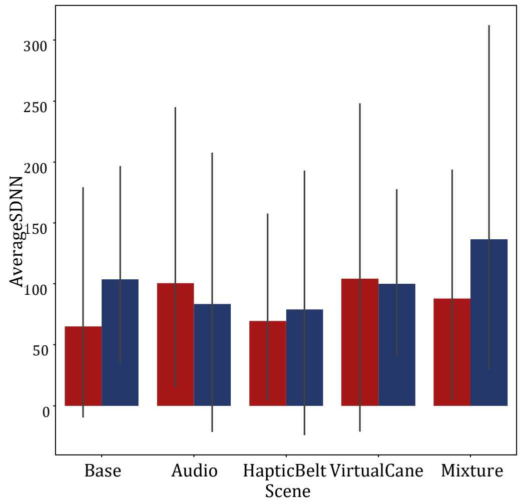


FIGURE 7.26 – Bar plot of the standard deviation of the heart of the blind participants on each method.

The Figure 7.25 shows a comparison between both groups

The Table 7.53 show the the variation of the heart beat in each the rounds of each participant. In general, all the standard deviation increased, meaning that the mental

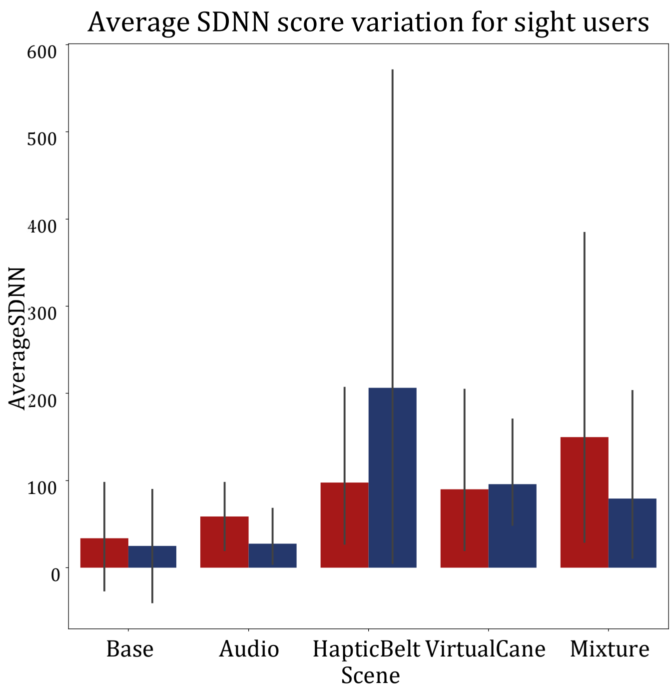


FIGURE 7.27 – Bar plot of the standard deviation of the heart of the sighted participants on each method.

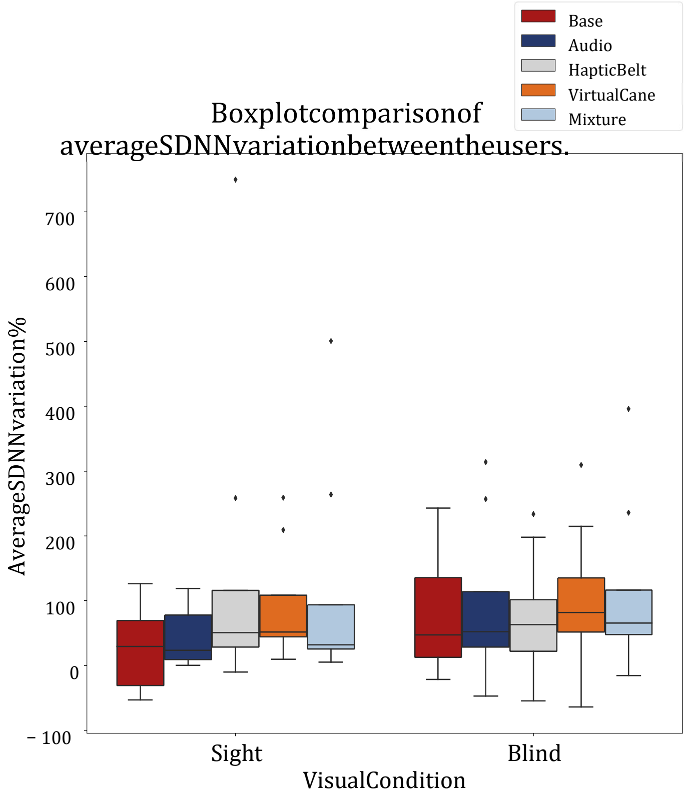


FIGURE 7.28 – Boxplot of the average heart rate of the participants on each method.

workload decreased between the "Baseline" and the method.

TABLE 7.53 – ECG Average SDNN variation in relation to the baseline by participant and method.

