A Computer-based Mental Mapping Skills Assessment Tool

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Abstract

For visually impaired individuals, there are two major senses that play important roles to help them get through with their daily routines, and those are by recognizing their environment via auditory orientation and tactile feedback. Individuals who are newly visually impaired should undergo an orientation and mobility training to help them learn essential safe travel skills in both their home and around their community. Orientation refers to the ability to place objects via spatial cognition in an environment and being aware of one's location and its association with the environments. As for mobility, it showed the aptitude to resourcefully and safely move in a situation unaided. Part of this sensory training encompasses the strengthening of the mental mapping skills. Mental mapping helps a person to determine their current location and their intended destination with relation to other objects in their current environmental space. This research uses a computer-based assessment tool to evaluate the mental mapping skills of the participants.

Our reliance on mental mapping is fundamental to help us find our way around an environment but not limited to remembering the location of things that are close by. In order to address the above-mentioned issues, this thesis introduced a computer-based assessment tool for mental mapping skills evaluation. The assessment tool is a computer-based software that takes place in a virtual 2D environment. Each assessment level had a different starting point and its respective ending points along with the different length of the path and location of a traffic light. The map design was based on Stuart Tactile Maps Test, which was originally developed to test a person's ability to learn spatial information and stay orientated during mobility. It showed the number of attempts a person needs to practice to get it right. The results from Stuart's test can be equated with active coordination skills observed throughout functional orientation and mobility assessment.

An evaluation with 25 participants was conducted using the proposed computer based mental mapping skills assessment tool. The participants were categorized into visually impaired with no vision, visually impaired with low vision, and sighted. By evaluating the game times and game scores gathered by the participants throughout the assessment sessions as well as their sketch scores conducted within 7 days, two hypotheses were

evaluated. The null hypothesis H_0, states that the assessment results do not show any inconsistencies for both the total game time and total sketch score throughout the three sessions. The alternative hypothesis H_1, theorizes that the assessment results show inconsistencies for both the total game time and total sketch score during the course of the evaluation sessions. The results of the evaluation showed that over the course of three sessions, the scores of the participants were consistent. This proves the proposed computer-based mental mapping skills assessment tool is a reliable assessment tool which provides scores that are aligned with human mental mapping skills, which do not fluctuate in a short period of time. Thus, the computer based mental mapping skills assessment tool is recommended for the visually impaired as this tool could save time, save manpower, improve record keeping, allow consistent assessment and repeated use, being interactive with audio and haptic feedback.

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Declaration of Originality

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and to the best of my knowledge contains no material previously published or written by another person, except where due reference is made in the text of the thesis. Work based on joint research or publications in this thesis fully acknowledges the relative contributions of the respective authors or workers.

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Date : 28 June 2018

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Chapter 1 Introduction

This chapter provides an overview of this thesis. It starts by providing the background of study and the research questions pertaining to the undertaking of this thesis. Subsequently, a brief description on the aim of the thesis and the approaches and techniques employed to fulfil the objectives of this research are outlined, followed by the research scope and its contribution. Finally, the thesis outlines are presented by summarizing the thesis chapter structure.

1.1 Background of Study

Humans are born with five important senses, which when working together, allows one to fully experience the world that we live in. We have a nose to smell, tongue to taste, a pair of ears to hear, tactile sensors in our skins to feel, and by far the most important organs of them all, a pair of eyes to see. To survive in a hostile world, we rely heavily on the accuracy of our vision to guide our actions. About 285 million people are estimated to be visually impaired worldwide with 39 million of those permanently visually impaired with no vision (World Health Organization, 2013) while the remaining figures represent those suffering from visual impairment with low vision. For these visually impaired individuals, gaining a reliable and safe method of travel and interacting with their environment is one of the most significant problems they face.

Two major senses that play an important role to help the visually impaired get through with their daily routines are by recognizing their environment via auditory orientation and tactile feedback. Auditory orientation or sound localization is the ability to identify the location of a sound source while tactile feedback uses the sense of touch to sense vibrations or motions around the person. Individuals who are newly visually impaired should undergo an orientation and mobility training to help them learn essential safe travel skills in both their home and around their community. When speaking about individuals with visual impairments, orientation and mobility are used to quantify the capability of human movement as well as the assessment of their surroundings. Orientation refers to the ability to place objects via spatial cognitive in an environment and being aware of one's location and its association with the environments (Kerster, Rhodes and Kello, 2016). Mobility refers to the aptitude to resourcefully and safely move in a situation unaided (Cuturi *et al.*, 2016).

In short, orientation and mobility are defined as the capacity to know where one is and desires to go and their ability to travel from one location to the next in an efficient, safe, and effective manner (Giudice, Bakdash and Legge, 2007). This means walking confidently without falling or colliding with stationary or moving objects. Orientation and mobility training usually includes learning how to use important devices like the cane, or even a guide dog, and strategies to listen for auditory clues from their environments such as moving vehicles or traffic lights patterns. The traditional orientation and mobility training also includes sensory development that involves training all of one's senses to assist the individual in knowing their current whereabouts and the direction to head in order to reach their desired destination. Part of this sensory training encompasses the strengthening of their mental mapping skills.

Mental mapping helps a person to determine their current location and their intended destination with relation to other objects in their current environmental space. Our reliance on mental mapping is essential to help us find our way around surroundings but not limited to recalling the location of things that are nearby. In this research project, an alternative approach was introduced to evaluate the mental mapping skill of an individual. More explicitly, the spatial cognitive memory of the individual was measured by means of a computer-based assessment tool.

Throughout this thesis, the terms mental mapping skill, spatial memory skill, and spatial cognitive skill are used interchangeably. This is because, in the context of this research topic, they refer to one’s ability to relate to two objects within a defined space. Mental mapping explores an individual’s capacity to traverse a place and to move in and out of a particular area based on the locations of buildings and walkable paths (Gutsche, 2014). Similarly, the part of memory that is responsible for storing information about a person’s directional orientation as well as the information on their current surrounding environment is also known as the spatial memory (Lekan, 2016). These terms are all linked together to define one’s capability to orient themselves with their surroundings.

1.2 Research Questions

The research question of the thesis is on the development of a computer-based assessment tool, which was used to evaluate the mental mapping skills of an individual. To tackle this main research question, the following sub-questions needs to be answered:

1. Is it feasible to create a computer-based mental mapping skills assessment tool?
   The types of visual impairments and how it led to the rise of orientation and mobility for those who required them are investigated. Tools and methods to help the visually impaired in their orientation and mobility are presented as well as a look into the current approaches that are available. These techniques together with the literature review done by other researchers are discussed in Chapter 2 of this thesis.

2. What are the criteria for a good computer-based mental mapping skills assessment tool?
   Existing methods to measure the mental mapping skills are used as a guideline for developing a good computer-based mental mapping skills assessment tool. An appropriate method from the currently available study was selected and the steps to translate it into a computer-based assessment tool were outlined. The conceptualization of the methods and its implementation and prototype are discussed in greater depth in Chapter 3.

3. Would the mental mapping skills of the participant be consistent over the duration of the assessment?
   Since birth, new-borns are encouraged to walk as soon as possible by their caregivers. Progress may go on for years as the child develops their balance and sense of direction. Similarly, this thesis focuses on evaluating whether a participant's mental mapping skills remain consistent or show improvement at the end of the assessment experiment. The procedures for the evaluation and the results of the assessment are described in Chapter 4.

1.3 Research Hypothesis

This research intends to test two hypotheses on the outcome of the computer-based evaluation of an individual's mental mapping capability. The first is the null hypothesis H_0 (1), which states that the assessment results do not show any changes for both the total game time and total sketch score throughout the three sessions. The second hypothesis is the alternative hypothesis H_1 (2), which theorizes that the assessment results showed changes for both the total game time and total sketch score during the course of the evaluation sessions. The formula given in (1) for the null hypothesis means that the mean results from the first session, μ_1, remained relatively consistent for the second, μ_2, and third session, μ_3. In the alternative hypothesis as shown in equation (2), the mean result from the first session, μ_1, the second session, μ_2, and the final session, μ_3, are not consistent. In this research context, an inconsistent result between each session can be seen as either the total game time improving or worsening and the total sketch time improving or worsening.

$$H_0 : \mu_1 = \mu_2 = \mu_3 \tag{1}$$

$$H_1 : \mu_1 \neq \mu_2 \neq \mu_3 \tag{2}$$

1.4 Aim

The aim of this research was to develop a computer-based assessment tool for mental mapping skills evaluation. The research experiment was carried out with three different groups of participants. The first group and second group comprised of participants who are visually impaired and have no vision or low vision respectively. The third group consists of sighted participants. All participants underwent three separate sessions of assessment to evaluate their mental mapping skills.

1.5 Research Objectives

This research focuses on developing a computer-based assessment tool to assess the mental mapping skills of an individual. To achieve this goal, the specific objectives of this research are as follows:

1. To study the existing mental mapping skills assessment tools used for people with visual impairment.
2. To design a computer-based mental mapping skills assessment prototype.
3. To evaluate the proposed mental mapping skills assessment prototype with the volunteers.

1.6 Thesis Outline

The thesis consists of five chapters, including this introductory chapter, which gives a background on the research program, objectives, and the related purposes pertaining to this research topic that needs to be fulfilled.

The second chapter provides the literature review of the research matter. The topic on visual impairment types is covered to give the reader a quick outline of common visual impairments that afflict visually impaired individuals. An overview on orientation and mobility and how they relate to the visually impaired are communicated here. A general overview of spatial memory and the research conducted by other scholars and its vision-related outcomes, which are used in chapter 3, are explained in this chapter.

Chapter 3 goes into the methodology of the research. The design and development of the assessment tool are presented. From the concept stage to the finished product of the assessment tool, this chapter clarifies the approach taken to develop a computer-based assessment tool. This assessment tool was later used to evaluate the mental mapping skills of individual subjects. The implementation of it is discussed in the following chapter.

Selection of the participants and their grouping is explained in Chapter 4. This chapter includes the description of the process and procedure used in the research data gathering sessions and the details on how the assessment sessions were carried out. The study duration for the experiment lasted for several sessions in order to capture the required data. The results are used for data analysis. The data captured during the research study phase was analysed. A one-way analysis of variance was used to analyse the results. The statistical test was run for the total game time and total sketch score for the result from the visually impaired group with no vision, visually impaired group with low vision, sighted group, and all three groups combined. The statistical summary and one-way analysis of variance statistical result for each participant are explained.

The thesis concludes with the final chapter, chapter 5, by discussing the results from the experiment and analytical efforts derived from chapter 4. It also presents the limitations and recommendations for future directions

Chapter 2 Literature Review

This chapter reviews the literature on the research matter. The topic of visual impairment types is covered to give the reader a quick outline of common visual impairments that can afflict individuals. A brief consideration of orientation and mobility and how they relate to the visually impaired is communicated here. A general overview of mental mapping skills and research conducted by other scholars is explained in this chapter. This chapter also seeks to find the answers for the research question on the feasibility of creating a computer-based mental mapping skills assessment tool and to understand the required criteria to pursue such an endeavour.

2.1 Visual Impairment

In 2010, the assessed number of people who are visually impaired in the world is 285 million, 39 million of them have no vision while the remaining 246 million have low vision (World Health Organization, 2013). There are numerous different causes and categories of visual impairment, including detached retinas, cataracts, and glaucoma. There are several definitions of visual impairment, which covers a broad scale of people. It ranges from people who are partially sighted to those who are completely visually impaired.

It affects both young and the old, from a congenital visual disorder such as German measles (Rubella) (Bouthry *et al.*, 2014), an infection transmitted from the mother to the foetus during pregnancy all the way to adults who suffer from age-related macular degeneration (Congdon *et al.*, 2004). Certain diseases or disabilities are accompanied by visual impairment, some of which may lead to permanent blindness. These include diabetes (Majeed and Molokhia, 2015), macular diseases (Jonas *et al.*, 2014), and hepatic encephalopathy (Cheng-Tagome *et al.*, 2017). Individuals with visual impairment in this research project are grouped into two categories; no vision and low vision. A person with normal vision has a visual acuity of 20/20 in the Snellen Chart (Barry and Denniston, 2017) while the visual acuity for low vision is defined as a refractive correction between 20/70 (Tunay *et al.*, 2016).

A multitude of eye disorders can lead to visual impairment and this does not include those that are caused by nerve and brain disorders or due to injury. When speaking about visual impairment, this is usually referred to a loss of vision which is not correctable with glasses. Amblyopia, a leading cause of pediatric vision impairment (Varma *et al.*, 2006; Tarczy-Hornoch *et al.*, 2013) or also known as "Lazy eye" is a term used to describe the condition whereby the decreased vision in one or both eyes is a functional defect characterized by damage to the visual pathways or the retina (Michaelides, 2004). In amblyopia patients, the brain "turns off" one of the eyes in favour of the other eye with a better vision. Achromatopsia is a congenital defect which is characterized by the patient’s inability to differentiate colors (Ansar *et al.*, 2015). This is caused by the malformation and partial or total absence of the cones. It is a hereditary condition that is not progressive. The patient sometimes experiences vision loss in brightly lit areas.

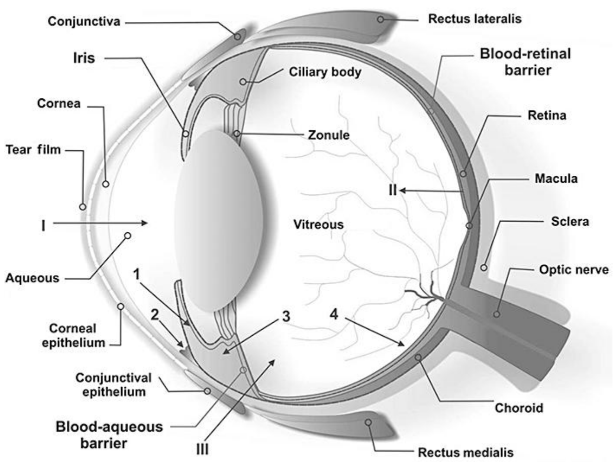

Figure 1: Schematic illustration of the structure of the eye and the ocular barriers (Willoughby *et al.*, 2010)

Cataracts, which is a pathological condition characterized by cloudiness or opacity of the crystalline lens, which results in a blurred image forming on the retina. It is estimated that 95 million people worldwide are affected by cataracts, which remains the leading cause of blindness in low-income and middle-income countries (Liu *et al.*, 2017). Cataracts may be caused by age, trauma, disease, or even congenital. Glaucoma which is caused by increased intraocular pressure is a pathologic condition. This results in the damage of the retinal nerves and optic nerve fibers (Davis and Gilhooley, 2017). A patient with glaucoma suffers from defects in their field of vision and increase in their optic cup size. The deterioration of the macula (Figure 1), which results in loss of central visual acuity is a pathologic condition called macular degeneration. Patient with this condition suffers from the loss of central vision which affects the color vision, acuity, and light sensitivity.

Optic Nerve Atrophy is caused by the dysfunction of the optic nerve which impairs the conduction of electrical impulses to the brain which leads to loss of vision (Al-Mendalawi, 2015). There is a loss of pupillary reaction and the optic disc becomes pale. When the retina of the eye separates itself from the underlying pigment epithelium, this pathological condition is known as retinal detachment. The most common cause of retinal detachment is the passing of fluid from the vitreous into sub-retinal space due to a retinal tear. Strabismus is a functional defect in the eye-muscle system which causes misalignment in an eye or both eyes to move abnormally (Gunton, Wasserman and DeBenedictis, 2015). The extraocular muscle imbalance causes one fovea to not be directed at the same object as the other. Strabismus has several different variations in regards to the control of the eye or eyes. Esotropia is when one or both eyes turn toward the nose. The opposite of this is exotropia whereby one or both eyes turn away from the nose. Hypertropia occurs when the eye or eyes deviate upward and hypotropia when it's downward (Barry and Denniston, 2017).

2.2 Orientation and Mobility

According to the Effective Mobility Framework (Deverell, 2016) shown in Figure 2, orientation is one of the important contributors to achieve effective mobility. Furthermore, the orientation ability of persons with visual impairment depends heavily on their mental mapping skills. For the visually impaired, orientation and mobility training is a form of a rehabilitation program that is designed for newly visually impaired individuals or those with a significant loss of vision. These programs provide support and training to help these individuals make the emotional and physical adjustments necessary to live independently as a normal member of the society. Part of the orientation and mobility training is to improve the cognitive mapping skill or spatial memory, which helps a person to determine their current location and their intended destination with relation to other objects in their current environmental space.

There are many organizations, both public and private, which offer assistance in the form of orientation and mobility training. An orientation and mobility specialist can help a visually impaired individual develop or re-learn the skills and methods needed to travel independently and safely within their home and around the community. These include sensory development to help them know where they are and interact with nearby objects, using a cane to travel safely and effectively and strategies to find their destination which includes following directions or using landmarks (American Foundation for the Blind, 2017a).

Orientation and mobility programs aim to teach lifelong skills that would prove useful for a visually impaired individual. Sensory awareness allows an individual to gain information about the world around them via smell, hearing, and touch. Realizing that an object exists even though it's not felt or heard and understanding the relationships which exist between objects and in the space around them is the spatial concept skill. Another part of orientation and mobility training is learning how to locate items and objects efficiently. This may be as simple as finding a cup or searching for things that are obscured. Orientation and mobility are important skills for every individual regardless of their age, or how physically active they are, or the degree of their vision loss, there are skills in the orientation and mobility domain which would probably benefit them that need to be developed and polished. Orientation and mobility instructors work to develop the directional and distance concepts in an individual with visual impairment(s). This is part of the cognitive mapping skill around which this research is centred.