			Base	Audio	Haptic Belt	Virtual Cane	Mixture
Participant	Visual Condition	Round					
001	Sight	First	120.4%	119.0%	258.5%	259.1%	500.6%
		Return	126.4%	85.1%	749.4%	209.1%	263.7%
001C	Blind	First	3.4%	36.2%	58.8%	108.7%	64.2%
		Return	53.6%	66.6%	67.5%	100.6%	58.8%
002C	Blind	First	-21.3%	5.4%	-13.4%	-63.7%	-15.4%
		Return	16.1%	-47.0%	-54.3%	21.6%	14.6%
003	Sight	First	27.9%	75.3%	14.0%	51.2%	34.0%
		Return	-53.0%	0.6%	-9.8%	46.0%	5.3%
003C	Blind	First	41.0%	46.6%	34.2%	62.1%	67.1%
		Return	101.8%	57.5%	69.3%	62.9%	76.5%
004	Sight	First	31.2%	31.9%	68.5%	39.9%	37.2%
		Return	52.3%	9.3%	33.5%	52.6%	29.9%
004C	Blind	First	237.1%	313.8%	198.2%	309.4%	235.9%

		Return	242.9%	257.0%	233.7%	215.0%	395.9%
005	Sight	First	-44.7%	8.7%	49.5%	9.9%	27.5%
		Return	-25.8%	15.6%	52.3%	75.3%	19.1%

The Shapiro–Wilk normality test on the Table 7.54 shows that all of the "blind"sample data are normally distributed, with the exceptio of the "Mixture" method. In the "sight" sample only the "Base" and the "Audio" method are normally distributed. That means that the following analyses cannot be made with those exceptions.

TABLE 7.54 – Shapiro test p-value for the ecg average SDNN for each method and visual condition

Method	Shapiro P-Value
Base blinded users	0.078
Base sighted users	0.347
Audio blinded users	0.071
Audio sighted users	0.130
Haptic Belt blinded users	0.414
Haptic Belt sighted users	0.001
Virtual Cane blinded users	0.723
Virtual Cane sighted users	0.015
Mixture blinded users	0.027
Mixture sighted users	0.001

Acording to the T-Test presented on the Table 7.49 there are no difference on the heart rate frequency variation between the sample groups.

TABLE 7.55 – T test p-value for the ecg average SDNN each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.230
Audio	0.317
Haptic Belt	0.434
Virtual Cane	0.862
Mixture	0.976

The Table 7.50 shows the Anova test p-value of the heart rate frequency of the "blind" sample between the guidance methods presented on the Table 7.47. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

TABLE 7.56 – Anova p-value for the average SDNN on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	7039.359	4	1759.840	0.130	0.970
Inside factors	474190.070	35	13548.288		
Total	481229.429	39			

The Table 7.51 presents the conclusion of a pairwise Fisher LSD test of the blind heart rate frequency variation between all the guidance methods. The results show no difference between the methods.

TABLE 7.57 – Cross validation p-value for the average SDNN on each method for blinded users.

Method	Analysis
Base versus Audio	$H0 : \mu_{Base} = \mu_{Audio}$
Base versus Haptic Belt	$H0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$H0 : \mu_{Base} = \mu_{V irtualCane}$
Base versus Mixture	$H0 : \mu_{Base} = \mu_{Mixture}$
Audio versus Haptic Belt	$H0 : \mu_{Audio} = \mu_{HapticBelt}$
Audio versus Virtual Cane	$H0 : \mu_{Audio} = \mu_{V irtualCane}$
Audio versus Mixture	$H0 : \mu_{Audio} = \mu_{Mixture}$
Haptic Belt versus Virtual Cane	$H0 : \mu_{HapticBelt} = \mu_{V irtualCane}$
Haptic Belt versus Mixture	$H0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H0 : \mu_{V irtualCane} = \mu_{Mixture}$

According to the Anova test at Table 7.56 and the LSD test at 7.57 there are no differences between the methods. Besides that, all of the provoked a decrease on the mental workload.

7.3.2 Galvanic skin reaction and temperature data;

The GSR analysis is made by analysing the average in each round and comparing with the "Baseline" average. The temperature was analysed with the GSR to see if there is some influence and by a graphical analysis there was none.

The Table 7.58 presents the average skin conductance by each participant on each scenes and they are plotted in the Figures 7.29 and 7.30. It is possible to see that in all of the methods there was an increase of the average skin conductace, meaning that the user was aroused and maybe an increase of the mental workload.

TABLE 7.58 – GSR Average felled by the participants.

Part	Visual Condition	Round	Baseline	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	4.270	8.800	15.190	15.667	15.187	14.155
		Return	NaN	11.481	14.952	15.086	15.723	21.515
001C	Blind	First	0.371	0.484	1.026	3.138	3.785	3.900
		Return	NaN	0.835	1.585	2.807	4.038	4.570
002C	Blind	First	0.170	0.906	0.225	0.170	0.170	0.170

		Return	NaN	0.428	0.173	0.161	0.170	0.170
003	Sight	First	0.193	0.187	0.170	0.170	0.170	0.170
		Return	NaN	0.170	0.170	0.170	0.170	0.170
003C	Blind	First	0.303	0.562	0.558	0.619	0.855	1.087
		Return	NaN	0.622	0.634	0.645	0.916	1.060
004	Sight	First	0.303	0.562	0.558	0.619	0.855	1.087
		Return	NaN	0.622	0.634	0.645	0.916	1.060
004C	Blind	First	1.235	2.342	3.070	3.493	2.277	2.232
		Return	NaN	2.572	2.947	3.199	2.208	2.243
005	Sight	First	0.467	1.879	1.583	1.437	1.372	1.329
		Return	NaN	1.658	1.527	1.470	1.492	1.335

The Figure 7.25 shows a comparison between both groups

The Table 7.59 show the the variation of the heart beat in each the rounds of each participant. It is also possible to notice the same increase noticed before.

The Shapiro–Wilk normality test on the Table 7.60 shows that only the "Audio" method is normally distributed for the "blind" sample while for the "sight" sample only the "Virtual Cane" is not normally distributed

Acording to the T-Test presented on the Table 7.61 there are no difference on the heart rate frequency variation between the sample groups.

The Table 7.62 shows the Anova test p-value of the heart rate frequency of the "blind"

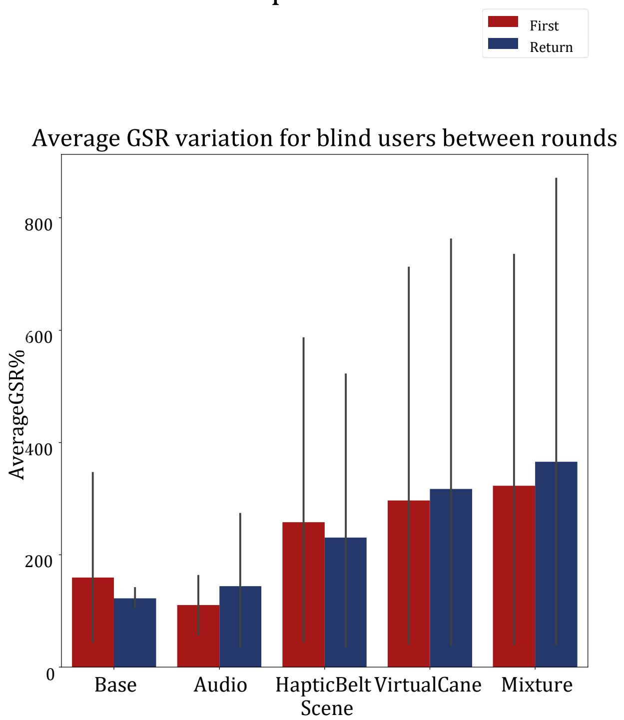


FIGURE 7.29 – Bar plot of the average skin conductance of the blind participants on each method.

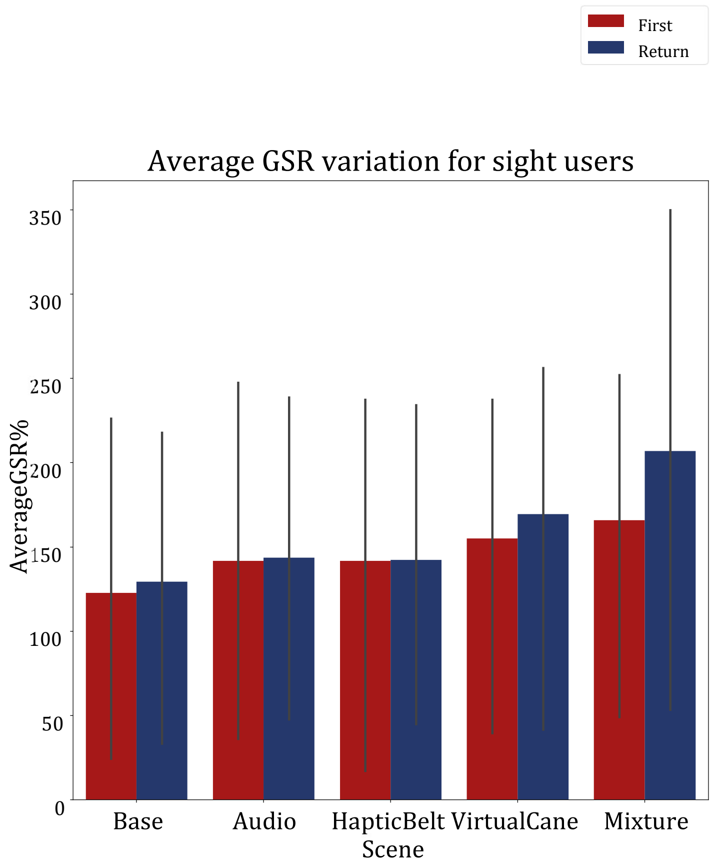


FIGURE 7.30 – Bar plot of the average skin conductance of the sighted participants on each method.