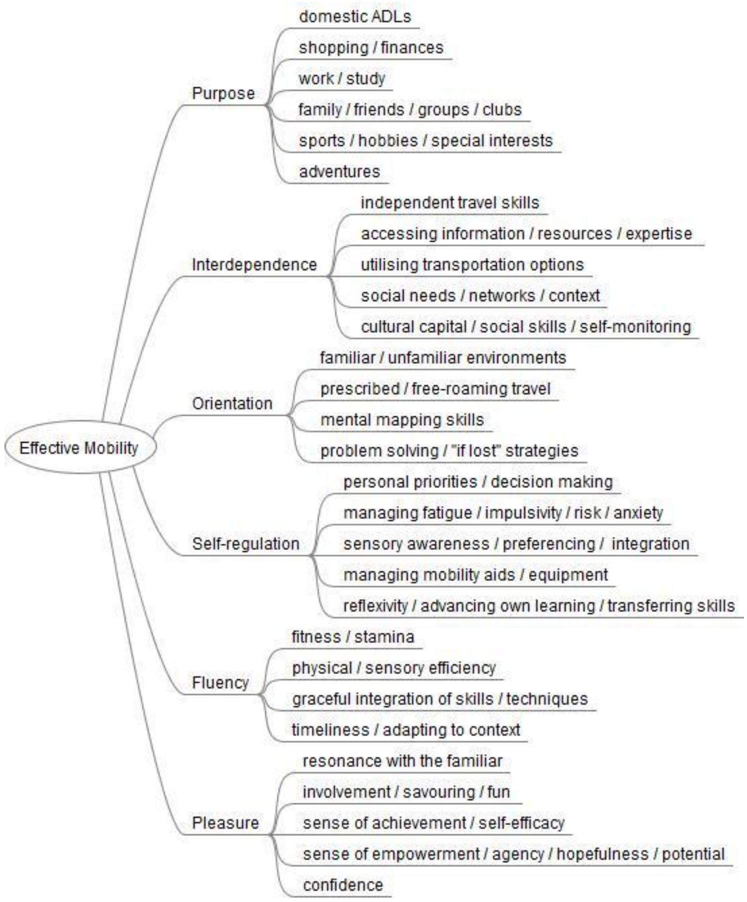

Figure 2: Effective Mobility Framework (Deverell, 2016)

Physical development in babies and children who are visually impaired is important and many resources are needed for orientation and mobility training. Some examples to train the orientation of the child include pointing out stationary objects as they are walked around the neighbourhood (American Foundation for the Blind, 2017b). These landmarks would become useful when they begin to walk around independently. Teaching the child to trail walls to allow them to find their way as well as giving them a sense of control over where they are going. These activities require constant parental or instructor supervision to ensure that the child is safe from bodily harm. These training activities, however, are no different for adolescent or adults who became visually impaired later in their life. Although they have a firm grasp of the shape and colour of an object as well as the type of sound produced when interacting with them, this by no means makes it any easier.

2.3 Mental Mapping Skills Training Tools

Aiming to improve the mental mapping skill of an individual, an Audio-based Environment Simulator (AbES) software was developed by a team of researchers to improve the orientation of adolescents who were visually impaired (Connors *et al.*, 2014). The AbES was developed to specifically train the navigation and spatial cognition skills in seven early visually impaired adolescents aged between 16 and 17 years. The application lets the participants explore an existing building but in a virtual world, which was set in an action video game metaphor. The architectural floor plan of an existing two-story building was used as a reference to render the virtual map. The player (yellow icon) was required to navigate through the virtual map environment using only auditory clues. The clues were used to locate hidden jewels and to avoid being captured by any monsters that were chasing them. The software used text to speech to provide participants with information regarding their orientation, heading, location and any obstacles or objects in their way. The effectiveness gained by exploring a particular virtual environment was investigated and it was found that following the intervention, participants were able to transfer and mentally manipulate acquired spatial information based on several navigation tasks conducted in the actual environment. Because the AbES software provided an immersive, safe, and engaging environment for participants to train and develop their spatial mental construct, the self-exploration and discovery nature of the software promotes the development of spatial cognitive skill. Apart from auditory feedback, the other important sense that is often used by the visually impaired to help them navigate their surrounding is the sense of touch or haptic feedback.

By combining both auditory and haptic feedback, a group of researchers were able to support the significance of their application in aiding the spatial knowledge and cognitive mapping skills (Papadopoulos *et al.*, 2015). Eleven adults, age ranged from 20 years to 61 years, with blindness took part in the research. Participants were asked to study an audio-haptic map to see how well their independent and efficient movement within the mapped area were and for detecting if specific points of interest were initially presented on the map or not. The map was provided through a multimodal application and was studied with the use of a force feedback haptic device. The program gave different types of audio messages to the participant, which included the direction of building and streets relative to the player and a short vibration on the handle if they come across an intersection. The results clearly support that the structure of spatial knowledge and cognitive maps can be developed using a specific application as an aid. That kind of knowledge could be used subsequently for orientation and mobility in an urban environment.

A similar study was done (Sanchez and de Borba Campos, 2013) to evaluate the impact and usefulness of an audio and haptic-based video game on the progress of orientation and mobility skills in school-age visually impaired learners which consists of ten visually impaired learners with ages ranging from 9 to 15 years old. An Audio Interface was used by the participants to help them navigate the map. An example was the use of spatialized sound to represent the ambience of the corridors. For example, if the user has a corridor to the left, he can hear an ambience sound through the left-hand channel of the speaker. A Novint Falcon haptic device was used for haptic feedback. The player can control a 3D cursor inside the virtual environment using the haptic device. Haptic textures were used to represent unique objects on the map thus the haptic feedback of the object's texture is different depending on what the player touches with the 3D cursor. Post-intervention validation was carried out by teachers based on an orientation and mobility skills checklist that was designed by special education teachers who were specialists in visual disabilities. The skills pertaining to orientation and mobility training was evaluated to validate the impact of the video game. Results from the study showed that when properly designed, a video game can be used as a medium to improve the orientation and mobility of the visually impaired.

Figure 3: Graphical interface of the 3D video game (Sánchez, Saenz and Garrido, 2010)

Training exercises conducted in a virtual environment can be used to provide people with visual impairment a place to improve their cognitive navigation skills. By using a haptic-based device and a 3D sound video game, researchers (Sánchez, Saenz and Garrido, 2010) were able to prove that there were significant gains in the improvement of orientation skills of visually impaired children. In the 3D video game (Figure 3), the player would need to manoeuvre through an environment to obtain game tokens while evading enemies who try to steal the token from them. The interaction with the game was via a custom-built haptic device called the Digital Clock Carpet (DCC). The DCC was a wooden platform, which supports the player standing on it. It was divided into 30 degrees sections, representing each hour of the clock. If the player needs to turn by 90 degrees, the player would have to turn to 3 o'clock on the DCC. The evaluation was performed on 19 visually impaired children ages 6 to 12 years old. The result showed significant improvement after the temporo-spatial orientation. This showed that the 3D video game with the DCC and cognitive tasks combined as an audio-based tool could be used to increase the temporo-spatial orientation skills in visually impaired children. Mental mapping helps a person to determine their current location and their intended destination with relation to other objects in their current environmental space. For the visually impaired, it is essential that they develop this area of skill well.

In the early page of this thesis, it was mentioned that mental mapping skill explores an individual's capacity to traverse a place and to move in and out of a particular area based on the locations of buildings and walkable paths (Gutsche, 2014). Similarly, the part of memory that is accountable for storing information about a person's directional orientation as well as the information on their current surrounding environment is also known as the spatial memory (Lekan, 2016), hence this sub-topic on spatial memory. Our brain has the unique aptitude to remember information and to retrieve those important bits of memory for essential usage. Spatial memory is the ability of the brain to retain and later, the retrieval of information that is needed when planning a route to a preferred location or to recall the location of an object or where an event had occurred.

Our reliance on spatial memory is fundamental to help us find our way around an environment but not limited to remembering the location of things that were close by. When we travel around our world, we tend to accumulate information about our surroundings to build a logical spatial image in our memory. Spatial memory is an important section of reasoning, defined as the preservation, assembly, and use of information about the surroundings (Dukas, 2004). It specifically comprises the use of elementary geometry and topographical information (Kamil and Jones, 1997) to evaluate the associations in any given setting. In human behavior and reasoning, scavenging and foraging-like practices were involved in the visual search, memory, spatial navigation, and various other search functions.

A video game developed to examine the role of spatial memory in a recognized foraging task by a group of researchers (Kerster, Rhodes and Kello, 2016), found that players use spatial memory to capture simple features when searching. These basic types of search methods include but were not limited to information search (Pirolli and Card, 1999), visual search (Klein and MacInnes, 1999), and memory search (Hills, Jones and Todd, 2012). In their research study, the participants used spatial memory to benefit from target distributions that were bundled together, which is similar to patch foraging and area-restricted search. Analysis of the exploration routes from over 2000 human players suggested that foraging movements were naturally clustered. It is thought that this clustering was influenced by memory for spatial locations of known objects and assisted by spatial memory hints.

Spatial memories are not limited to just humans but are also observed in the animal kingdom. A group of frogs called "Poison frogs" (*Dendrobatidae*) regularly transport their tadpoles from surface-dwelling holds to dispersed water installation places (Pašukonis *et al.*, 2016). An experiment carried out by the researchers to investigate if these frogs relied on spatial memory to reposition recognized deposition spots. A total of 56 male poison frogs were sampled during the experiment period with a total of 331 confinement points. The researchers temporarily removed an array of artificial ponds that was initially used as a main deposition resource for the tadpole population. At the same time, a number of mock sites and spots were set up to contain tadpole odour hints of the same species. The spot preferences and movement configurations were then quantified for the tadpole-transporting males by tracing individual frogs and rigorous sampling of the zone. The results were that the tadpole-carrier whereabouts were generally focused on particular locations of removed ponds and most individuals stop by other removed pond spots. The researchers also noted that these tadpole-transporting frogs were attracted to fresh sites that contained high concentrations of tadpole odour of similar species. Their results suggested that the male frogs relied greatly on spatial memory for effective exploitation of numerous and widely spread out deposition spots once they were learned.

In another research experiment involving animals, researchers (Croston *et al.*, 2016) studied the spatial memory and learning in mountain chickadees, *Poecile gambeli*, a small songbird that inhabits the mountain regions of Sierra Nevada with an elevation range between 1900 meters to 2400 meters. Caching or hoarding in terms of animal behavior is the storing of food in places that were hidden from the sight of other animals. Spatial memory allows animals to recall the locations of food reserves for winter survival (Pravosudov and Roth II, 2013) and for food-caching animals such as the *Poecile gambeli* species that reside in environments with a strong seasonal difference, the availability of food was often limited by severe winter conditions. Therefore, animals in such weather conditions could stand to benefit from more accurate spatial memory (Croston *et al.*, 2015).

The researchers set up programmable bird feeders that were fitted with radio frequency identification technology (RFID) to test for any individual discrepancy in the spatial memory of the mountain chickadees at two different elevations within a winter environment. Each individual bird has access to a single rewarding feeder out of an array of eight, and thus these birds had to learn the whereabouts of their own distinctive rewarding feeder. The researchers found that birds that stayed at a lower elevation (around 1900 meters) of the mountain visited the arrays much less than the birds that were at higher elevation (around 2400 meters). Apart from that, the same group of birds at the higher elevation performed better at pinpointing their rewarding feeder those from the lower elevations. When the bird feeder arrays were rotated, they noted that these birds relied explicitly on spatial memory in order to find their rewarding feeder.

Moving on to spatial memory capability in humans, one researcher (Tikhomirova, 2017) conducted an experiment to measure the level of cognitive performance with relation to mathematical fluency. Earlier research showed that mental rotation routine predicts the success in the mathematical domains of word problems and geometry (Delgado and Prieto, 2004). The understanding of arithmetic operations and the various aspects of mathematical knowledge could be associated with spatial memory performance (Zorzi, Priftis and Umiltà, 2002). In the study, 426 students Russian high school students aged from 14 to 18 years with different levels of mathematical strength were asked to complete the Corsi Block-Tapping Task and the Mental Rotation Task. The Corsi Block-Tapping Task, a psychological test that assesses visuo-spatial short-term working memory, was presented to the participants as a set of square blocks, which light up one after another in a sequence.

Participants were asked to repeat the sequence presented by clicking on the blocks with a computer mouse. If the participant made an error in the sequence, the test was automatically stopped. Mental rotation is the ability to rotate a mental representation of both two-dimensional and three-dimensional objects (Thomas, 2016). In this test, the participants were presented with pictures at the bottom part of the screen, which was a mock-up of the object being modelled at the top of the screen. The participants need to solve as many tasks as possible in fewer than 3 minutes. The program recorded the number of right answers and the total number of finished tasks. The results showed that participants with higher levels of mathematical fluency scored better for spatial thinking efficiency and spatial memory on average, compared to participants of lesser mathematical articulacy.

In a study on the effect of gender and age with relation to spatial memory performance in humans, researchers (León, Tascón and Cimadevilla, 2016) recruited 135 subjects from elderly centres, entertainment, and social locations in Almeria, Spain. Participants consisted of 75 males and 60 females, aged 45 to 74 years old. The apparatus included a portable computer, colour monitor, and a joystick for the participant to navigate a virtual room. The participants were requested to use a joystick to navigate a 3-dimensional room, which contains sixteen brown boxes that were symmetrically distributed in the room. The goal of the program is to find the position of a number of boxes containing rewards. If the participant were to come close to a box, the colour of the box turned blue indicating that it is interactable by pressing a button on the joystick. There were two outcomes from the interaction with the box, the first is that a reward box was opened and when that happens, the box turned green and a pleasant sound is played. However, in the other scenario, the wrong box was opened and the box colour turned red while being accompanied by an unpleasant tone.

Figure 4: Representation of the virtual room (León, Tascón and Cimadevilla, 2016)

The opened boxes remained either red or green until the time limit is reached (150 seconds) or all the reward boxes were opened. They were ten consecutive trials and in every one of them, the reward boxes remained in the same locations during the experiment. Within the virtual room, a number of stimuli were added to distract the participant. These objects included a door, several pictures, and a window (Figure 4). Participants were requested to locate the reward boxes and avoid the wrong boxes in the shortest amount of time. In each trial, the starting position (North, East, South, and West) of the participant were changed. The results overall showed that spatial memory declined with age.

Researchers (Iachini, Ruggiero and Ruotolo, 2014) studied the effects of visual status on the capability to represent allocentric (one's ability to mentally control objects from a static point of view) and egocentric spatial associations based on the size of space being explored found that visual familiarity is indispensable when it comes to developing precise allocentric depictions. This is especially true when placed in a large-scale space setting as their results showed that participants that were visually impaired since birth have more difficulty in expressing spatial information allocentrically when compared to those who were sighted or late blind individuals. The researchers gathered 132 participants, 46 females and 86 males and placed them into three groups. The first group consisted of 22 congenitally blind participants aged 20 to 53 years old while in the second group, there were 22 adventitiously visually impaired with an age range of 26 to 58 years old. The final group comprised of 44 blindfolded sighted participants aged 22 to 58 years old. The experiment had two parts, a small space condition and a large space condition. In the small space condition, participants sat in front of a desk with a plasterboard panel laid out on the table. Up to three 3D geometrical objects (stimuli) of different size were placed on the panel one after another for the participant to feel or see (for the sighted). The stimuli consisted of 12 well-known 3D geometrical objects such as cube, pyramid, cone and sphere. Before starting the task, the participants were then asked to remove their hands from the panel (sighted subjects were blindfolded) and the stimuli were rearranged on the panel according to pre-assigned positions. In the large space condition, the stimuli were larger and conducted within a large room.

In both settings, participants were required to vocally provide two kinds of spatial judgments for each configuration. Example of spatial judgements to measure egocentric spatial orientation was: “Which object was closest to you?” For the allocentric spatial judgements, participants were asked: “Which object was closest to a target object (stimulus)?”. The main purpose of the experiment was to study if, given the diverse degrees of visual experience, would the size of space affect an individual’s capability to represent their spatial information in either an egocentric frame or an allocentric frame of reference. They also noted that in the small-scale condition, the participants’ allocentric performance fell short compared to the egocentric performance of all groups. With the lack of visual experience of any sort, egocentric spatial representations in small-scale space were preferred because the body has a stable anchor point.

When comparing the performance of sighted participants and age-matched visually impaired Braille readers, researchers (Grant, Thiagarajah and Sathian, 2000) concluded that the visually impaired did not have a greater advantage over sighted participants. Although during the start of the experiment, the visually impaired participants considerably outdid the sighted group at a hyperacuity task involving Braille-like dot patterns but, given sufficient practice, both groups eventually accomplished similarly well. This was similar to the research that was carried out to determine how visual and haptic experience differ between late-blind, early-blind, and blindfolded sighted participants (Postma *et al.*, 2007). In this experiment, seventeen late-blind, thirteen early-blind, and sixteen sighted participants were enrolled in a test that measures the haptic spatial associations by means of haptic shape recognition and incidental memory. The results indicated that all three groups showed substantial improvement over the course of the trials. Moreover, each group showed their strength in a different aspect of the trials. The role of visual and haptic experience as it seems depends on the type of task that was tested. Further research (Akpinar, Popović and Kirazci, 2012) on the effect of different types of feedback on the spatial memory for visually impaired and blindfolded-sighted participants concluded that different types of feedback have a similar effect on spatial memory task for both groups. In the experiment, participants were asked to estimate a pre-set distance by using their dominant hands. The outcome of the statistical analysis revealed little dissimilarities for the tasks given.

Previous findings by academics have provided evidence that visual experience may not be an essential requirement for the development of the spatial inferential complex for representations (Tinti *et al.*, 2006). The experimental group for the first case were composed of twenty participants with congenital blindness and another twenty blindfolded sighted participants for the second group as a control. The participants in this experiment were required to do four survey representation-based tasks and the results showed that visually impaired participants performed better than the blindfolded sighted participants did. In the second experiment, thirteen late-blind participants were recruited for the same tests and this group performed better than the blindfolded sighted participants did. However, there were little differences in the performance comparison between the group with congenital blindness and this group consisting of participants with late-blindness. The researchers concluded that when visual awareness is absent, the ability to assemble environmental spatial information provided by nonvisual modalities might explain how spatial encoding works well for these individuals.

Meanwhile, a total of 35 participants participated in a study (Papagno *et al.*, 2016) to examine if there was any tactile discrimination, both in the temporal domain and the spatial domain. The participants were classified into four main groups: seven deaf individuals, seven deaf-blind participants, seven blind participants, and finally a control group consisting of fourteen participants who have normal hearing and vision. Each group were tested on spatial and temporal related tactile tests. The final results showed that there was no enhanced tactile discrimination even in multisensory-deprived participants when performing these tests. The outcome was echoed in a research experiment where researchers (Chen, Huang and Wang, 2010) conducted two experiments to examine the performance variance on the spatial working memory between sighted and visually impaired individuals by influencing visual, tactile, and auditory stimuli. From these experiments, the results showed that the sighted participants' performance with visual stimuli was comparable to the visually impaired participants' performance with tactile stimuli. The researchers concluded that the visually impaired individuals were able to conceptualize spatial information on a similar level to a sighted individual.

In contrast, a research on 32 participants was recruited by scholars (Norman and Bartholomew, 2011) to execute two tasks in order to find a link between the perceptual and sensory capabilities of the sighted and visually impaired. The first task was on tactile grating orientation discrimination, which helped to determine the tactile acuity of the participant and the other task involved haptic three-dimensional (3-D) shape discrimination. The results indicated that the sighted performed poorly compared to their visually impaired counterparts on both tactile tasks, which lead the researchers to suggest that early visual practice may play an aid in haptic 3-D shape perception. This finding was similar to the investigation done by academia (Pasqualotto and Proulx, 2012) on how vision plays an important role in the spatial tasks development between an individual with late blindness and those with congenital blindness. In this study, they noted that the lack of visual experience might have an impact on executing spatial tasks especially when combinations of inputs were required from different modalities. The study research also showed that the multisensory part of the brain structures requires early visual familiarity in order to develop an ability to represent and integrate multisensory information in a normal way.