sample between the guidance methods presented on the Table 7.59. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

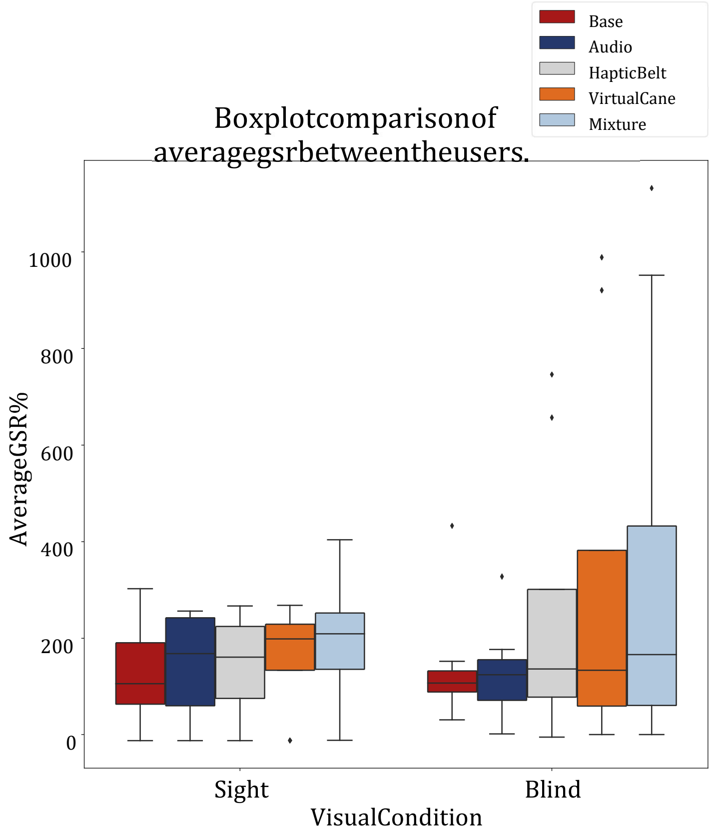


FIGURE 7.31 – Boxplot of the average skin conductace of the participants on each method. TABLE 7.59 – GSR average variation in relation to the baseline by participant and method.

Part	Visual Condition	Round	Base	Audio	Haptic Belt	Virtual Cane	Mixture
001	Sight	First	106.1%	255.7%	266.9%	255.6%	231.5%
		Return	168.9%	250.1%	253.3%	268.2%	403.9%
001C	Blind	First	30.5%	176.5%	746.0%	920.7%	951.7%
		Return	125.2%	327.4%	656.9%	988.9%	1132.3%
002C	Blind	First	432.6%	32.2%	0.0%	-0.0%	0.0%
		Return	151.7%	1.6%	-5.1%	0.0%	0.0%
003	Sight	First	-2.9%	-11.9%	-11.9%	-11.9%	-11.8%
		Return	-11.9%	-11.9%	-11.9%	-11.9%	-11.9%
003C	Blind	First	85.3%	84.2%	104.1%	182.3%	258.8%
		Return	105.3%	109.2%	112.9%	202.3%	249.7%
004	Sight	First	85.3%	84.2%	104.1%	182.3%	258.8%
		Return	105.3%	109.2%	112.9%	202.3%	249.7%
004C	Blind	First	89.6%	148.5%	182.8%	84.3%	80.6%

		Return	108.2%	138.6%	159.0%	78.7%	81.6%
005	Sight	First	302.4%	239.1%	207.7%	193.8%	184.7%
		Return	255.2%	227.0%	214.9%	219.5%	185.8%

TABLE 7.60 – Shapiro test p-value for the gsr average for each method and visual condition

Method	Shapiro P-Value
Base blinded users	0.002
Base sighted users	0.565
Audio blinded users	0.544
Audio sighted users	0.065
Haptic Belt blinded users	0.017
Haptic Belt sighted users	0.194
Virtual Cane blinded users	0.004
Virtual Cane sighted users	0.020
Mixture blinded users	0.011
Mixture sighted users	0.281

TABLE 7.61 – T test p-value for the average GSR on each method for blinded users versus sighted users.

Method	T-Test P-Value
Base	0.802
Audio	0.780
Haptic Belt	0.367
Virtual Cane	0.348
Mixture	0.354

TABLE 7.62 – Anova p-value for the average GSR on each method for blinded users.

Source	Squared sum	DOF	Squared average	F	p-Value (F 0 > F)
Between factors	301240.786	4	75310.197	0.797	0.535
Inside factors	3307916.688	35	94511.905		
Total	3609157.475	39			

The Table 7.63 presents the conclusion of a pairwise Fisher LSD test of the blind heart rate frequency variation between all the guidance methods. The results show that the "Virtual Cane" and the "Mixture" have different variation, but since they are not normally distributed this conclusion can not statistically be made.

According to the Anova test at Table 7.62 and the LSD test at 7.63 only the "Virtual Cane" and the "Mixture" method provoked a different reaction than the "Base" method, but since the Shapiro test at the Table 7.60 showed that they are not normally distruted, than this conclusion has no foundation.

TABLE 7.63 – Cross validation p-value for the average GSR on each method for blinded users.

Method	Analysis
Base versus Audio	$H_0 : \mu_{Base} = \mu_{Audio}$
Base versus Haptic Belt	$H_0 : \mu_{Base} = \mu_{HapticBelt}$
Base versus Virtual Cane	$**H_1 : \mu_{Base}! = \mu_{VirtualCane}**$
Base versus Mixture	$**H_1 : \mu_{Base}! = \mu_{Mixture}**$
Audio versus Haptic Belt	$H_0 : \mu_{Audio} = \mu_{HapticBelt}$
Audio versus Virtual Cane	$**H_1 : \mu_{Audio}! = \mu_{VirtualCane}**$
Audio versus Mixture	$**H_1 : \mu_{Audio}! = \mu_{Mixture}**$
Haptic Belt versus Virtual Cane	$H_0 : \mu_{HapticBelt} = \mu_{VirtualCane}$
Haptic Belt versus Mixture	$H_0 : \mu_{HapticBelt} = \mu_{Mixture}$
Virtual Cane versus Mixture	$H_0 : \mu_{VirtualCane} = \mu_{Mixture}$

8 Conclusion

At this final chapter, the goals will be revised along with the results collected. It will be divided in four sections, one for each goal and a final one for future works and suggestions, and each section will have four more subsections, one for each data source gathered and one for a final conclusion and comentaries for that goal.

8.1 Do BVI users feel present in the VE as if they were in the real world?

8.1.1 Answers based on the simulation data

Analysing the time that each user took to complete each scene, it is not possible to infer a conclusion, because this data was not meant to measure this goal.

8.1.2 Answers based on the subjective data

This data also was not made to assess this goal, because there are no base of comparison with a subjective data from before the experiment, hence before the user started to use the virtual reality.

8.1.3 Answers based on the physiological data

According to the ECG data, there was a decrease in the mental workload during the experiment while the expectation was to be an increase instead. This difference proves that the users were impact by the experiment in the virtual reality, but does not represent the same situation outside the virtual reality.

The GSR data also showed a change when the users were using virtual reality. The results showed that the users were aroused or had an increase of the mental workload.

8.1.4 Final conclusions

The physiological data gathered was the only source of data to assess this goal, and they had opposite conclusion regarding the expectation. The ECG showed a decrease on the mental workload, while the GSR showed an increase.

The ECG data is less realiable than the GSR due to the sensibilty of the sensors used. It was noted that the ECG is very sensible to movements and to the position of the sensors in relationship with the data receiver. If something stands in the way between the sensor and receiver, such as a human body, that data is lost, causing the resulting analysis to be noiseness or to be made using corrections such as the one used.

So, this goal was partially achieved.

8.2 Does BVI users rely more on a type of information than the other?

8.2.1 Answers based on the simulation data

With the regards on the time, and since the Anova test showed that all of the data are differente between each other, one can look at the Table 7.4 and notice that the method that the users took the shorter time was the ”Mixture”method, which was along with the expectation that the BVI users rely on both of the information, but the second shortest was the ”Virtual Cane”, so it indicates that the BVI user rely more on an haptic source of information. But this data is not entirely reliable, since there was a couple of mistakes in the first experiment to close each simulation, hence increasing the final time of each user at the round.

8.2.2 Answers based on the subjective data

Analysing the Figures 7.7, 7.12, 7.17 and 7.22 one can notice that the haptic source of information is preferable for they have the best results in general for each questionnaire, but the Anova test disagree with that conclusion in some cases, but that can a conseguence of the fact that only 4 individuals of each group did the experiment.

8.2.3 Answers based on the physiological data

Disconsidering that all of the ECG data were against the expected variation, according to the Anova test, only the ”Audio”method can be concluded that is different the ”Base”

method and Figure 7.23 shows a similar conclusion.

The skin conductance Anova test resulted that only the ”Virtual Cane”and the ”Mixture”method are different than the ”Base”method, and, also according with the skin data, they aroused more the user or have higher mental workload. Another conclusion from the Anova test is that ”Audio” method has a similar workload than the ”Base” method, and ironically this was the only one that could be said that arouses less or has a lesser mental workload.