An earlier collaboration by Pasqualotto and his colleague found that the development of spatial cognition in the visually impaired, especially if it is congenital, is underdeveloped when compared to the sighted and late blind individuals (Pasqualotto and Newell, 2007). His team investigated the effect that visual experience plays on the spatial representation and the updating of haptic scenes by comparing the recognition performance across congenitally blind, late blind, and sighted participants. In their experiment, participants were asked to feel objects in front of them that was surrounded by a small curtain. These objects were made by glueing smaller regular shaped objects together in a random configuration. The small objects included a triangle, a sphere, an arc, a square, and a rectangular, all of which were no more than 5cm in dimension. Seven of these random configured objects were placed on top of a small rotating platform surrounded by a curtain to prevent participants from recognizing the shape and placement.

The participant was seated in front of the platform containing these objects and was asked to feel the objects by placing their hands under the curtain. They were given sixty seconds to recognize the unique shape of each object as well as their position in relation to one another. During the next step, the researcher was to either randomly displace one of the objects or rotate the platform or both and the participants were then asked to identify the displaced objects if any. The location of the objects with respect to one another was not scored but rather the position of the object itself. This means that if all the objects were in the same position but only the platform was rotated, the correct response would be that none of the objects was moved. The results showed that when the platform was rotated, it incurred a cost in the recognition performance across the group. On the other hand, the overall haptic scene recognition performance was poorest in the congenitally blind participants.

This difference was observed between the late blind or sighted participants compared to the congenitally blind participants who were not able to compensate for the change in the scene when the platform was rotated. The researchers concluded that vision had an important role to play when updating or representing the spatial information that was encoded through our haptic sense and this may have a vital effect on the development of neuronal areas that are involved in spatial memory. The importance of the mental mapping skills in helping the visually impaired to navigate their surrounding had led to the development of different types of assessment tools in order to gauge the mental mapping skills of the visually impaired individual.

2.4 Mental Mapping Skills Assessment

There are several methods and techniques that have arisen as a result of the dedication and effort put in by scholars from around the world to understand more about the subject of mental mapping skills.

In his research and role as the professor of social studies, John Benson conducted an experiment to use commonplace names such as Centerville and get students to guess where in the United States of America the place is located (Benson, 2000). The place Centerville was chosen because, in the United States, there are at least 38 places with a similar name. In his research, which was conducted more as a classroom activity rather than as an experiment, the materials used were a copy of the AAA Road Atlas and a deck of playing cards. The roadmap was cut into two-inch square pieces and was attached to the front of the playing cards (Figure 5). The cards were then shuffled and a random card was drawn for the students to determine its location. The researcher's intention was to get the students to locate all of the Centervilles and Centrevilles in the United States using only the mental map knowledge that these students have based on the many features of the states in the United States. This activity when carried out in a classroom setting was geared towards a contest. This was done by dividing the students into groups of 2 or 3 people and dividing the playing cards evenly among the groups. The team who got the most correct locations would be the winner.

Figure 5: Playing card example for Centerville, New Jersey (Benson, 2000)

The Stuart Tactile Maps (STM) was developed by Dr Ian Stuart, a neuropsychologist from Melbourne, as part of his doctoral study (Stuart, 1995). The test was designed as a non-visual, tabletop test of the mental cognitive mapping skills of an individual. The mental mapping skill is an individual's ability to learn spatial information in order to become and stay oriented during motion. By participating in the test, it showed the number of attempts made by an individual to get the route right in theory. With this result, the dynamic orientation skills can be compared to those observed during functional orientation and mobility assessment. In the STM test, there were three sets of maps, labelled Set A, Set B, and Set C (Figure 6). The reasons for the different sets of maps were as follows: Of the three sets, Set C had the simplest sets of maps. It was used to check if a participant could recognize basic directions. This particular set was only used if the participant performed poorly on Set A or Set B, which suggests a severe spatial deficit. The maps in both Set A and Set B have equivalent complexity but with different configurations. The measurement of complexity for these maps is the number of angles and lines at each level. Either set of Set A or Set B can be used as the initial test. If Set A was used first, then Set B can be used as an alternative for the second evaluation. Because the configurations between Set A and Set B were different, these two different sets prevent the participant from memorizing what was learned when first tested. Each corresponding level in between Set A and Set B had the same amount of complexity. For example, in Set A level one, there were five lines, which is also the same number of lines for Set B level one albeit in a different configuration. For level two and level three, there were seven lines and eleven lines respectively. The outlier here is Set C which had a simpler complexity level compared to the other two sets. In Set C, level one had only one line, and with each increasing level, the number of lines is increased by one. The number of complexity (the lines and angles) grows from level one to level three for all sets. The STM was adopted by a group of researchers (Meyer, Deverell, Stuart, Theng, Ling, *et al.*, 2017) by using a 3D printed version of the maps. An experiment was conducted among fifteen participants aged 15 to 55 years old, who were all sighted. Each participant was asked to feel the maps made of neodymium magnet with and without wearing a glove while being blindfolded. The participant's index finger was led by the instructor along the edges of the map from start to finish. Once completed, the participant draws out the shape of the map on a piece of paper. The accuracy of the maps drawn is scored. The researchers found that the age of the participants does not affect their mental mapping skill.

Furthermore, the data collected from the experiment were not sufficient to compare and determine the mental mapping skill between the two genders.

Similar research (Meyer, Deverell, Stuart, Theng, Hou, *et al.*, 2017) carried out on ten sighted participants aged 19 to 43 years old using Stuart's tactile map 3D printed on Acrylonitrile Butadiene Styrene (ABS), a type of thermoplastic, showed similar findings. The experiment procedures were carried out in a comparable fashion to the previous research except for the maps, which were now printed using a 3D printer on ABS. The finding was that the age of the participant does not play a role in determining one's mental mapping skill. The researchers noted that all participants had their own unique way of handling the assessment sessions, which were calculating, memorizing, and visualising. During the feedback session, the participants agreed that using gloves during the assessment session was preferred due to the fact that it is more comfortable as it produced less friction between the map and their fingertips.

As a conclusion for the research experiment, the researchers noted the accomplishment of the test with little problems encountered proved that the prototype was a success. The success of the above prototype led to the exploration for the development of a computer-based mental mapping skills assessment tool. The difference here is that the mental mapping skills will be carried out by a computer-based assessment tool rather than the physical Stuart tactile map sets. This could save time, save manpower, improve record keeping, allow consistent assessment and repeated use, interactive with audio and haptic feedback.

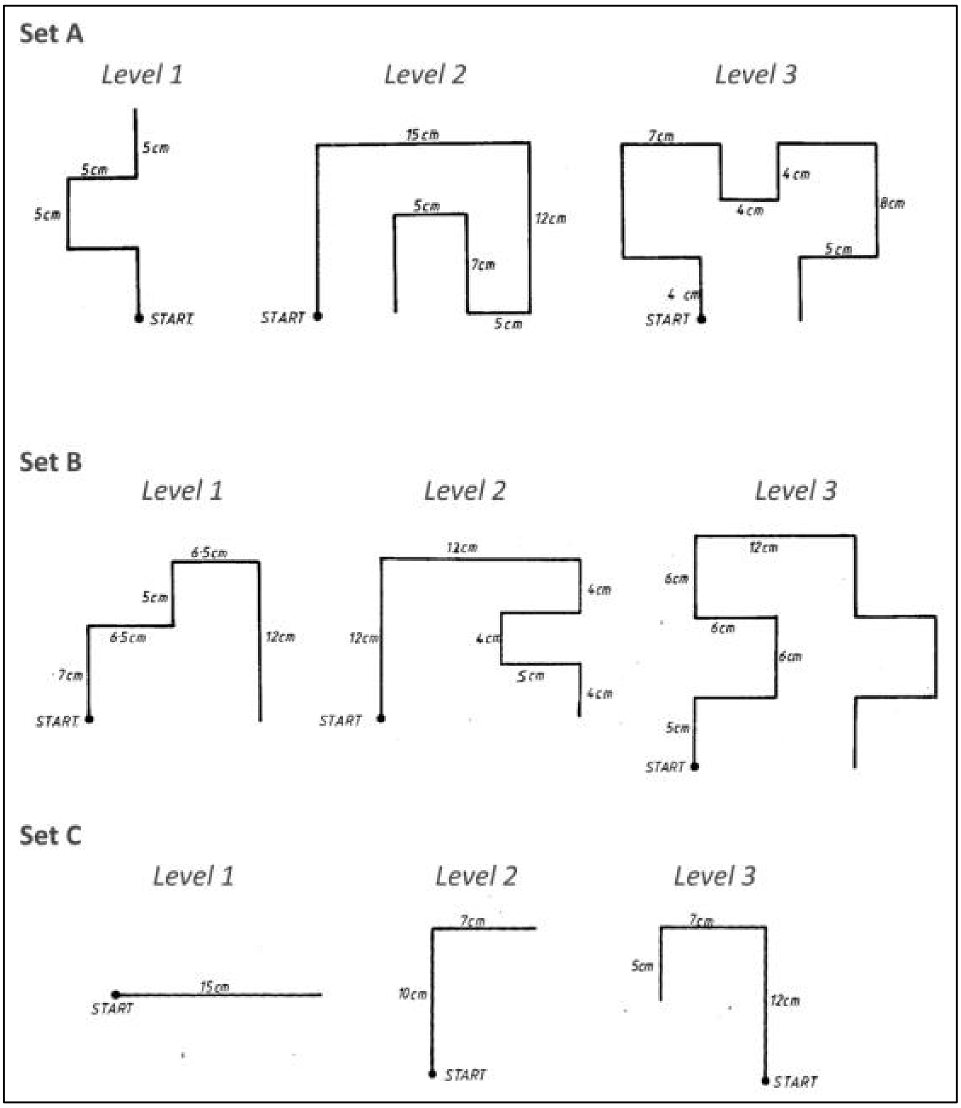

Figure 6: Stuart tactile maps dimensions (Ian Stuart, 1995)

2.5 Summary

Visual impairment affects people on a global scale. There are numerous different causes and categories of visual impairment, including detached retinas, cataracts, and glaucoma. For the visually impaired, orientation and mobility training is a form of the recovery program that is intended for recently visually impaired individual or those with a substantial visual loss in order to improve their mental mapping skill or spatial memory. Mental mapping helps a person to determine their current location and their intended destination with relation to other objects in their current environmental space. Our reliance on mental mapping is fundamental to help us find our way around an environment but not limited to remembering the location of things that are close by.

For the visually impaired, orientation and mobility training is a form of a rehabilitation program that is designed for newly visually impaired individual or those with a significant loss of vision.

To reduce the risk and stress of orientation and mobility training and to shorten the period of training, over the years, researchers have developed and innovated new ideas for a more effective approach. One such case was an Audio-based Environment Simulator software, which was developed by a team of researchers to improve the orientation of adolescents who were visually impaired (Connors *et al.*, 2014). This software provided an immersive, safe, and engaging environment for participants to train and develop their spatial mental construct, the self-exploration and discovery nature of the software promotes the development of mental mapping skills. Training exercises conducted in a virtual environment can be used to provide people with visual impairment a place to improve their cognitive navigation skills (Sánchez, Saenz and Garrido, 2010).

This brings us to the thesis's research topic, which is on the assessment of mental mapping skill with Stuart's tactile map test as a referencing point. Because Stuart's method was using a physical product, this thesis aimed to create a digitized version of it. A computer-based assessment tool was developed to capture the core mechanics of Stuart's methodology. This software would allow the test to be carried out more efficiently and readily as computers are ubiquitous in our current society. Another reason for having the assessment in digital form is the cost-effectiveness of deploying it to multiple computers at the same time. Furthermore, any changes to the map or scoring system and be deployed via a batch update over the internet easily if the need arises.

Based on the success of prototyping STM's maps on 3D printed ABS (Meyer, Deverell, Stuart, Theng, Hou, *et al.*, 2017), the creation of a computer-based mental mapping skills assessment tool was deemed feasible. A digital version of STM's map prototype would have several benefits. First, it is easy to deploy, as the hardware requirements are readily available and affordable to obtain. It consists of a laptop and an external keyboard as an input function. With the prevalence of budget laptop, the first goal was easy to achieve. The computer-based assessment tool was designed with minimal graphics to enable a wider range of laptop specifications to be able to run it. Second, using the computer-based assessment tool would be more efficient as the instructor does not need to swap the physical maps. It can all be done with a click on a button.

These two reasons also answer the other research question, which is the criterion needed for a good computer-based mental mapping skills assessment tool. Both the research discussed earlier using STM noted that the age and gender of the participants did not determine a person's mental mapping skills (Meyer, Deverell, Stuart, Theng, Hou, *et al.*, 2017; Meyer, Deverell, Stuart, Theng, Ling, *et al.*, 2017). Both experiments consisted of different participants groups with a varying age range. Noting that age and gender have no impact on one's mental mapping capabilities, the development of the assessment tool should focus on the deployment and evaluation of it with ease. Having easy access to the computer-based assessment tool for mental mapping skills is one of the criteria. In order to realize this, the software has low hardware requirements with an easy to read user interface. This allows the instructor to carry out the assessment sessions with little hindrance. Hence, the criteria for a good computer-based assessment tool for mental mapping skills are for it to be easy to use and efficient.

Chapter 3 Modelling and Prototyping

This chapter discusses the modelling and prototyping of the mental mapping skills assessment tool. From the concept stage to the finished product of the assessment tool, this chapter clarifies the approach and requirements taken to develop a computer-based assessment tool. One of the motivations for designing the computer based mental mapping skills assessment tool is to improve an existing model used in mental mapping skills assessment, which is Stuart's Tactile Map (STM) discussed in Chapter 2. Thus, this chapter goes over the conceptual design of the assessment tool and the final prototype before the evaluation in the next chapter.

3.1 Conceptual Design

The summary of the conceptual design for the assessment tool is as follows: the goal of this assessment tool is to evaluate the mental mapping skills of the player. To do this there were two measurements taken in the experiment. The first is the game time that each participant is required to complete the assessment level. Each assessment level begins at a pre-selected starting point and the player needs to navigate a 2D virtual map in order to reach their destination point. The instructor and not the participant choose the assessment level types. In the assessment tool, each level had a start and a viable end. This is to say that there is a walkable path from the starting position to the destination point. A virtual character is represented as an agent that the participant can control. However, this virtual character is not visible to the participant.

Along the way from the starting point to their destination point, the participant would encounter a distraction obstacle in the form of a traffic light. The purpose of the traffic light is to catch participant off guard while they are trying to remember to route taken. Each assessment level has only one traffic light and its placement is arbitrary for each assessment level to prevent the participant from anticipating it. During the assessment, the participant was able to inquire for directions to their next destination point via an input from the keyboard. Although the initial design was to help assist the participants who are lost, it seems that this feature was not useful. This will be elaborated on and discussed later. Upon reaching the destination point, a congratulatory audio message is played to the participant. The game time is noted and for the final step, the participant would need to draw out the path that they have just taken. The sketch path direction needs to match the level path for it to be counted as correct.

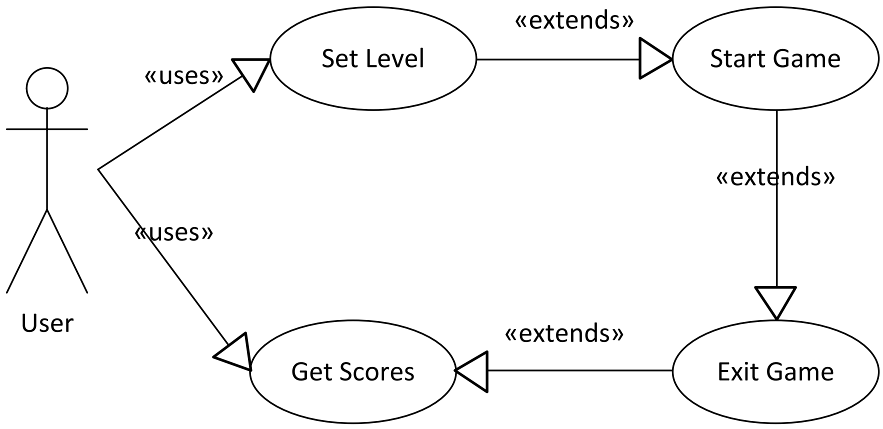

Figure 7: UML use case diagram of the assessment tool.

The use case diagram for the assessment tool is shown in Figure 7. At the beginning of the program, the instructor is able to set the map level of the assessment tool. Each map level was based on Stuart's tactile map (Figure 6) which increases in complexity in order to test the mental mapping skill of the participant. The game begins when the instructor selects a level and for each new level, the game time and score are set to the initial values of zero and one hundred respectively. When the player completes the game, the instructor is able to view the game scores for both game time and game score or they may choose to exit the game. The tool requires a participant, also known as the player, and an instructor. In this instance, the instructor who is able to see the screen, which is turned away from the participant.

The software design for the assessment tool is simple with only two object classes used to store the required information to run the game. As seen in Figure 8, the Unified Modelling Language (UML) class diagram shows three classes, namely, ToolManager, User, and Map.

The ToolManager class is responsible for running and managing the gameplay. When the tool is loaded, it calls the Initialize function to set up the user interface and basic objects for the user and map. If the user selects a map, the StartGame function is called to begin the game. It accepts input from the user and translates this to movement on the 2D virtual map via the GetInput function. As the user traverses the 2D visual map, the nodes in front of the user, as well as those that the user is currently standing on, are checked via the IsObstacle function. Any obstacles encountered by the user are alerted by the PlaySound function, which would give a warning tone to let the user know that there is an obstacle in front of them. The ArrivedAtDest function is called for every successful movement to check whether the user has reached their destination point. If they have, a congratulatory audio message is played and the game ends.

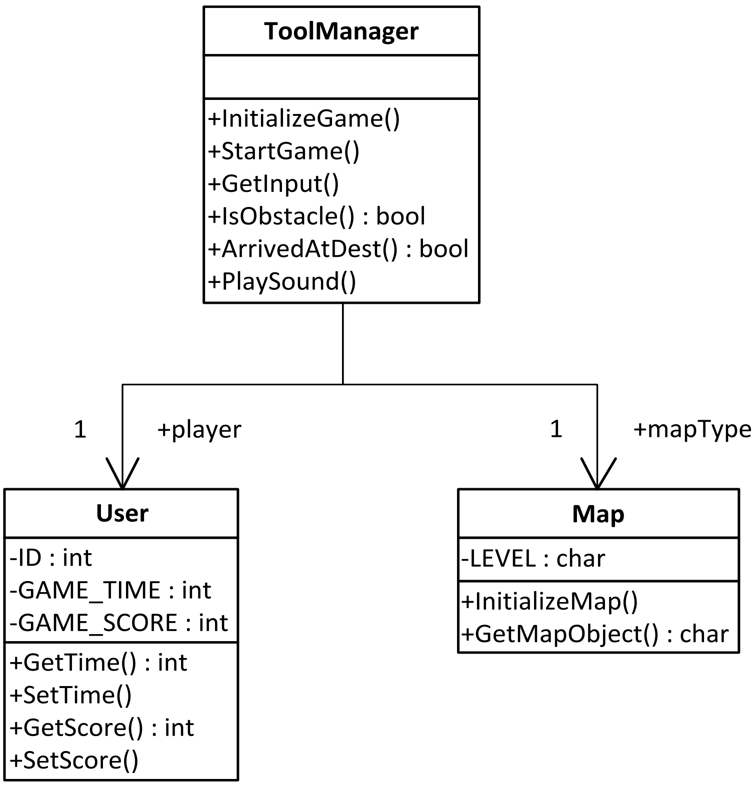

Figure 8: UML class diagram of the assessment tool.

The user class holds the identification (ID) of the user as well as the game time and game score for the level selected. The basic functions are available at this point are GetTime and SetTime to read and write the game time. The GetTime is called to display the time lapsed on the current level while SetTime is called to set the user time lapsed. This occurs every one second to correspond to the actual flow of time in the real world. The other functions are GetScore and SetScore which reads and writes the user game score for the current level. The game score is updated based on the number of penalties incurred by the user as they navigate the 2D virtual map. The map class contains the vector class of ASCII character, which is used to symbolize the type of obstacles on the 2D virtual map. This class has the InitializeMap function to set the current map based on the user selection. The GetMapObject function returns the object type in the form of a char when called. The arguments that need to be passed are the coordinates of the grid such as 1, 7, which represents the second row and eighth column. It is not the first row and seventh column because the vector is a zero-based index, which means the first index of the vector list starts at zero rather than one.

The Entity Relationship Diagram (ERD) in Figure 9 and its accompanying data dictionary (Table 1) describes the type of data the program stores. Each user entity contains user ID, the game time and game score, all of which are of type integer. The map entity contains the level of type vector class, which holds the object type represented in a 13 by 13 grid layout. This vector class is of type char to store the symbolic representation of the type of obstacles and nodes in the virtual 2D map.

Table 1: Data dictionary of the assessment tool.

Entity	Attribute	Type	Constrain	Description
USER	ID	int	Primary Key	Identification of user
USER	GAME_TIME	int	Not Null	User game time
USER	GAME_SCORE	int	Not Null	User game score
MAP	LEVEL	vector char	Primary Key	Map level

The user interface of the assessment tool is a simple one screen display as shown in the wireframe model in Figure 10. The significant information on the current assessment level is shown in the top row. These are: the current level of the map, the game time, and the game score. As the game progresses, the game time increases with each passing second while the game score decreases based on the number of errors that the player incurs. A brief description of the keys is shown in the middle left part of the screen, which is for the benefit of the instructor. The active map is shown in the middle of the screen which contains the obstacles, the start and end points of the map, location of traffic lights, and the current position of the player in the 2D virtual map. This map can be toggled to hide everything with a keyboard shortcut if needed. The lists of available map levels are shown in the right part of the screen. The instructor selects the map level based on the complexity that is required.

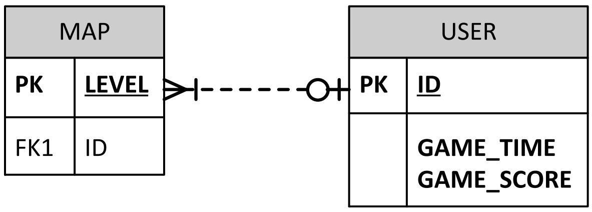

Figure 9: Entity relationship diagram of the assessment tool.

The conceptual model of the map levels is shown in Figure 11. They are eight different map levels available for the instructor to assess. Each map was designed based on Stuart's tactile map with certain modifications on some maps. For example, map A-1R and A-2R are the reverse of map A-1 and map A-2. The reversal of the map is to prevent the player from memorizing it after their first sessions. As there are multiple sessions per participant for the research experiment, it is possible that the player may remember the layout of the map in the first session and score well when presented with it again in a later session. In Figure 11, the capital letter S represents the starting position of the participant while the capital letter E represents the destination point, where the participant should head to in order to complete the level. The capital letter T represents the area with traffic lights. The traffic lights are implemented as a form of distraction to the participants as they attempt to remember the map that they are navigating. This is used to model real-world mapping with external sources that disorient players.

Figure 10: Wireframes of the assessment tool

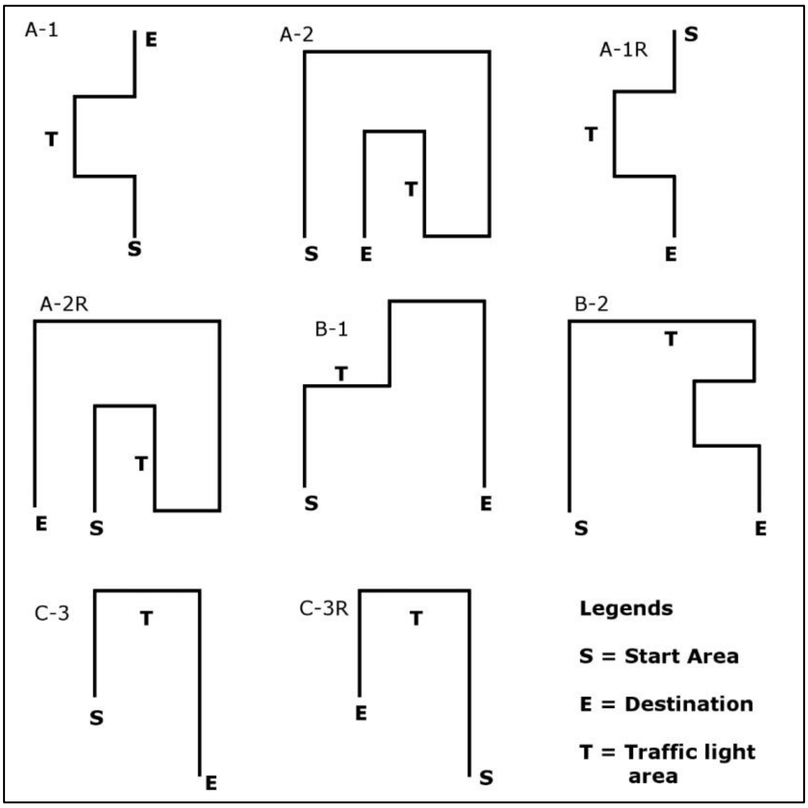

Figure 11: Design of the map levels.

3.2 Prototype of the Assessment Tool

The software was built using Unity (Unity Technologies Ltd, 2017) game engine version Unity 2017.1.1p1 (64-bit) with the codes written in C# (as C# is the default language for Unity). Unity was chosen because it was free to use for non-commercial purpose while having the software's full commercial features available even to free users. It is quick to pick up and there are numerous tutorials and guides available on the internet. The assessment tool was designed as a game for the participant to play. However, due to the setup of the experiment, the participant would not be able to see the interface. This is because the participant would be sitting facing opposite the instructor with the laptop that is used to run the assessment tool facing the instructor. What was available for the participant to interact with was an external keyboard used as an input to the assessment tool. Figure 12 shows an example of the assessment tool interface with its simplistic design. At the top left corner (A) is the current map level for the assessment tool. An overview of the keys for the instructor is available at the middle left of the screen (B). The inputs that are of importance to the participant are the arrow keys (up, right, down, left) and the left control key. The arrow keys control the movement of the virtual character in the map. The orientation of the map does not change or move with the input from the participant. The left control key gives the player a brief description on the next direction to move and the movement numbers required.

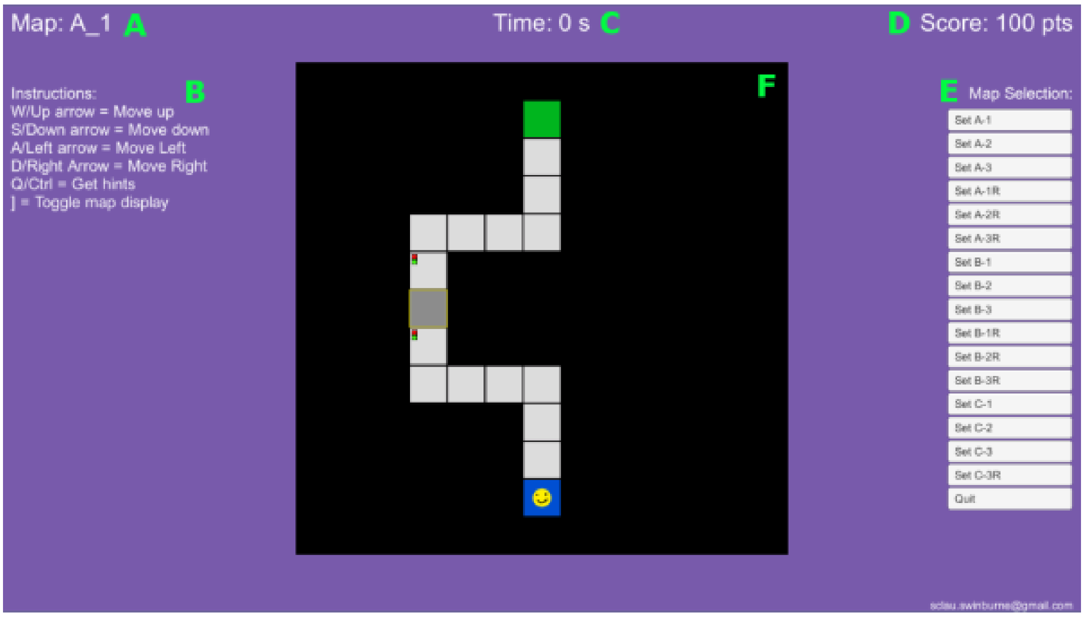

Figure 12: The graphical user interface of the assessment tool.

The timer and game score is at the top centre (C) and top right (D) respectively. When the game begins, a countdown timer with three seconds on the clock begins. The purpose is to give both the instructor and participant a short buffer time before the assessment begins. The game timer can be paused by the instructor by pressing the space key, which also pauses the game and disables movement input from the participant. The map selection is to the right of the screen (E). Any new selection of a map would erase the previous progress and start a new level with the selected assessment map. The assessment map for the current level is at the centre of the screen (F). Note that this user interface screen is not visible to the participant as the laptop that runs this software would be facing away from the participant and towards the instructor. The legend for the assessment map is shown in Figure 13. The single user interface fulfils one of the criteria for a computer-based mental mapping skills assessment tool that is easy to use. All the required information is presented to the instructor in one scene. The descriptive buttons and additional text info help the user to understand the software better. A rundown of the gameplay mechanics is described in section 3.4.

3.3 Map Development

The assessment tool is a computer-based software that takes place in a virtual 2D environment. Each assessment level has a different starting point and its respective ending points along with the different length of path and location of a traffic light. The map design was based on Stuart Tactile Maps Test (Ian Stuart, 1995) which was originally developed to test a person's ability to learn spatial information and stay orientated during mobility. It shows the number of attempts a person needs to practice to get it right. The results from Stuart's test can be equated with active coordination skills observed throughout functional orientation and mobility assessment. There are in total eight assessment level types that the participant would be able to attempt (Figure 13).

Each map design is a modification of Stuart's test and it follows the number of paths based on the original map. The only modification is the addition of a traffic light as a means to distract the concentration of the participant. Whenever a participant approaches a traffic light, an audio feedback announces that they are at the traffic light. At the same time, the inputs are disabled for one second to prevent the participant from continuously pressing the movement keys. After this, the participant would need to wait for a randomized amount of time from three seconds up to seven seconds for the traffic light's buzzer. The buzzer is an indication that the participant can cross the road. If the participant were to step on the road before the traffic light buzzer sound, a penalty of 5 points is deducted from the total game score. A warning audio message is played to indicate that the player is on the road.

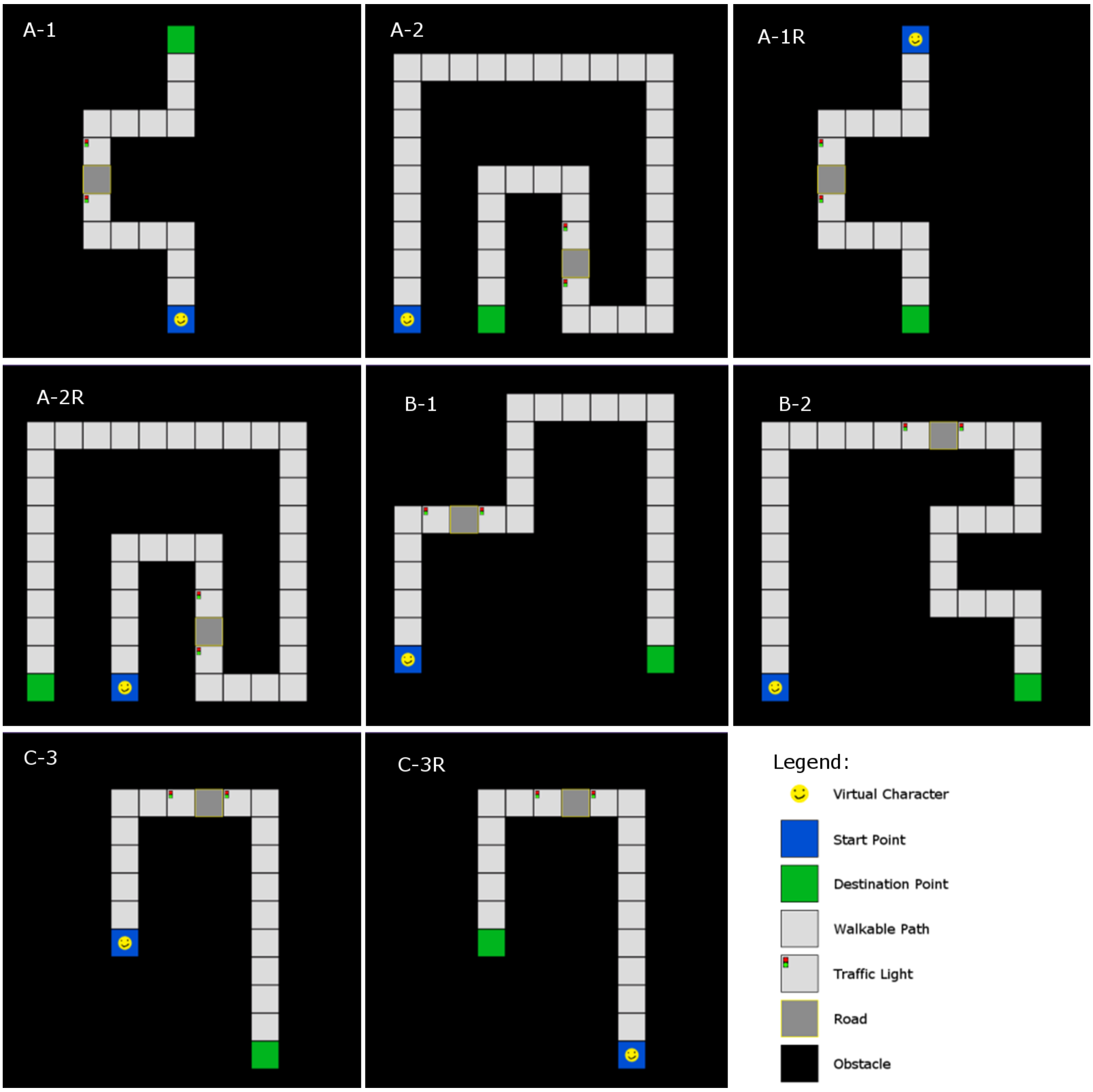

Figure 13: Maps designed in the assessment tool.

The initial design includes game score as a third measurement variable but after the experiment, it was noted that this was hardly used because a majority of the time the participant would score 100 or the full score of the assessment level. This particular anomaly is discussed further in the next subsection on the gameplay mechanics of the assessment tool. Each assessment map level is divided into nodes of size 13 by 13. A node in this software is a mere representation of an object, such as a floor tile, while each node having a Cartesian coordinates of x and y. The purpose of this representation Every node in the map is either a starting node, a path node, a traffic light node, a road node, a destination node, or an obstacle node. The participants' virtual character always starts at the starting node, which is represented by a blue square. The goal for the participant is to move their virtual character from the starting node to the destination node. A yellow smiley face represented the virtual character and it can travel on all nodes except obstacle nodes. Because the design for the entire map is in a sense linear, the participant would never get lost or encounter a dead end. In each session, the participant plays three different assessment levels or maps.

Each map is more difficult than the previous with increasing complexity on the number of lines. For the first session, participant plays through map C-3, A-1, and A-2. In the second session, the maps change but would have similar complexity to the first session. The maps for the second session are maps C-3R, B-1, and B-2. For the final session, the first map would be similar to the first session, which is C-3, but the second and third map use a reversed version of the initial session. These maps are A-1R and A-2R (R here stands for reverse). The reversal method is done by swapping the starting node and destination node of the A-1 and A-2 maps.

3.4 Game Algorithms

The mechanics of the assessment tool are discussed in detail in this section with a step-by-step example using the map shown in Figure 14. When a participant begins the assessment level, an audio message is played which is similar to when the left control key is pressed. The spoken message for our example is "Langkah ke hadapan lima kali" which is in the Bahasa Melayu language. The reason for choosing this language was because it is the country's national language that is widely used in the local community. The Bahasa Melayu text above translated into English would be "Step forward five times". The participant can respond by pressing the up arrow key on the external keyboard five times to move the virtual character. If the participant did not move within two seconds from the starting position, the audio message would be played again. This is only applicable when the virtual character is at the starting node and at a turning point. From the starting point, the participant could move the virtual character in four different directions but only the up direction is the correct response. If the movement direction is an obstacle, an unpleasant tone is played and one game point would be deducted.