8.2.4 Final conclusions and comentaries

The majority of the graphics showed an tendecy that haptics source of data are more favorable for the BVI users, but the conclusion draw by the hypothesis test did not support that analysis. This may be due to the small sample size.

One observation made during the experiment, is that the BVI users during the ”Audio” and ”Mixture”method did not used, or used only a few times, the audio guidance provided by the researcher. This does not discard that they did not rely on sound information, because the simulation has filled with audio cues. This may be because of their previous experience in navigation and mobility alone.

The final conclusion for this goal would be that they do rely more in a mixture of haptic and audio data, the first for obstacles detection at and short distance, the latter for a guidance and information gathered at bigger distances.

8.3 Do non BVI users have the same demands and skill as BVI users when designing assistive products?

8.3.1 Answers based on the simulation data

Results from the simulation data and the T-Test showed that the only time data that was different between the groups is the ”Audio”. Analysing the rest of the data one can conclude that the results had no difference.

Results from the Figure 7.3 showed a rather similar average duration between the two groups going along with the conclusion from the T-Test, but there is the matter of the unreliability of this data meantioned before.

8.3.2 Answers based on the subjective data

The T-Test of each questionnaire showed that there are no differences between the groups, but the Figures 7.7, 7.12 and 7.17 showed a noticible difference between the groups. This unmatched results may be because of the small sample number.

Draft Version: May 22, 2022

8.3.3 Answers based on the physiological data

The Figure 7.28 indicates that there are not visual difference between the groups. The Figure 7.25 indicates a difference on the distribution and a rather similar average. The Figure 7.31 indicate a higher arousal or mental workload by the ”blind” users. All the T-Test indicate that both groups have the same variation of workload and arouseness.

8.3.4 Final conclusions and comentaries

The T-Test results showed in general that all both groups had similar results, while the some graphics showed the opposite. This may happened because of may be for two reasons. First because of a small sample size. Second because of a tendecy of the ”sight” sample. The sighted participant all were used to technology and to voluntiring for experiments, while the same can not be said for the BVI participants.

To close up, this goal is considered not achieved for lack of a bigger and more diverse sample size.

8.4 Future works and suggestions

For future works related to the this one it could be suggested:

- Repeat the experiment in a real situation and compare with this one to verift the first goal;
- Repeat the experiment with more devices with different proporsions of haptic and audio information sources;
- Repeat the experiment with a bigger sample size and a more and diverse sample to verify if the results of the hypothesis test do remain the same;

Bibliography

BORGHINI, G.; ASTOLFI, L.; VECCHIATO, G.; MATTIA, D.; BABILONI, F. Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. Neuroscience & Biobehavioral Reviews, Elsevier, v. 44, p. 58–75, 2014. 32

BRADLEY, N. A.; DUNLOP, M. D. Investigating context-aware clues to assist navigation for visually impaired people. In: Proceedings of Workshop on Building Bridges: Interdisciplinary Context-Sensitive Computing, University of Glasgow. [S.l.: s.n.], 2002. ix, 43, 44, 45

BRADLEY, N. A.; DUNLOP, M. D. An experimental investigation into wayfinding directions for visually impaired people. Personal and Ubiquitous Computing, Springer, v. 9, n. 6, p. 395–403, 2005. ix, xiii, 43, 45, 46, 47

CAIN, B. A review of the mental workload literature. Defence research and development Toronto (Canada), 2007. 30, 31

CARDOSO, M. d. S.; GONTIJO, L. A. Evaluation of mental workload and performance measurement: Nasa tlx and swat. Gest˜ao &, Produ¸c˜ao, v. 19, p. 873–884, 2012. 30

CHAKLADAR, D. D.; DEY, S.; ROY, P. P.; DOGRA, D. P. Eeg-based mental workload estimation using deep blstm-lstm network and evolutionary algorithm. Biomedical Signal Processing and Control, Elsevier, v. 60, p. 101989, 2020. 31

CHIU, M.-L. An organizational view of design communication in design collaboration. Design studies, Elsevier, v. 23, n. 2, p. 187–210, 2002. 37

CUMMINGS, J. J.; BAILENSON, J. N. How immersive is enough? a meta-analysis of the effect of immersive technology on user presence. Media psychology, Taylor & Francis, v. 19, n. 2, p. 272–309, 2016. 41

DOOLANI, S.; WESSELS, C.; KANAL, V.; SEVASTOPOULOS, C.; JAISWAL, A.; NAMBIAPPAN, H.; MAKEDON, F. A review of extended reality (xr) technologies for manufacturing training. Technologies, Multidisciplinary Digital Publishing Institute, v. 8, n. 4, p. 77, 2020. 35, 36

DUL, J.; WEERDMEESTER, B. Ergonomics for beginners: a quick reference guide. [S.l.]: CRC press, 2003. 27, 28