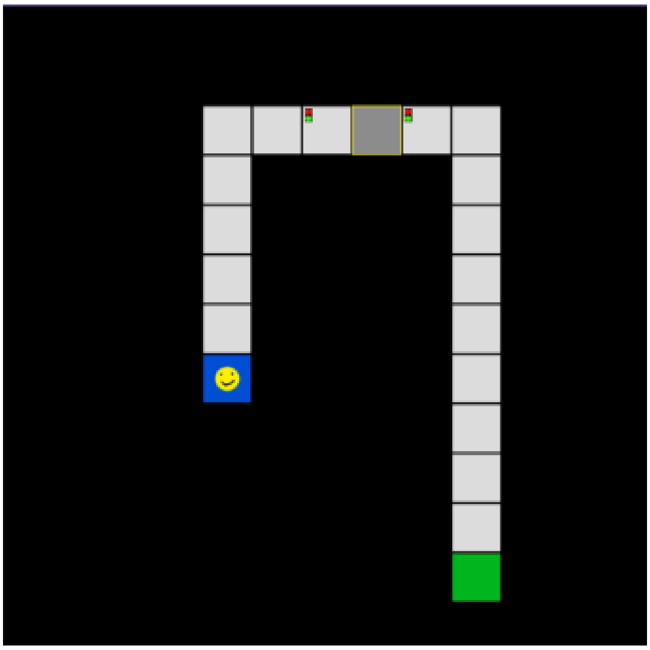

Figure 14: An example of a map.

In our example, let us say the participant chose the right direction and moved up five times, they would reach a turning point. In this assessment tool, whenever the virtual character is at a turning point, an audio message is played to indicate the next direction to head as well as the number of steps to get there. This was the reason why the game score was unnecessary because after the experiment was conducted, a majority of them did not require the left control key function nor did they walk into obstacles. All the participants had to do was to follow the instruction given and remember the direction and number of steps needed while paying attention to any traffic light they may encounter. At the turning point for the example above, an audio message is played which would be “Langkah ke kanan lima kali” (Step to the right five times).

At the second step to the right, the participant would reach the traffic light. Here their inputs are disabled for one second to prevent unwanted movement and at the same time, an audio message indicating that the player is at the traffic light is played. This audio message in Bahasa Melayu is “Lampu isyarat” (Traffic light). From here the participant needs to wait for the traffic light buzzer to sound before crossing the road. The time delay of the buzzer is randomized between three to seven seconds to prevent the participant from memorizing it. If the participant were to step on the road before the buzzer, a penalty score of five points is deducted followed by a warning audio message, “Anda berada di jalan raya” (You are on the road). The participant can continue with the direction of the path if they are on the road. When the participant moved right after the road, they would encounter another traffic light. The same audio message is played indicating that the participant is at a traffic light while simultaneously their input is disabled for one second. The purpose of the second traffic light was in case the player made a mistake and moved back from his original direction after crossing the road, this second traffic light would inform the participant that a road is up ahead.

When the participant reaches the second turning point, an audio message is played to give them the final direction, which is “Langkah ke bawah sembilan kali” (Move down nine times). Upon reaching the destination node the player is greeted with a congratulatory audio message, “Tahniah, anda sampai di destinasi” (Congratulations, you have reached your destination) and the input for the movement keys and direction message (left control) is disabled. Once the level is completed, the instructor would ask the participant to sketch the path that was taken in the level. Further elaborations on the sketch system are made available in later section. At any point in the game, with the exception of reaching the destination and the game being paused, pressing the left control key lets the participant know the direction they should move their virtual character and the total number of steps to do so. The algorithm behind this is a simple one; all the maps are hard-coded into the software. By doing this, the walkable nodes are all saved in an array upon the selection of a new level or map. Pressing the left control key simply counts the number of nodes until the next destination. All the spoken audio messages are using a text to speech translation software called eSpeak(Duddington, 2007), which is available for free for non-commercial use.

3.5 Hardware and Environment

The assessment tool was developed and run on a laptop with the specifications stated in Table 2 as well as an old laptop from the year 2008 (Table 3), which meets the criteria needed to develop a computer-based mental mapping skills assessment tool with low hardware requirements. The additional hardware required is an external keyboard. Because the input keys for the assessment tool can be programmed, the type of external keyboard can be a generic type. A reasonably quiet environment is required for the participant to clearly hear the auditory feedback that is provided by the assessment tool.

Table 2: Recommended laptop specifications.

Processor	Intel® Core™ i5-5200M (2.2 GHz; Dual-core)
Memory	8 GB
Operating System	Windows 7 Enterprise
Storage	500 GB hard drive
Screen	14" HD (1366 x 768) resolution
Graphics	Intel® DDR3 Shared graphics memory
Ports & Connectors	1x USB 3.0, 3x USB 2.0

Table 3: Minimum laptop specifications.

Processor	Intel® Core™ 2 Duo T9400
Memory	4 GB
Operating System	Windows Vista
Storage	320 GB hard drive
Screen	15.4" HD (1280 x 720) resolution
Graphics	NVIDIA GeForce 9600M GT
Ports & Connectors	4x USB 2.0

3.6 Game Scoring

This subsection elaborates on the design of the game scoring. At each new level, a participant has a total of 100 points. For every mistake made during the assessment, a pre-determined number of points are deducted (Table 4). There are only three events whereby the game score is reduced. The first is when the participant attempts to move into an area that is not part of the path. One point is deducted for each attempt and at the same time, an unpleasant tone is played. The word “attempt” was used because the virtual character can not move into an area that is out of bounds. The second event is when a participant uses the left control button to get assistance on the next direction to head and the steps needed. One point is deducted for each usage. Finally, the last event which decreases the game score is when the participant moves unto the road before the traffic light buzzer is sounded. Five points are deducted when this occurs and a warning message is played to inform the participant of his/her infraction.

The initial design of the game score is to catch the mistakes that the participant makes. However, post research experiment results showed that most of these mistakes are avoidable when a participant pays attention to the game instruction and the mechanics of how things work. The traffic light system was implemented as a result of the game score as an additional means to measure how well a participant performed. Because an offence at the traffic light deducts the highest score, it is thought that this would lead to a lower game score at the beginning of the session. This, however, does not seems to be the case. In Chapter 5, more details are elaborated concerning the exclusion of the game score from the final data analysis.

Table 4: Game scoring system.

Penalty Type	Points Deducted
Collision with obstacle	1
Usage of direction hint	1
Cross traffic light before buzzer	5

3.7 Sketch Scoring System

Upon reaching the destination point, a congratulatory audio message is played to the participant. The game time is noted and for the final step, the participant needs to draw the path that they have just taken. The sketch path direction would need to match the level path for it to be counted as correct. If the player fails to draw a matching path, they have to try the same level again. These steps are repeated until the player successfully draws a pattern equivalent to the actual shape of the level or if the participant requests to skip this level and proceed to the next one. Because this assessment tool was conducted in a voluntary manner, participants have the option to withdraw at any given time. With each failed attempt on the sketching of the path, the original score is reduced by one point (Table 5). In the beginning of each assessment level, the participants are able to score the maximum of five points if they are able to sketch the correct path in the first attempt. Should they fail and wish to try again, the participant would have to replay the same assessment level and attempt to sketch the route for the second time.

Table 5: Sketch scoring system for each assessment map.

Number of Attempts	Sketch Score
1	5
2	4
3	3
4	2
5	1
6 or Stop	0

In the second attempt, the maximum sketch score that the participant can be awarded is four, which is one point less than maximum points because this is the second attempt. If the participant failed to sketch a matching pattern in the second attempt, they could try for the third time. However, at this point, a correct sketch score is only awarded three points. A participant can attempt each assessment level up to five times. The final game time that is counted towards the data analysis is the last attempt made. A score of zero points for the sketch score is given when either the participant decided to not retry a failed level or has attempted the same assessment level five times in a row. In the event that the participant got the correct path for the level, they are not allowed to replay it to get a better game time or sketch score.

To give an example of how this scoring system would work, Table 6 shows a mock result for one session of the assessment. In this mock session, the participant successfully sketches the correct path for the first map (C-3R) in the first attempt. The participant was awarded five points for his sketch score and the game time for that map was recorded. In the second map, map B-1, the participant failed to get the correct sketch at the beginning but he managed to get it correctly matched in the second attempt. Here, the participant was awarded four points for his sketch score and the game time for the second attempt was recorded. In the final map, the participant struggled to remember the path but nevertheless succeeded in his fourth attempt. He was awarded two points and the game time for the successful attempt was recorded. The manner which this scoring system is calculated was used throughout the remaining session for all the participants involved.

Table 6: An example of assessment scoring result for one session.

Map	Game Time	Attempt #	Sketch Score
C-3R	43	1	5
B-1	57	2	4
B-2	70	4	2

Throughout this thesis, the total game time and total game score are both mentioned when referring to the overall scores obtained by a participant. The total game time is calculated by summing all the time spent in every game session. There are three sessions per participant and in each session, a participant would evaluate three different map levels and obtain a game time and sketch score for each map level. The summation of these game time and sketch score for each session are known as the total game time and total sketch score. Using Table 6 as a reference, the total game time was 170 (43 + 57 + 70) and the total sketch score was 11 (5 + 4 +2).

3.8 Summary

The design and development of the mental mapping skills assessment prototype, which is used to evaluate the spatial cognitive skill of an individual were presented in this chapter. The goal of this assessment tool is to evaluate the mental mapping skills of the player. To do this there are two measurements taken in the experiment. The first is the game time that each participant required to complete the assessment level and for the last step, the participant needs to draw out the path that they have just taken. The sketch path direction needs to match the level path for it to be counted as correct. The assessment tool is designed as a game for the participant to play. The participant would be sitting facing opposite the instructor, with the laptop that is used to run the assessment tool facing the instructor. What is available for the participant to interact with is an external keyboard used as an input to the assessment tool.

The assessment tool is a computer-based software that takes place in a virtual 2D environment. The map design is based on Stuart Tactile Maps Test (Ian Stuart, 1995) which was originally developed to test a person's ability to learn spatial information and stay orientated during mobility. It showed the number of attempts a person needs to practice to get it right. The results from Stuart's test can be equated with active coordination skills observed throughout functional orientation and mobility assessment. Each map design is a modification of Stuart's test and it follows the number of paths based on the original map. The main modification is the addition of traffic lights as a method to distract the concentration of the participants. The initial design includes game score as a third measurement variable but after the experiment, it was noted that this was hardly used because a majority of the time the participant would score 100 or the full score of the assessment level. Each map is more difficult than the previous with increasing complexity and number of lines.

The criteria for the computer-based mental mapping skills assessment tool that was specified in the previous chapter was for it to be easy to use and efficient to deploy. Having a single user interface concept whereby all the required information is presented to the instructor in one scene makes it easier to operate. The descriptive buttons and additional text information helped the instructor to understand the software better. The low hardware requirements for the assessment tool allowed for a more efficient deployment experience as this enables it to be run on a wider spectrum of laptop configurations. The lower the hardware requirements are for a software, the more devices it can be used in.

With the design of the assessment tool complete, the actual software is realized and ready for implementation. Participants who are visually impaired and sighted were recruited for the research experiment. The evaluation and result analysis are presented in the next chapter.

Chapter 4 Evaluation

The selection of the participants and their grouping are explained in this chapter, which includes the description of the process and procedure used in the research data gathering sessions and the detail on how the assessment session was carried out. The study duration for the experiment lasted for three sessions within seven days in order to capture the required data. In this chapter, the data captured during the research study phase is analysed. A one-way analysis of variance was used to analyse the results. The statistical tests are run for the total game time and total sketch score for the result from the visually impaired no vision group, visually impaired low vision group, sighted group, and all three groups combined. The statistical summary and one-way analysis of variance statistical result for each participant are explained.

4.1 Conduct of Intervention

A preliminary notice of request for participation (Appendix 44) was distributed to the targeted participants as a means of informing them of the objective of the program and highlighting the expected outcome. The information handout explained the reason for conducting the research and the general nature of the participation. It also explains that no monetary cost was involved for participating in this project and that their participation was voluntary. Those that chose to participate have a right to withdraw from participation, including the withdrawal of data collected, at any time without having to explain the reason for the withdrawal. A consent form (Appendix 55) was handed out to the interested participants to get their approval for participation. An important passage from the consent form points out how the assessment data from the participants was handled. It would be de-identified and their identity is not to be named in any publications or otherwise without their express written consent.

4.2 Participants

The target participants were adults, aged 20 to 65 years old, who consisted of individuals that are visually impaired and those that are sighted. These participants were divided into three groups; those that are visually impaired with no vision, those visually impaired with low vision, and sighted individuals. Recruitments were from an existing organization specializing in the care of the visually impaired such as Sarawak Society for the Blind (SSB) while sighted participants were recruited from Swinburne University of Technology Sarawak Campus (SUTSC). An invitation was sent to the centre's appropriate officer in order to seek their approval for participation. The selection criteria for a participant were as follows:

1. No significant motor impairment that may restrict his/her participation.
2. No significant physical disability that would render the participation impractical.
3. Able to comprehend and follow basic instructions in either the English language or Bahasa Melayu (the national language for Malaysia).

Visually impaired participants from SSB were placed in the first group while the sighted participants from SUTSC, which were placed in the second group (Table 7). The second group contained those who have a refractive error, e.g., near-sightedness, far-sightedness, or astigmatism.

4.3 Risks and Mitigation Plan

The possible risks that may be incurred as well as their mitigation process are described here. The mitigation plans were set in place in case of undesirable events that could possibly occur. Most of the risks presented in this subsection were of a minimal nature as the worst case that could happen was the participant inflicting minor injury to himself or herself when using the keyboard. The first risk was that participants may incur minor injury to themselves while using the laptop during the evaluation session. This was mitigated because the chances of participant causing minor injury to them were low due to the setup of the intervention. No sharp equipment was involved, and no erratic movement was required.

Table 7 List of Participants with details on age, gender and diagnosis

Participant	Gender	Age	Diagnosis
1	M	27	Low Vision
2	M	21	No Vision
3	M	27	No Vision
4	M	28	No Vision
5	M	23	Low Vision
6	M	22	Low Vision
7	M	22	Low Vision
8	M	28	No Vision
9	F	49	No Vision
10	M	20	Low Vision
11	M	24	Low Vision
12	M	32	Low Vision
13	M	49	No Vision
14	M	22	No Vision
15	M	65	No Vision
16	F	25	Low Vision
17	F	21	Sighted
18	M	22	Sighted
19	F	22	Sighted
20	F	21	Sighted
21	M	25	Sighted
22	M	22	Sighted
23	F	26	Sighted
24	M	24	Sighted
25	F	25	Sighted

There was a risk that participants may refuse to participate in this program. The mitigation process for this is to allow the participants to withdraw from the program. A brief interview may be conducted to find out any root cause but they were within their rights not to entertain this notion. It was also possible that the caregivers or the participants themselves may withdraw mid-program. Although this would cause disruption in the research study, caregivers, as well as participants, have the right to withdraw from the program. A brief interview may be conducted to find out any root cause. It was foreseeable that the participants may have trouble getting motivated to participate in this program. To prevent this, a gamification of the assessment tool was implemented to retain the attention of the participant. The form of this gamification was the audio feedbacks for directions, offences, and warnings that the participant might trigger. In any case, participation in this assessment tool was strictly voluntary.

During the assessment session, it was possible that the participants have trouble understanding the program's instructions. A tutorial session was carried out at the beginning of the program's procedures and again if needed during the experiment. If it was required during mid-session then the scores were not recorded and participant needed to redo the level. There was a risk that the environment for the conduct of experiment was noisy. For participants from SSB, a notice was given in advance to book their conference room for use. In the case of the SUTSC participants, the campus discussion room at the library was booked in advance to mitigate this risk.

4.4 Procedure

The evaluation of the assessment tool was carried out in three separate sessions for each participant. The procedure for the assessment tool entailed the environment setup, the introductory phase, and the assessment phase where the participant's game time and sketch score were recorded (Figure 15).

4.4.1 Environment

The place chosen for the research experiment needs to be reasonably quiet for the participant to clearly hear the auditory feedback that would be provided by the assessment tool. For the session with the SSB participants, the venue for the conduct of experiment was at their office building, which is located at Jalan Ong Tiang Swee, Sarawak, 93710 Kuching, Malaysia. The room used was their conference room at the second level because it provided a quiet environment for the assessment session. Since the SUTSC participants were conducted within the campus, the discussion room at the library was chosen as the best place to carry out the assessment session.

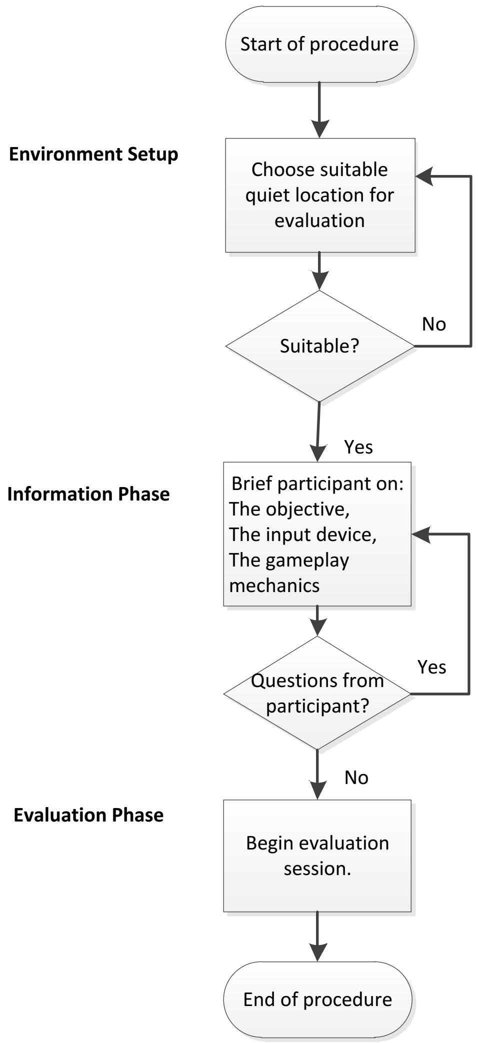

Figure 15 Flow of the entire evaluation phase

4.4.2 Information Phase

All participants were given a verbal introduction to the assessment tool during their first session. This was to get them to be familiarized with the working mechanics of the tool so that they can complete the session without any doubts. In the introduction, the participant was told the objective of the tool, which was to get from their starting point to their destination point. The monitor for the laptop was turned away from the participant to prevent them from seeing the events on the screen. The input, which was an external keyboard, was placed in front of the participant. As such, the participant and instructor would be facing each other with the monitor of the laptop facing the instructor and the external keyboard in front of the participant as shown in Figure 16.

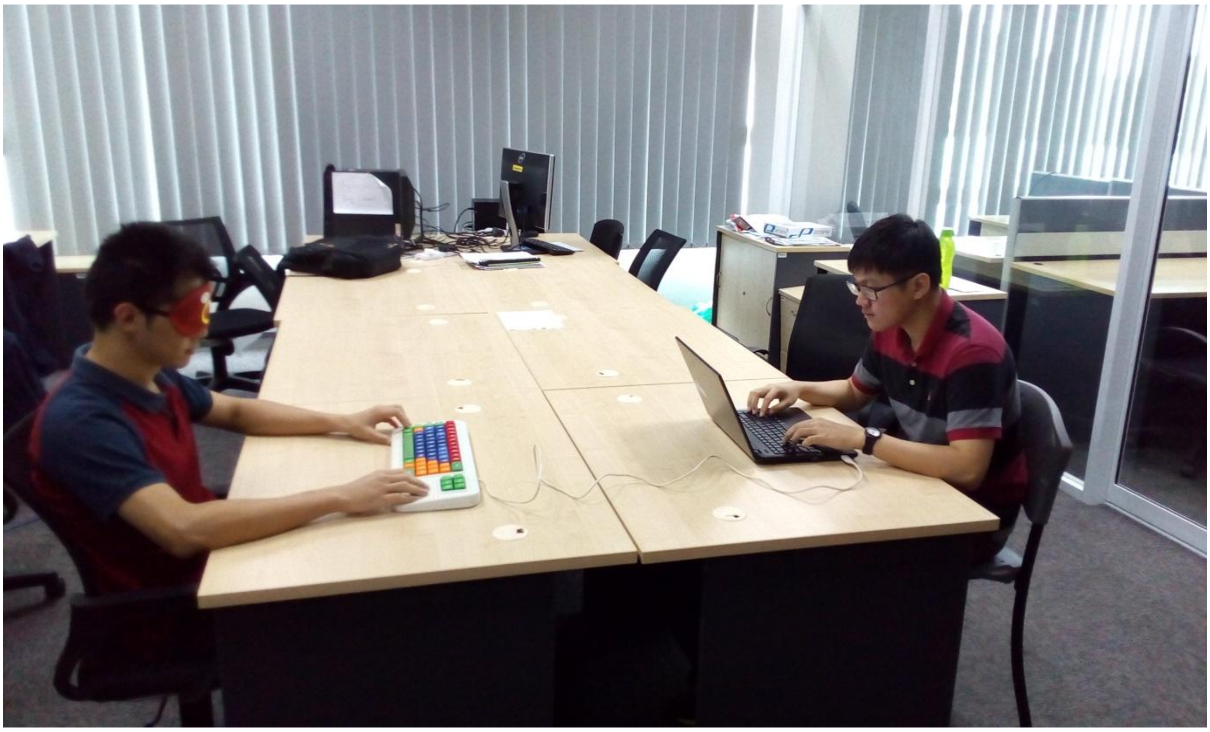

Figure 16: Assessment session setup with the player on the left and the instructor on the right. Player is blindfolded with an external keyboard in front of them.

They were only five buttons that the participant needed to know and these were the four arrow keys (up, down, left, and right) and the left control key. The arrow keys were used for navigating the virtual map in the assessment tool. The up arrow moves the character in the game up or north, the down arrow moves the character down or to the south while the left and right arrows move the character left or east and right or west respectively. The left control when used gives an auditory feedback on the next direction to head and the number of steps needed to reach it.

For example, if the participant had four more steps before reaching the next destination point to the left, pressing the left control button gives the following auditory feedback, “Langkah ke kanan empat kali”. The language used by the software is in Bahasa Melayu as most of the participants from SSB were not familiar with the English language. They were, however, able to listen and communicate in the national language, which is Bahasa Melayu. Going back to the auditory feedback above, “Langkah ke kanan empat kali” when translated to the English language means “Step to the right four times”. The consent form (Appendix 5) and information participation (Appendix 4) were both written in English and were translated verbally to the participants from SSB prior to their participation and later on signed by the warden in charge.

When the assessment tool was started, an auditory feedback similar to when the left control key is pressed was played. The purpose is to let the participant know that the level had started and where the participant should move their virtual character. In each level of the assessment tool, there may be a traffic light present. When the participant reaches a traffic light, an auditory message is played and the participant would need to wait for the traffic light to buzz before moving ahead. Once the participant reaches their destination, a congratulatory message is played to indicate the end of the level. The participant was then asked to sketch the direction that was taken in that level.

4.4.3 Assessment Phase

There were in total three assessment sessions for each participant. The duration between each session was one day whenever possible. Where it was not feasible to continue with the next session on the following day due to personal issue from the participants or because it was the weekend, the session was continued in the next following week or when it was convenient for the participants. Note that for all the participants in this research study, their total length of sessions combined never exceeded seven days. With the exception of a few who had personal matters to attend to, these participants were able to complete them within two or three days from the last session. The reason for having multiple maps ties closely with the need for three sessions. The assessment levels for each session are shown in Table 8. In the first session, each participant started with map C-3 as the first level before moving on to map A-1. The last level would have the participant be assessed on map A-2, which had higher complexity than the first two. This pattern was repeated for the remaining two sessions to maintain consistency of the gradual increase in level complexity as they progress. Note however that each session uses a different map type with the exception of session one and session three, which use the same map, i.e., C-3, for the first level. The aim was to prevent the participant from memorizing the path in the previous session and use it to their advantage in future sessions.

Table 8: Assessment levels for each session.

	Session #1	Session #2	Session #3
Level 1	Map C-3	Map C-3R	Map C-3
Level 2	Map A-1	Map B-1	Map A-1R
Level 3	Map A-2	Map B-2	Map A-2R

The assessment session for each participant followed the listed procedure below (Figure 17).

1. In each session, the participants were assessed on three different virtual maps. The goal for the participant was to begin at the starting point and make their way to the destination point.
2. Upon completion, the participant was asked to sketch on a piece of blank paper the path their virtual character took in the assessment tool. This method only applies to the SUTSC participants because they were able to see the paper and pen. After each sketch by the SUTSC participants, the paper was withdrawn from them and kept out of their view by the instructor. A new side of the paper was given to the SUTSC participants for each map level. For the SSB participants, the instructor verbally inquired from the participant the path taken by their virtual character.
3. If the participant fails to sketch or verbally inform the correct path, they are asked if they would like to repeat the level.
   3.1. If the participant agrees, the process was repeated for the same level but with a reduced sketch score for each attempt up to five attempts.
   3.2. However, if the participant does not want to repeat the level, the instructor proceeds with the next virtual map. The current assessment levels have the game time based on this level but the sketch score was zero.

4. Once a correct sketch was given, the game time for that particular assessment was recorded. The sketch score was recorded as well based on the number of tries. There were up to a maximum of five tries and with each attempt, the sketch score was reduced by 1 point.
5. The steps above were repeated for all three virtual maps.

4.5 Evaluation Sessions

The evaluation of the participant was carried out by calculating two separate scores. The first score was the game time from the assessment tool. The other was scored once the player had completed the level. The participant was asked to draw on a piece of blank paper the path that was taken in the recent assessment. This was the sketch score and it was measured in points. This was based on Stuart's Tactile Map (Ian Stuart, 1995) test that showed the spatial ability of a player to remember and retain the memory of one's environment and in this case, the player's orientation while in the assessment tool 2D virtual map. Each level allows the player to attempt the sketching of the path up to five times. A score was given depending on the number of attempts made. The max score was five, which was given when the player was able to sketch a comparable path compared to the ideal path in the first attempt. Should the player fail to draw a similar path, they would need to try the assessment level again and another attempt was made to sketch the path taken.

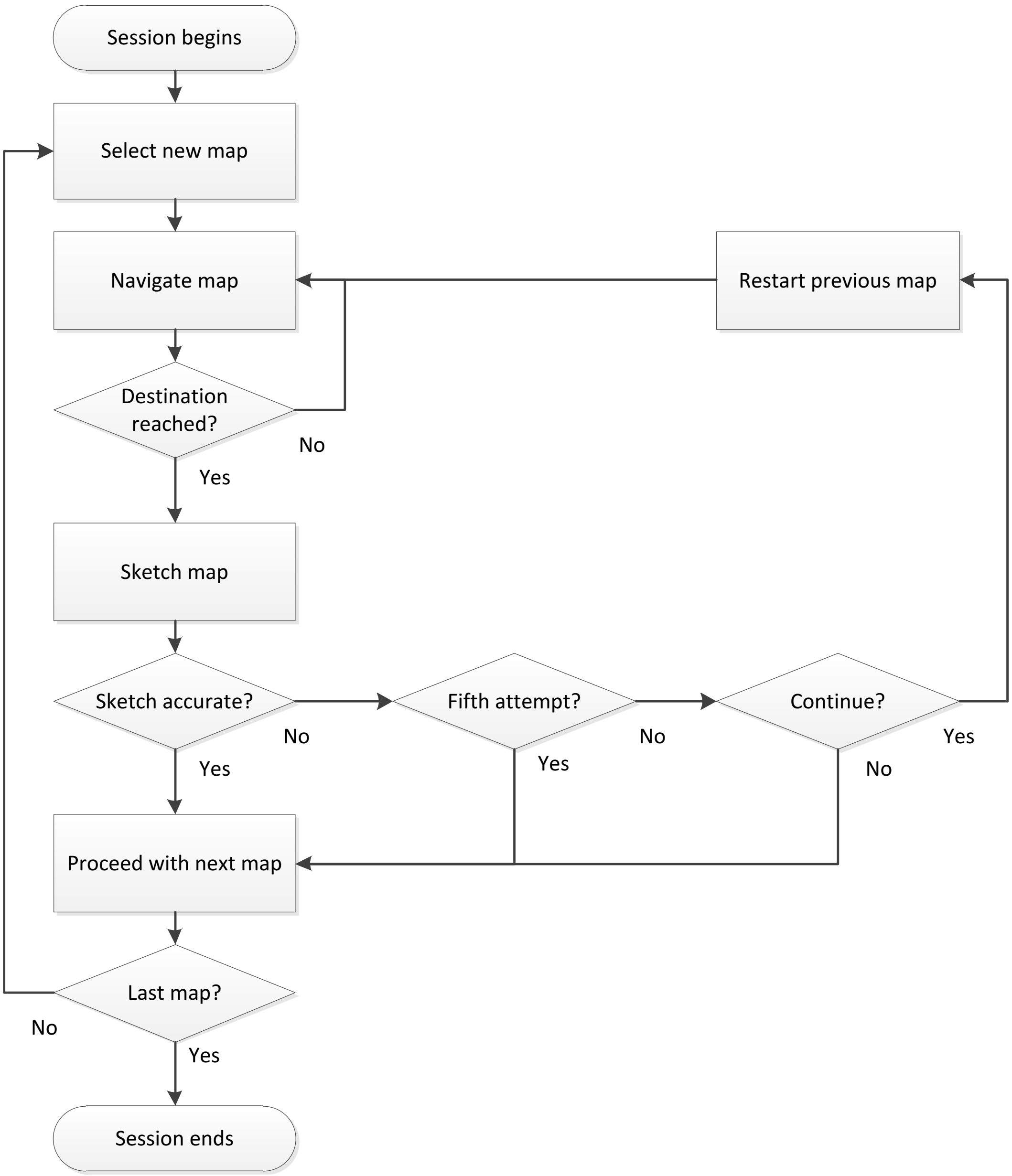

Figure 17: Flowchart for an assessment session.

A successful sketch in the second attempt awards only four points as compared to five points when done correctly the first time. With each attempt, the score was reduced by one point until it reaches zero. A zero point score indicated that the player had failed to sketch the same path taken in the training tool when compared to the correct path, five times in a row. With the above sketch score combined with the game time taken, these values were used to reject either the null hypothesis (H_0) or the alternative hypothesis (H_1) depending on the outcome of the experiment. The alternative hypothesis states that the player's mental mapping skills would improve after training with a computer-based audio assisted assessment tool while the null hypothesis shows that the player's mental mapping skills do not improve even with a computer-based audio assisted assessment tool. In the alternative hypothesis, after each session, the sketch score was expected to increase which proves that the spatial memory of the individual had improved over the course of three sessions. Similarly, the time taken to complete each level drops proving that the individual becomes more familiar with the level's orientation.

4.6 Results Analysis

The goal of this assessment tool is to evaluate the mental mapping skills of the player. This was done by measuring the participants' game time and sketch score over the course of three sessions. The assessment tool was designed as a game for the participant to play. What was available for the participant to interact with was an external keyboard used as an input to the assessment tool. The user interface screen was not visible to the participant as the laptop that runs this software was facing away from the participant and towards the instructor. The assessment tool is a computer-based software that takes place in a virtual 2D environment. Each assessment level had a different starting point and its respective ending points along with the different length of path and location of a traffic light.

The map design was based on Stuart Tactile Maps Test (Ian Stuart, 1995) which was originally developed to test a person's ability to learn spatial information and stay orientated during mobility. Each map was designed as a modification from Stuart's test and it follows the number of paths based on the original map. The evaluation of the assessment tool was carried out in three separate sessions for each participant. The assessment tool was run on a laptop with an external keyboard for the input from the participant. All participants were given an introduction to the assessment tool during their first session. This was to get them familiarized with the working mechanics of the tool so that they can complete the session without any doubts. In each session, the participants were assessed on three different virtual maps. Upon completion, a sighted participant was asked to sketch on a piece of blank paper the path their virtual character took in the assessment tool. The visually impaired participants had to verbally repeat the instructions they had been given.

Once a correct sketch was given, the game time for that particular assessment was recorded. The mitigation plans were set in place in case of undesirable events that could possibly occur with the worst case that could happen was a participant inflicting minor injury to themselves while using the keyboard. The evaluation of the participant was carried out by calculating two separate scores. The first score was the game time from the assessment tool. The other was scored once the player had completed the level. These values were used to reject either the null hypothesis (H_0) or the alternative hypothesis (H_1) depending on the outcome of the experiment, which is discussed in the next sections.

4.7 Participants' Results

Participants for the assessment tool fall into three groups (Table 7). Group one comprises participants with visual impairments who have no vision, the second group were participants with visual impairments as well but have low vision and the final consists of participants without any visual impairment. The reason for having three groups was to see if participants who were visually impaired performed worst or better compared to the sighted participants, including between those with no vision and low vision. The data from group one (Table 9) consists of participants with visual impairments with no vision age between 21 years to 65 years old (M = 36.130, SD = 15.040). Group two (Table 10) contains participants with visual impairments with low vision age between 20 years to 32 years old (M = 24.380, SD = 3.498). There were sixteen participants in total from the first two groups, with two of them being female while the remaining were males. These participants were volunteers from SSB, a non-profit organization that provides education, rehabilitation, vocational training, employment, and social integration and welfare of the visually impaired and other programs and schemes for the prevention of blindness.

The third group of participants were students from SUTSC with the results for the total game time and total sketch score shown in Table 11. They consist of nine students with age ranging from 21 to 26 years old (M = 23.11, SD = 1.792). A majority of the participants in the third group were females, which makes up for five female participants and the remaining four participants were males which gives a group total of nine participants. The research experiment was conducted over three sessions for each participant. In each session, the duration taken to complete the assessment tool and the sketch score was recorded.

Table 9: Total game time and sketch score over three separate sessions for participants with visual impairments (no vision).

Participant	Gender	Age	Total Game Time			Total Sketch Score		
			1st	2nd	3rd	1st	2nd	3rd
2	M	21	124	135	125	4	7	10
3	M	27	110	111	81	6	4	5
4	M	28	128	103	71	3	10	10
8	M	28	126	120	120	4	3	4
9	F	49	133	123	129	9	14	13
13	M	49	118	125	122	12	8	13
14	M	22	105	106	108	7	7	8
15	M	65	197	214	168	4	5	5

Table 10: Total game time and sketch score over three separate sessions for participants with visual impairments (low vision).

Participant	Gender	Age	Total Game Time			Total Sketch Score		
			1st	2nd	3rd	1st	2nd	3rd
1	M	27	104	110	101	7	7	8
5	M	23	110	107	123	14	14	15
6	M	22	102	103	93	11	15	15
7	M	22	133	124	113	14	14	15
10	M	20	132	120	128	12	12	11
11	M	24	122	121	122	8	10	9
12	M	32	116	118	115	15	14	15
16	F	25	110	109	107	15	14	15

Table 11: Total game time and sketch score over three separate sessions for participants with no visual impairments (sighted group).

Participant	Gender	Age	Total Game Time			Total Sketch Score		
			1st	2nd	3rd	1st	2nd	3rd
1	F	21	159	153	138	15	14	15
2	M	22	142	131	129	14	14	15
3	F	22	157	133	136	15	15	15

4	F	21	144	155	154	15	15	14
5	M	25	193	166	155	15	15	14
6	M	22	155	142	137	14	15	14
7	F	26	191	170	172	15	15	15
8	M	24	190	156	146	15	15	14
9	F	25	175	158	147	15	15	15

The scatter plot for the total game time for all participants (Figure 18) showed no discernable pattern between the game time with relation to the age and gender of the participants. However, for the total sketch score scatter plot (Figure 19) it was noted that the female participants scored better compared to the male participants. When viewing the scatter plot data, the lower the game time the better it was. This translates to a participant completing the map level faster. For the sketch score, it was the opposite as higher score meant less attempt was made on each map level.

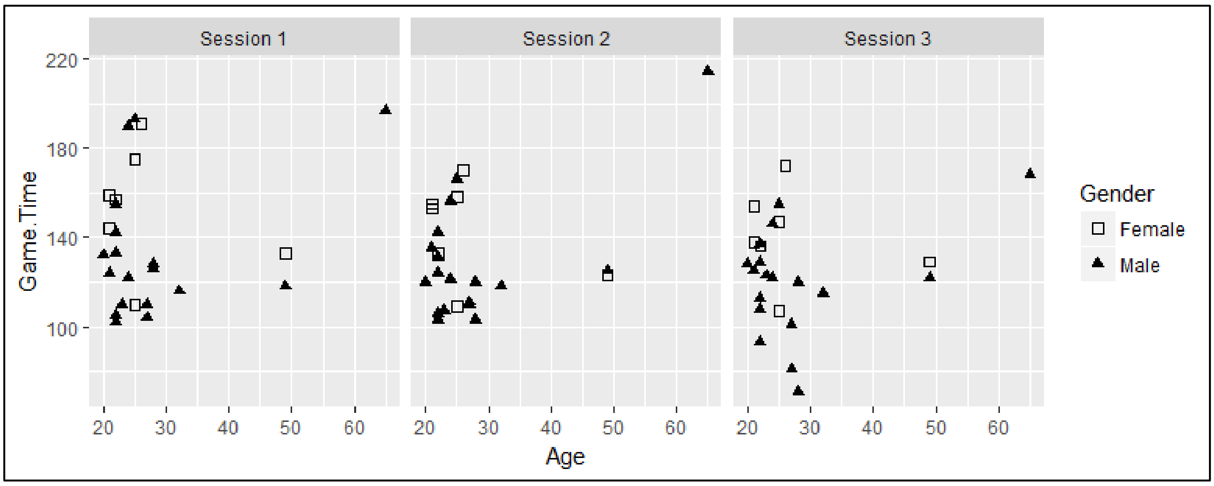

Figure 18: Scatter plot for the total game time of all participants.