EASY EDA. Dispon´ıvel em: <https://easyeda.com/>. 64

ENDSLEY, M. R. Design and evaluation for situation awareness enhancement. In: SAGE PUBLICATIONS SAGE CA: LOS ANGELES, CA. Proceedings of the Human

Factors Society annual meeting. [S.l.], 1988. v. 32, n. 2, p. 97–101. 33

ENDSLEY, M. R. Situation awareness global assessment technique (SAGAT). In: IEEE. Proceedings of the IEEE 1988 national aerospace and electronics conference. [S.l.], 1988. p. 789–795. 34

ENDSLEY, M. R. Measurement of situation awareness in dynamic systems. Human factors, SAGE Publications Sage CA: Los Angeles, CA, v. 37, n. 1, p. 65–84, 1995. 33, 34

ENDSLEY, M. R. Automation and situation awareness. In: Automation and human performance: Theory and applications. [S.l.]: CRC Press, 2018. p. 163–181. 33

ESPRESSIF SYSTEMS. ESP32-DevKitC V5: Getting sstarted guide. 2022. Dispon´ıvel em: <https://docs.espressif.com/projects/esp-idf/en/latest/esp32/hw-reference/esp32/get-started-devkitc.html>. Acesso em: 18 fev. 2022. xii, 141

FALLAHI, M.; MOTAMEDZADE, M.; HEIDARIMOGHADAM, R.; SOLTANIAN, A. R.; MIYAKE, S. Effects of mental workload on physiological and subjective responses during traffic density monitoring: A field study. Applied ergonomics, Elsevier, v. 52, p. 95–103, 2016. 30, 31

FARRELL, W. A. Learning becomes doing: Applying augmented and virtual reality to improve performance. Performance Improvement, Wiley Online Library, v. 57, n. 4, p. 19–28, 2018. 23, 35, 36

FARRER, C.; FRITH, C. D. Experiencing oneself vs another person as being the cause of an action: the neural correlates of the experience of agency. Neuroimage, Elsevier, v. 15, n. 3, p. 596–603, 2002. 42

FARSHID, M.; PASCHEN, J.; ERIKSSON, T.; KIETZMANN, J. Go boldly!: Explore augmented reality (ar), virtual reality (vr), and mixed reality (mr) for business. Business Horizons, Elsevier, v. 61, n. 5, p. 657–663, 2018. 36

HART, S. G.; STAVELAND, L. E. Development of nasa-tlx (task load index): Results of empirical and theoretical research. In: Advances in psychology. [S.l.]: Elsevier, 1988. v. 52, p. 139–183. 32

JICOL, C.; WAN, C. H.; DOLING, B.; ILLINGWORTH, C. H.; YOON, J.; HEADEY, C.; LUTTEROTH, C.; PROULX, M. J.; PETRINI, K.; O'NEILL, E. Effects of emotion and agency on presence in virtual reality. In: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. [S.l.: s.n.], 2021. p. 1–13. ix, 41, 42

JONDANI, J. A. Strategies for addressing the special needs of people with visual impairments during the covid-19 pandemic. Journal of Visual Impairment & Blindness, SAGE Publications Sage CA: Los Angeles, CA, v. 115, n. 3, p. 263–267, 2021. 23

KAHN, K. B. Interdepartmental integration: a definition with implications for product development performance. Journal of product innovation management, Elsevier, v. 13, n. 2, p. 137–151, 1996. 37

KARWOWSKI, W. The discipline of human factors and ergonomics. Handbook of human factors and ergonomics, Citeseer, v. 4, p. 3–37, 2012. 27 KLEINSMANN, M. S. Understanding collaborative design. 2006. 37, 38

KYLECORRY31. Haptic compass belt. 2020. Dispon´ıvel em: <https://www.instructables.com/Haptic-Compass-Belt/>. 63

LOZANO, C. A.; KACZMAREK, K. A.; SANTELLO, M. Electrotactile stimulation on the tongue: Intensity perception, discrimination, and cross-modality estimation. Somatosensory & motor research, Taylor & Francis, v. 26, n. 2-3, p. 50–63, 2009. 23

MA, J. Y.; CHOI, J. S. The virtuality and reality of augmented reality. J. Multim., Citeseer, v. 2, n. 1, p. 32–37, 2007. 35, 36

MANSIKKA, H.; SIMOLA, P.; VIRTANEN, K.; HARRIS, D.; OKSAMA, L. Fighter pilots' heart rate, heart rate variation and performance during instrument approaches. Ergonomics, Taylor & Francis, v. 59, n. 10, p. 1344–1352, 2016. 31

MARSTON, J. R.; LOOMIS, J. M.; KLATZKY, R. L.; GOLLEDGE, R. G.; SMITH, E. L. Evaluation of spatial displays for navigation without sight. ACM Transactions on Applied Perception (TAP), ACM New York, NY, USA, v. 3, n. 2, p. 110–124, 2006. x, 47, 48