When the scatter plot for the total game time was divided by group (Figure 20), the data distribution was tight for the low vision group while the sighted group had a small area of distribution. The group with no vision, however, had a larger scattering area. The same result can be seen in the scatter plot for the total sketch score by group (Figure 21) for the no vision group. The sighted participants had a very concentrated area in the high quadrant sketch score (above 12 points), while the low vision group were slightly spread out. An explanation for the disparity between the low vision and sighted with the no vision group was that individuals with vision may have better spatial memory neuronal development due to the part that their vision played (Pasqualotto and Newell, 2007; Pasqualotto and Proulx, 2012).

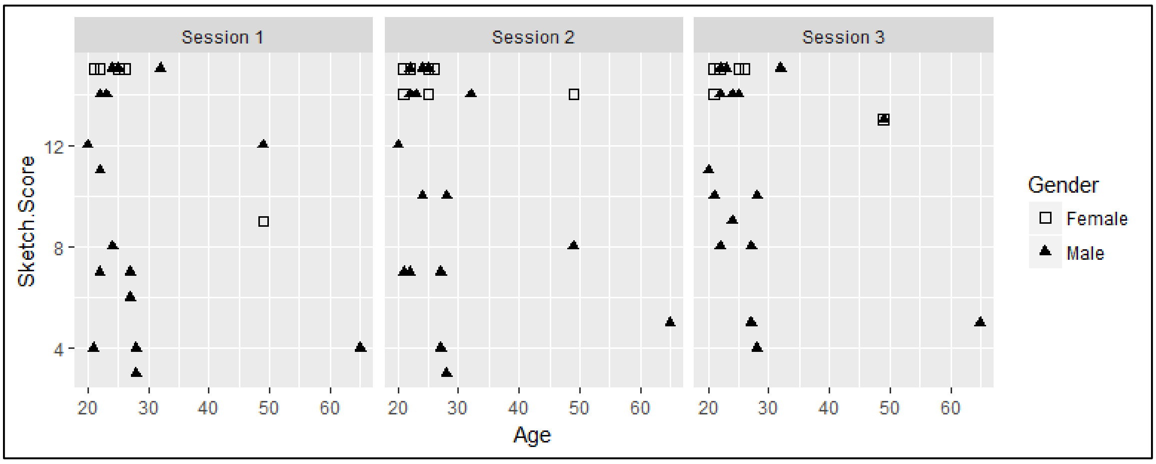

Figure 19: Scatter plot for the total sketch score of all participants.

Figure 20: Scatter plot for the total game time by group.

Figure 21: Scatter plot for the total sketch score by group.

4.8 VROOM Survey

An additional vision-related outcome in orientation and mobility (VROOM) survey (Deverell, 2016) was used to understand better the functional vision for mobility of the participants with visual impairments. It is a series of questions (Appendix 2) designed to evaluate the participants' social activities and general lifestyle of living with visual impairment. The VROOM questionnaires look into several domains regarding the individuals' skills, attitudes, and activities that occurred within the past month from the date of the questionnaire. The domains included the level of activities that the individual participated in and their satisfaction level. The second item in the domain was on the individuals' social life and their daily interaction with their peers around them. The third was on their capability to travel around their area of residence, such as the amount of difficulty they faced to travel within their residence and beyond their local community. It also inquired about their general orientation, which was when travelling around, how well do they get around independently. The final question in the domain space was regarding agency. Was their mobility limited by other people who care for them and how able were they to travel by themselves? Refer to Table 14 for the scoring system for each of the domain.

Table 12: VROOM scores for participants with visual impairments with no vision.

Participant	2	3	4	8	9	13	14	15
Gender	M	M	M	M	F	M	M	M
Age	21	27	28	28	49	49	22	65
Activities	3	2	3	3	3	3	3	3
Connections	2	1	2	3	3	2	2	2
Life-space	1	1	1	1	0	1	1	2
Orientation	1	1	1	1	1	1	1	2
Agency	2	0	1	2	1	1	1	2
Reading	0	0	0	0	0	0	0	0
Visual certainty	1	0	1	1	0	0	0	0
Mobility aids	0	1	1	1	0	0	0	0
People	0	0	1	1	0	0	0	0
Pleasure	0	0	1	2	0	0	0	0
VROOM Score	10	6	12	15	8	8	8	11

The second part of the VROOM questionnaires goes into the lifestyle of the individual with visual impairment. There were five questions mainly on the observations and discussion about the activities of the individual within the past month. It checked on the individuals' reading competence, not on literacy but on visual certainty, and their visual confidence, e.g., if their vision causes hesitation and frustration and how clearly can they identify food packaging. The next item on the questionnaire asked about the type of mobility aids that the individual uses: whether it was a cane, guide dog or none at all. The fourth question talked about their ability to recognize people and objects, how well they could detect moving objects and recognize people's faces. The final question in the VROOM inquired about the general pleasure these individuals obtain from their current state of vision. It was scored based on how they dealt with their lack of vision. These scores from each question in the VROOM was used as a means to measure the functional vision for mobility by reducing the qualitative data into a single score. A tangible measurement in the form of a tactile test was designed and developed to test the mental cognitive skills of not only the visually impaired but the sighted as well. Refer to Table 15 for the scoring system for each of the domain.

Table 13: VROOM scores for participants with visual impairments with low vision.

Participant	1	5	6	7	10	11	12	16
Gender	M	M	M	M	M	M	M	F
Age	27	23	22	22	20	24	32	25
Activities	3	3	3	1	3	3	3	4
Connections	3	3	2	2	2	3	2	3
Life-space	3	3	2	3	2	3	1	3
Orientation	3	3	3	3	3	3	2	4
Agency	3	4	3	2	3	3	3	3
Reading	0	4	1	0	1	1	0	0
Visual certainty	3	4	3	3	3	3	3	3
Mobility aids	2	4	2	2	2	2	3	2
People	2	4	2	1	2	2	2	3
Pleasure	2	4	2	1	2	2	2	2
VROOM Score	24	36	23	18	23	25	21	27

Table 12 and Table 13 shows the VROOM scores for the participants with visual impairments with no vision and low vision respectively. These include the individuals' reading competence, hesitation and frustration caused by their visual impairment, type of mobility aids, and the general pleasure these individual obtain from their current state of vision. It was scored based on how they dealt with their lack of vision. These score from each question in the VROOM was used as a mean to measure the functional vision for mobility by reducing the qualitative data into a single score. The assessment score for the participants who were visually impaired is discussed further in a future section of this chapter.

Table 14: Part 1 of VROOM survey questions.

Domains	Score according to discussion about skills, attitudes and activities **within the past month**
Activities	0 I find activities overwhelming 1 My mix of activities is not quite right. I don't know how to fix it, or I'm not yet ready for change 2 I like some of my activities, but I'm ready for new directions 3 I'm satisfied with my current mix of activities 4 I find my mix of activities challenging and enriching
Connections	0 I feel isolated and lonely; I'm not sure who to connect with 1 I feel quite dependent on others to take me out or do things for me 2 I know where to find people; I'm linked in with some people or groups

	3 I meet with people regularly; I feel welcomed and included 4 I actively contribute; I have mutual friendships; we're there for each other
Life-space	0 I'm house-bound; I rarely go beyond the front gate 1 I do routine travel, only in well-known local areas (e.g., home block, local shops) 2 I explore in my local community; I like to try different routes 3 I travel to known places beyond the local community (e.g. commuting for work, visiting friends) 4 I like to explore beyond the local community, discovering new places
Orientation	0 Even at home, I get lost and need help; I have trouble understanding shapes, angles, & distances 1 I can find the way at home; beyond home, I need a companion or I get lost 2 I travel independently beyond home; if I get lost, I rely on help from other people 3 I travel independently beyond home; if I get lost, I can usually work it out by myself 4 I can go anywhere independently; I use mental mapping and I'm rarely disorientated for long
Agency	0 My travel is managed by other people; I don't make the decisions 1 I need travel restrictions – I'm not always aware of what's safe and what is not 2 I'm aware of my own limitations, but I limit my travel rather than learning new skills 3 I'm aware of my own limitations; I plan ahead, source information and get help with my travel skills 4 I'm in charge; I evaluate my travel and learn from experience as I go; I develop my own skills

Table 15: Part 2 of VROOM survey questions.

Part B: Lifestyle	Score together from observations and discussion about activities **within the past month**
Reading	0 I have no useful vision for reading text 1 If I'm close enough, I can identify large signs (e.g., stop sign) by text, size, shape, colour 2 I can sometimes read vehicle number plates & shop signs 3 I can sometimes identify different foods by looking at text and packaging (e.g., types of milk) 4 I can read regular print (i.e., letters, N12)
Visual certainty	0 My vision is never useful when I'm moving around; too little, too late 1 I can't rely on my vision when I'm doing things 2 My vision causes hesitation and frustration; it undermines confidence when I'm moving 3 My vision has its limitations, but I know how to work with it 4 My vision is reliable for travel; I don't really have to think about it much
Mobility aids (beyond home)	0 I use non-visual skills (cane/dog/guide) beyond home – my vision is useless 1 I rely on my cane/dog/guide – vision provides some extra information 2 I need non-visual skills sometimes (e.g., night travel, fluctuating vision) 3 I can go without it, but a mobility aid gives me confidence, relieves fatigue, expands my options

	4 My vision is good enough for travel – I don't need a mobility aid
People	0 I can't see people's shapes or movement; or see if a conversation partner moves away 1 I can see a body moving past, but I can't tell who it is; I sometimes collide 2 I can recognise people by their shape, colours, size or gait; I can usually avoid collisions 3 I can see faces, but not details; I do miss some social cues 4 I can recognise faces, read facial expressions and social cues
Pleasure	0 My vision is un-motivating; it rarely or never prompts a closer look 1 My vision is limited or frustrating; often more trouble than it is worth 2 My vision is useful for some things, but not for others 3 I can see interesting things; it is usually worth the time it takes to look 4 I can see beautiful or engaging things that bring calm, contentment, excitement, even bliss

There was a discernable difference in the results between the first group and the second group of participants as shown in Table 16. In the first group, the participants with visual impairments with no vision had a lower VROOM score (Table 12) on average (M = 9.750, SD = 2.680) compared to the second group (M = 24.625, SD = 4.973), which consists of participants whom were visually impaired but with low vision (Table 13). This variance was noticeable in the in the outcome of the total game time and total sketch score between these two groups. In the group with no vision, their collective total game time (Table 9) (M = 125.100, SD = 30.320) average was slower than those of low vision (Table 10) (M = 114.300, SD = 10.080). The total sketch score for the no vision group had a lower average value (M = 7.292, SD = 3.335) compared to those with low vision (M = 12.460, SD = 2.798). The better performance in the low vision group could be due to the past or current experience that allows them to identify objects via visual mapping, which increases their chances of successfully mentally map the 2D virtual map of the assessment tool. For comparison, the sighted participants in the third group achieved a far superior total sketch score (Table 11) among the three groups (M = 14.700, SD = 0.457).

Table 16: Mean and standard deviation for VROOM, total game time, and total sketch score

	VROOM Scores		Total Game Time		Total Sketch Score	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Visually impaired participants with no vision	9.750	2.680	125.199	30.320	7.292	3.335
Visually impaired participants with low vision	24.625	4.973	114.300	10.080	12.460	2.798
Sighted participants	NA	NA	155.000	17.580	14.700	0.457

4.9 Game Score Exclusion

As mentioned in Chapter 3 on gameplay mechanics, after the assessment sessions were over, a majority of the participant scored 100 points for the game score. The only recorded participant without a full game score was only one participant, who scored 95 points. For this particular instance, five points were deducted because the participant stepped on the road before the traffic light buzzer had sounded. This dip in the score by one participant represents only 4% of the entire test sample. The total participants were 25 people. With such a low incidence rate and with the remainder of the participants scoring 100 points on their game score, the total game score was excluded from the data analysis as it provides no useful pattern or information.

Every other participant except for the one scored 100 points for their game score. The reason was due to the gameplay mechanics of the assessment tool. At the start of the game, the participant was told the direction and number of steps needed to move. When the participant arrived at the intersection, the next direction was announced via an audio message. This cycle continues until the participant reaches the destination. If a participant were to commit no fault, he/she would score 100 points for the game. Because the assessment tool is to test how well an individual remembers the path taken, a participant who scored badly is most likely focusing on the direction given out rather than remembering the path.

4.10 Findings and Discussions

To determine if the means of two populations were equal, a statistical test called Analysis of Variance (ANOVA) was used. By using the F probability distribution function and the variances of each grouping of populations (between) and population (within) the significance of the variability within and between each population can be determined (Molugaram *et al.*, 2017). This study sought to determine whether a person's mental mapping would improve by repeating the test over several short sessions. The null hypothesis states that the results were consistent for both game time and game score throughout the three assessment sessions while the alternative hypothesis states that the results would differ for both game time and game score throughout the three assessment sessions. In this thesis ANOVA was used an alpha (α) value of 0.05.

A one-way ANOVA was calculated on the visually impaired participants with no vision: the total game time on three separate sessions is shown in Table 17. The analysis was not significant, $F(2, 21) = 0.553$, $p > 0.584$, which implied that the total game time did not improve over the three assessment sessions. Participants in the first session ($M = 130.125$, $SD = 28.593$) took a longer time to complete compared to the second session ($M = 129.625$, $SD = 35.697$) but even faster in the third session ($M = 115.500$, $SD = 30.043$). A reduction in the total game time in between sessions meant that a participant completed the current assessment session faster than the previous session. The reduction in the total game time taken to complete each successive session could be due to the increase in familiarity with the procedure of each assessment session.

The one-way ANOVA results for the visually impaired participants with no vision, using the total sketch score on three separate sessions (Table 18), showed that the result was not significant, $F(2, 21) = 0.970$, $p > 0.395$, which implied that the total sketch score did not have substantial improvement over the three assessment sessions. Participants in the first session ($M = 6.125$, $SD = 3.091$) have a lower sketch score compared to the second session ($M = 7.250$, $SD = 3.536$). In the third session, the visually impaired participants scored the most compared to the first two sessions ($M = 8.500$, $SD = 3.586$). An increase in the total sketch score meant that a participant makes fewer mistakes when sketching the map level and hence reduced the number of attempts needed for each map level. The upturn in the total sketch score taken to complete each successive session could be due to the gain in proficiency after each assessment session.

Table 17: Statistical summary and one-way ANOVA result on visually impaired participants with no vision for the total game time.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	8	1041	130.125	817.554	28.593
2nd	8	1037	129.625	1274.268	35.697
3rd	8	924	115.500	902.571	30.043

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	1103.083	2	551.542	0.553	0.584	3.467
Within Groups	20960.750	21	998.131			
Total	22063.833	23				

Table 18: Statistical summary and one-way ANOVA result on visually impaired participants with no vision for the total sketch score.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	8	49	6.125	9.554	3.091
2nd	8	58	7.250	12.500	3.536
3rd	8	68	8.500	12.857	3.586

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	22.583	2	11.292	0.970	0.395	3.467
Within Groups	244.375	21	11.637			
Total	266.958	23				

A one-way ANOVA was calculated on the visually impaired participants with low vision total game time on three separate sessions (Table 19). The analysis was not significant, $F(2, 21) = 0.204$, $p > 0.817$, which implied that the total game time did not significantly improve over the three assessment sessions. Participants in the first session ($M = 116.125$, $SD = 11.910$)

took a longer time to complete compared to the second session (M = 114.000, SD = 7.672) but even faster in the third session (M = 112.750, SD = 11.889). The improvement in the total game time was relatively low for the visually impaired participants with low vision, about two seconds after each assessment session. This could explain the gained competency of the sighted individual throughout the assessment sessions as they became more familiar with the procedure of the assessment. Findings by other researchers concluded that vision had an important role to play when updating or representing the spatial information and this have a vital effect on the development of neuronal areas that are involved in spatial memory (Pasqualotto and Newell, 2007; Pasqualotto and Proulx, 2012).

Table 19: Statistical summary and one-way ANOVA result on visually impaired participants with low vision for the total game time.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	8	929	116.125	141.839	11.910
2nd	8	912	114.000	58.857	7.672
3rd	8	902	112.750	141.357	11.889

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	46.583	2	23.292	0.204	0.817	3.467
Within Groups	2394.375	21	114.018			
Total	2440.958	23				

The one-way ANOVA results for the participants with no vision total sketch score on three separate sessions (Table 20) showed that the result was not significant, $F(2, 21) = 0.175$, $p > 0.841$, which implied that the total sketch score did not have substantial improvement over the three assessment sessions. Participants in the first session (M = 12.000, SD = 3.117) have a lower sketch score compared to the second session (M = 12.500, SD = 2.726). In the third session, the visually impaired participants scored the most compared to the first two sessions (M = 12.875, SD = 3.044). There were only small improvements in the total sketch score for the participants with no vision. One explanation was that the participant's mental mapping skill was at their maximum capability and further assessment does not improve the mental mapping skill but rather measured their current competency.

Table 20: Statistical summary and one-way ANOVA result on visually impaired participants with low vision for the total sketch score.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	8	96	12.000	9.714	3.117
2nd	8	100	12.500	7.429	2.726
3rd	8	103	12.875	9.268	3.044

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	3.083	2	1.542	0.175	0.841	3.467
Within Groups	184.875	21	8.804			
Total	187.958	23				

Table 21: Statistical summary and one-way ANOVA result on sighted participants for the total game time.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	9	1506	167.333	367.333	19.166
2nd	9	1364	151.556	164.691	12.833
3rd	9	1314	146.000	150.667	12.275

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	2204.741	2	1102.370	4.306	0.025	3.403
Within Groups	6144.222	24	256.009			
Total	8348.963	26				

A one-way ANOVA was calculated on the sighted participants' total game time on three separate sessions (Table 21). The result was significant, $F(2, 24) = 4.306$, $p > 0.025$, which implied that the total game time did improve over the three assessment sessions. Participants in the first session ($M = 167.333$, $SD = 19.166$) took a longer time to complete compared to the second session ($M = 151.556$, $SD = 12.833$) but even faster in the third session (M = 146.000, SD = 12.275). The one-way ANOVA results for the sighted participants' total sketch score on three separate sessions (Table 22) showed that the analysis was not significant, F(2, 24) = 0.667, p > 0.523, which implied that the total sketch score did not have substantial improvement over the three assessment sessions. Participants in the first session (M = 14.778, SD = 0.416) have similar sketch score compared to the second session (M = 14.778, SD = 0.416). In the third session, the sighted participants scored lower when compared to the first two sessions (M = 14.556, SD = 0.497). The result for the sighted participants in terms of improvement for both the total game time and total sketch score was similar to the visually impaired participants with low vision. This matches the findings by academics on the important role that vision had on the development of neuronal areas that are involved in spatial memory (Pasqualotto and Newell, 2007; Pasqualotto and Proulx, 2012).