MILGRAM, P.; KISHINO, F. A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, The Institute of Electronics, Information and Communication Engineers, v. 77, n. 12, p. 1321–1329, 1994. ix, 35

MOERLAND-MASIC, I.; REIMER, F.; BOCK, T. M.; MELLER, F.; NAGEL, B. Application of vr technology in the aircraft cabin design process. CEAS Aeronautical Journal, Springer, p. 1–10, 2021. x, xiii, 48, 49, 50, 51

MOHANAVELU, K.; POONGUZHALI, S.; RAVI, D.; SINGH, P. K.; MAHAJABIN, M.; RAMACHANDRAN, K.; SINGH, U. K.; JAYARAMAN, S. Cognitive workload analysis of fighter aircraft pilots in flight simulator environment. Defence Science Journal, v. 70, n. 2, 2020. 30, 31

MUJBER, T. S.; SZECSI, T.; HASHMI, M. S. Virtual reality applications in manufacturing process simulation. Journal of materials processing technology, Elsevier, v. 155, p. 1834–1838, 2004. 36

NIJHOLT, A.; TRAUM, D. The virtuality continuum revisited. In: CHI'05 Extended Abstracts on Human Factors in Computing Systems. [S.l.: s.n.], 2005. p. 2132–2133. 35

NOURBAKHSH, N.; WANG, Y.; CHEN, F.; CALVO, R. A. Using galvanic skin response for cognitive load measurement in arithmetic and reading tasks. In: Proceedings of the 24th Australian Computer-Human Interaction Conference. [S.l.: s.n.], 2012. p. 420–423. 32

ORLANDI, L.; BROOKS, B. Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance. Applied ergonomics, Elsevier, v. 69, p. 74–92, 2018. 31

RITCHIE, H.; MATHIEU, E.; ROD´eS-GUIRAO, L.; APPEL, C.; GIATTINO, C.; ORTIZ-OSPINA, E.; HASELL, J.; MACDONALD, B.; DATTANI, S.; ROSER, M. Coronavirus (COVID-19) cases. 2020. Dispon´ıvel em: <https://ourworldindata.org/covid-cases>. Acesso em: 8 fev. 2022. 23

RODR´IGUEZ, S.; SANCHEZ, L.; L´ OPEZ, P.; CA´ NAS, J. J. Pupillometry to assess air˜ traffic controller workload through the mental workload model. In: Proceedings of the 5th international conference on application and theory of automation in command and control systems. [S.l.: s.n.], 2015. p. 95–104. 31

SALAH, B.; ABIDI, M. H.; MIAN, S. H.; KRID, M.; ALKHALEFAH, H.; ABDO, A. Virtual reality-based engineering education to enhance manufacturing sustainability in industry 4.0. Sustainability, Multidisciplinary Digital Publishing Institute, v. 11, n. 5, p. 1477, 2019. 36

SANDERS, M. S.; MCCORMICK, E. J. Human factors in engineering and design. Industrial Robot: An International Journal, Emerald Group Publishing Limited, 1998. ix, 27, 28, 29, 30, 32, 33, 34

SANDOM, C.; HARVEY, R. S. Human factors for engineers. [S.l.]: Iet, 2004. v. 2. 27, 28

SHI, Y.; RUIZ, N.; TAIB, R.; CHOI, E.; CHEN, F. Galvanic skin response (gsr) as an index of cognitive load. In: CHI'07 extended abstracts on Human factors in computing systems. [S.l.: s.n.], 2007. p. 2651–2656. 32

SIU, A. F.; SINCLAIR, M.; KOVACS, R.; OFEK, E.; HOLZ, C.; CUTRELL, E. Virtual reality without vision: A haptic and auditory white cane to navigate complex virtual worlds. In: Proceedings of the 2020 CHI conference on human factors in computing systems. [S.l.: s.n.], 2020. p. 1–13. ix, 39, 40, 41

SMITH, K. G.; SMITH, K. A.; OLIAN, J. D.; JR, H. P. S. *et al.* Top management team demography and process: The role of social integration and communication. Irish Journal of Management, Irish Academy of Managment, v. 17, n. 1, p. 36, 1996. 37

STANTON, N. A.; HEDGE, A.; BROOKHUIS, K.; SALAS, E.; HENDRICK, H. W. Handbook of human factors and ergonomics methods. [S.l.]: CRC press, 2004. xiii, 29, 30, 31, 32, 33, 34

WANG, S.; MAO, Z.; ZENG, C.; GONG, H.; LI, S.; CHEN, B. A new method of virtual reality based on unity3d. In: IEEE. 2010 18th international conference on Geoinformatics. [S.l.], 2010. p. 1–5. 55

WOLF, A.; BINDER, N.; MIEHLING, J.; WARTZACK, S. Towards virtual assessment of human factors: A concept for data driven prediction and analysis of physical user-product