A one-way ANOVA was calculated for all three groups of participants (visually impaired with no vision, visually impaired with low vision, and sighted) on the total game time on three separate sessions (Table 23). The analysis was not significant, F(2, 72) = 1.520, p > 0.226, which implied that the total game time did not improve over the three assessment sessions. Participants in the first session (M = 139.040, SD = 29.707) took a longer time to complete compared to the second session (M = 132.520, SD = 25.989) and the fastest in the third session when compared to the earlier two sessions (M = 125.600, SD = 24.121). The one-way ANOVA results for both groups of participants (visually impaired and sighted) on the total sketch score on three separate sessions (Table 24) showed that the result was not significant, F(2, 72) = 0.355, p > 0.703, which implied that the total sketch score did not have substantial improvement over the three assessment sessions. Participants in the first session (M = 11.120, SD = 4.302) have a slightly lower sketch score compared to the second session (M = 11.640, SD = 3.948). In the third session, all participants scored higher when compared to the first two sessions (M = 12.080, SD = 3.577). When the data were combined, the overall result showed minimal improvement in both the total game time and total sketch. This suggests that the assessment tool does not improve the mental mapping skills of the participant.

Table 22: Statistical summary and one-way ANOVA result on sighted participants for the total sketch score.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	9	133	14.778	0.173	0.416
2nd	9	133	14.778	0.173	0.416
3rd	9	131	14.556	0.247	0.497

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	0.296	2	0.148	0.667	0.523	3.403
Within Groups	5.333	24	0.222			
Total	5.630	26				

Table 23: Statistical summary and one-way ANOVA result on all participants for the total game time.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	25	3476	139.040	882.518	29.707
2nd	25	3313	132.520	675.450	25.989
3rd	25	3140	125.600	581.840	24.121

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	2258.587	2	1129.293	1.520	0.226	3.124
Within Groups	53495.200	72	742.989			
Total	55753.787	74				

The correlation data (Table 25) showed strong positive average correlation coefficient for the total game time for the visually impaired group with no vision (r = 0.836), sighted group (r = 0.767), and when all data from participants were combined (r = 0.864). The visually impaired group with low vision indicated a moderately strong positive average correlation coefficient for the total game time (r = 0.740). The situation was different for the average correlation coefficient for the total sketch score. The visually impaired group with no vision showed a moderately strong positive (r = 0.623) average correlation coefficient while the visually impaired group with low vision exhibited a strong positive (r = 0.895) average correlation coefficient for the total sketch score. As for the sighted group, the average correlation coefficient for the total sketch score was a weak negative (r = -0.020). As a whole, the combined results from all the three groups presented a strong positive average correlation coefficient for the total sketch score.

Table 24: Statistical summary and one-way ANOVA result on all participants for the total sketch score.

Session	*Count*	*Sum*	*Mean*	*Variance*	*Std. Deviation*
1st	25	278	11.120	18.506	4.302
2nd	25	291	11.640	15.590	3.948
3rd	25	302	12.080	12.794	3.577

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	11.547	2	5.773	0.355	0.703	3.124
Within Groups	1172.240	72	16.281			
Total	1183.787	74				

Table 25: Correlation coefficient table for the total game time and total sketch score for visually impaired group (no vision), visually impaired group (low vision), sighted group, and both groups combined.

	Visually impaired Group (No Vision)	**Visually impaired Group (Low Vision)**	**Sighted Group**	**Combined**
Correlation for total game time between session #1 and session #2	0.939	0.910	0.766	0.903
Correlation for total game time between session #1 and session #3	0.727	0.700	0.651	0.821
Correlation for total game time between session #2 and session #3	0.842	0.609	0.884	0.868
Average correlation of total game time	0.836	0.740	0.767	0.864
Correlation for total sketch score between session #1 and session #2	0.389	0.841	0.357	0.860

Correlation for total sketch score between session #1 and session #3	0.625	0.888	0.060	0.878
Correlation for total sketch score between session #2 and session #3	0.856	0.956	-0.478	0.940
Average correlation of total sketch score	0.623	0.895	-0.020	0.892

The following sections presents the analysis of the data from the assessment sessions for the visually impaired participants of both no vision and low vision, the sighted participants, and finally looking at results as a whole by combining group one (visually impaired participants with no vision), group two (visually impaired participants with low vision) and group three (sighted participants). An elaboration on the VROOM assessment score for each participant from group one and group two but not from the third group was presented. The reason for this is because the assessments questions from the VROOM was conducted in order to comprehend the functional vision of those who were visually impaired.

4.10.1 Participant #1

Participant #1 was a 27-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary is shown in Figure 22 and Table 26 respectively. For the first session (M = 34.667, SD = 12.392) the participant took a shorter time to complete the assessment levels compared to the second session (M = 36.667, SD = 11.146). In the third session (M = 33.667, SD = 10.209) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 2.333, SD = 1.700) the participant had a similar sketch score as the second session (M = 2.333, SD = 2.055). At the final session (M = 2.667, SD = 2.055) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #1, he had a total domain score of 15 and a lifestyle score of 9 with an overall VROOM score of 24. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He met with people regularly and generally felt welcomed and included. He travelled to known places beyond the local community. He travelled independently beyond home but if he got lost, he could usually work it out. He was aware of his own limitations, but he planned ahead, sourced information, and got help with his travel skills. His vision had its limitations, but he knew how to work with it. He needed non-visual skills sometimes because his vision does provide some extra information. He could recognise people by their shape, colours, size, or gait, which allowed him to usually avoid collisions. His vision was useful for some things, but not for others.

Table 26: Statistical summary of participant #1 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	104	34.667	153.556	12.392
	#2	3	110	36.667	124.222	11.146
	#3	3	101	33.667	104.222	10.209
Sketch Score	#1	3	7	2.333	2.889	1.700
	#2	3	7	2.333	4.222	2.055
	#3	3	8	2.667	4.222	2.055

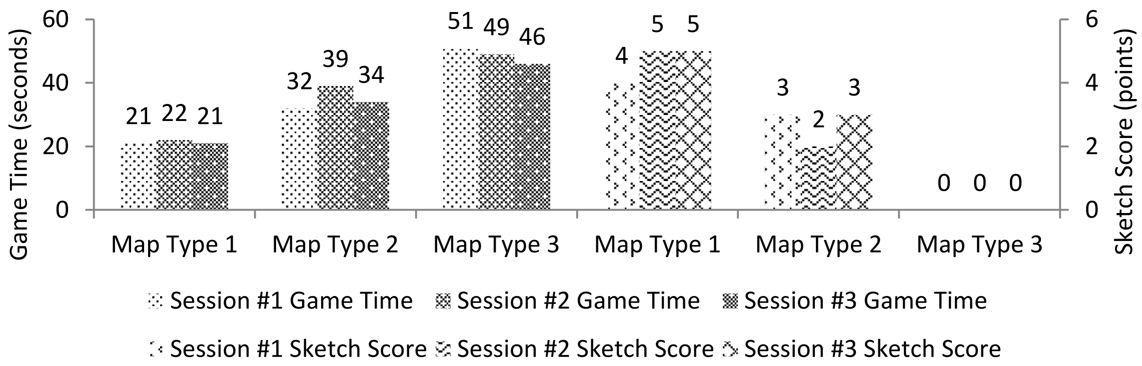

Figure 22: Participant #1 game time and sketch score.

4.10.2 Participant #2

Participant #2 was a 21-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 23 and Table 27 respectively. For the first session (M = 41.333, SD = 16.977) the participant took a shorter time to complete the assessment levels compared to the second session (M = 45.000, SD = 7.789). In the third session (M = 41.667, SD = 17.594) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 1.333, SD = 1.886) the participant sketch score was lower than the second session (M = 2.333, SD = 2.055). At the final session (M = 3.333, SD = 2.357) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #2, he had a total domain score of 9 and a lifestyle score of 1 with an overall VROOM score of 10. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He knew where to find people and was linked in with some people or groups. He was aware of his own limitations, but limited his travel rather than learning new skills. He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He could not rely on his vision when he was doing things.

Table 27: Statistical summary of participant #2 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	124	41.333	288.222	16.977
	#2	3	135	45.000	60.667	7.789
	#3	3	125	41.667	309.556	17.594
Sketch Score	#1	3	4	1.333	3.556	1.886
	#2	3	7	2.333	4.222	2.055
	#3	3	10	3.333	5.556	2.357

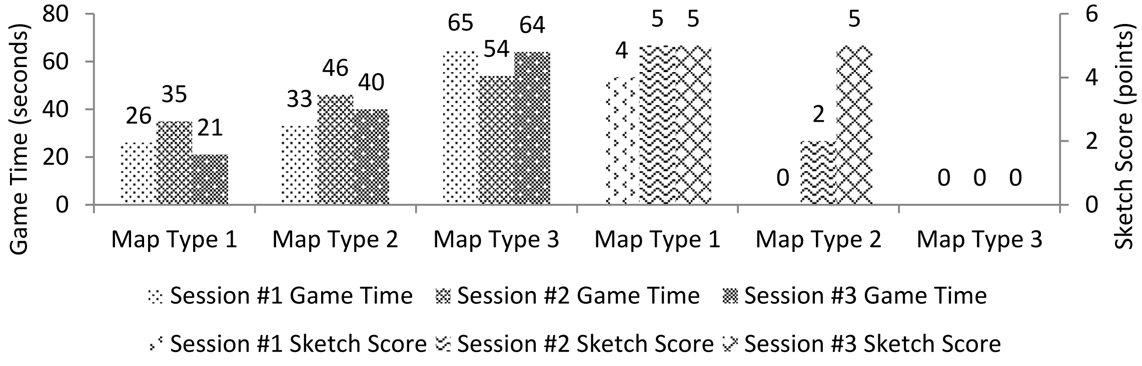

Figure 23: Participant #2 game time and sketch score.

4.10.3 Participant #3

Participant #3 was a 27-year-old male volunteer from SSB with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 24 and Table 28 respectively. For the first session (M = 36.667, SD = 10.339) the participant took a shorter time to complete the assessment levels compared to the second session (M = 37.000, SD = 13.491). In the third session (M = 27.000, SD = 14.353) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 2.000, SD = 1.633) the participant obtained a higher sketch score than the second session (M = 1.333, SD = 1.886). At the final session (M = 1.667, SD = 2.357) the participant achieved a better sketch score compared to the previous session.

Table 28: Statistical summary of participant #3 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	110	36.667	106.889	10.339
	#2	3	111	37.000	182.000	13.491
	#3	3	81	27.000	206.000	14.353
Sketch Score	#1	3	6	2.000	2.667	1.633
	#2	3	4	1.333	3.556	1.886
	#3	3	5	1.667	5.556	2.357

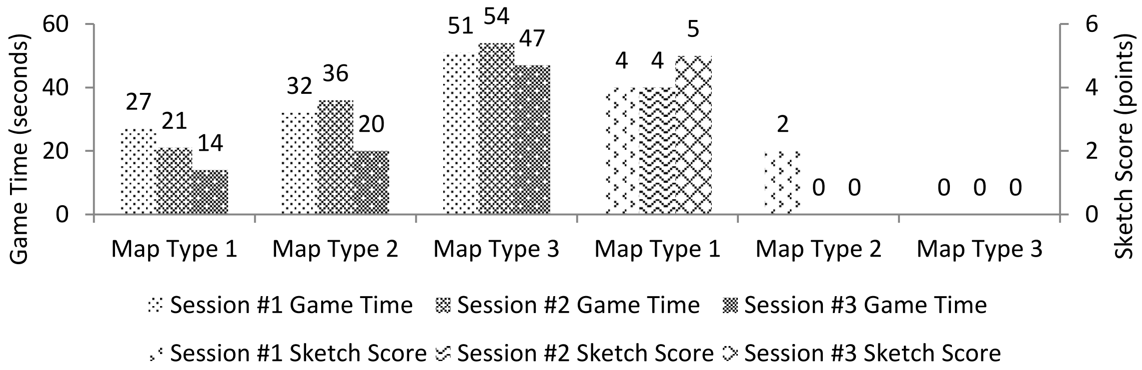

Figure 24: Participant #3 game time and sketch score.

Based on the VROOM analysis of participant #3, he had a total domain score of 5 and a lifestyle score of 1 with an overall VROOM score of 6. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He liked some of his activities, but he was ready for new directions. He felt quite dependent on others to take him out or to do things for him. He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He relied on his guide cane.

4.10.4 Participant #4

Participant #4 was a 28-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 25 and Table 29 respectively. For the first session (M = 42.667, SD = 17.153) the participant took a longer time to complete the assessment levels compared to the second session (M = 34.333, SD = 9.286). In the third session (M = 23.667, SD = 6.018) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 1.000, SD = 0.816) the participant sketch score was lower than the second session (M = 3.333, SD = 2.357). At the final session (M = 3.333, SD = 2.357) the participant had the same sketch score as the previous session.

Based on the VROOM analysis of participant #4, he had a total domain score of 8 and a lifestyle score of 4 with an overall VROOM score of 12. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He knew where to find people and was linked in with some people or groups. He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He needed travel restrictions because he was not always aware of what was safe and what was not. He could not rely on his vision when he was doing things. He relied on his guide cane. He could not see a body moving past and would sometimes collide. His lack of vision was frustrating.

Table 29: Statistical summary of participant #4 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	128	42.667	294.222	17.153
	#2	3	103	34.333	86.222	9.286
	#3	3	71	23.667	36.222	6.018
Sketch Score	#1	3	3	1.000	0.667	0.816
	#2	3	10	3.333	5.556	2.357
	#3	3	10	3.333	5.556	2.357

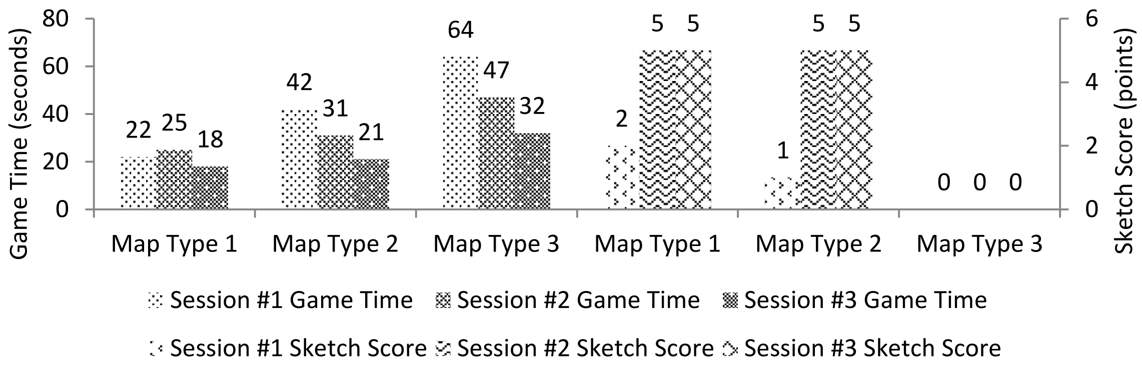

Figure 25: Participant #4 game time and sketch score.

4.10.5 Participant #5

Participant #5 was a 23-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 26 and Table 30 respectively. For the first session (M = 36.667, SD = 13.474) the participant took a longer time to complete the assessment levels compared to the second session (M = 35.667, SD = 10.209). In the third session (M = 41.000, SD = 20.216) the participant completed the assessment levels slower than the second session. During the first session (M = 4.667, SD = 0.471) the participant had a similar sketch score to the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session.

Table 30: Statistical summary of participant #5 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	110	36.667	181.556	13.474
	#2	3	107	35.667	104.222	10.209
	#3	3	123	41.000	408.667	20.216
Sketch Score	#1	3	14	4.667	0.222	0.471
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

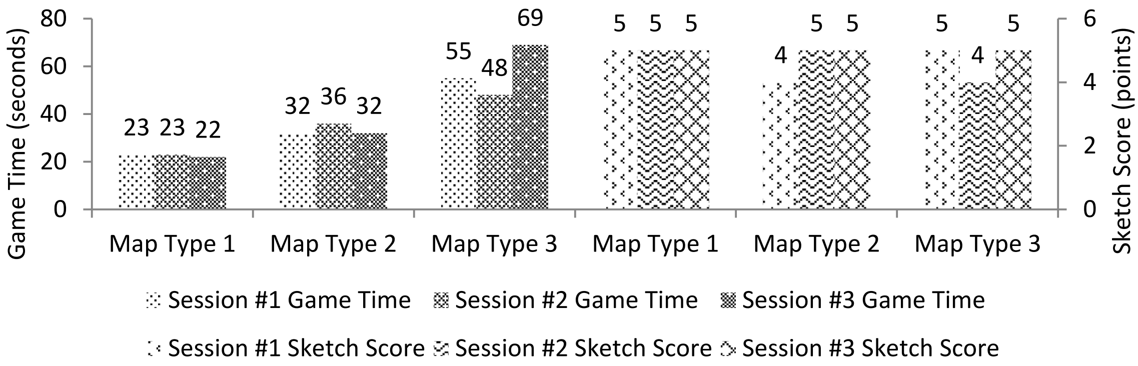

Figure 26: Participant #5 game time and sketch score.

Based on the VROOM analysis of participant #5, he had a total domain score of 16 and a lifestyle score of 20 with an overall VROOM score of 36. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was in charge and evaluated his travel and learned from experience along the way. This helped him to develop his own skills. He could read regular print such as a newspaper. His vision was reliable for travel and did not really thought about it much. His vision was good enough for travel and did not need a mobility aid. He could recognise faces, read facial expressions, and social cues. He could see beautiful or engaging things that bring calm, contentment, excitement and even bliss. He was satisfied with his current mix of activities. He met with people regularly and generally felt welcomed and included. He travelled to known places beyond the local community. He travelled independently beyond home but if he got lost, he could usually work it out.

4.10.6 Participant #6

Participant #6 was a 22-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 27 and Table 31 respectively. For the first session (M = 34.000, SD = 8.042) the participant took a shorter time to complete the assessment levels compared to the second session (M = 34.333, SD = 9.463). In the third session (M = 31.000, SD = 11.431) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 3.667, SD = 0.943) the participant sketch score was lower than the second session (M = 5.000, SD = 0.000). At the final session (M = 5.000, SD = 0.000) the participant had the same sketch score as the previous session.

Based on the VROOM analysis of participant #6, he had a total domain score of 13 and a lifestyle score of 10 with an overall VROOM score of 23. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He travelled independently beyond home but if he got lost, he could usually work it out. He was aware of his own limitations, but he planned ahead, sourced information, and got help with his travel skills. His vision had its limitations, but he knew how to work with it. He knew where to find people and was linked in with some people or groups. He explored in his local community and liked to try different routes. He needed non-visual skills sometimes because his vision does provide some extra information. He could recognise people by their shape, colours, size, or gait, which allowed him to usually avoid collisions. His vision was useful for some things, but not for others. If he was close enough, he could identify large signs by text, size, shape, or colour.

Table 31: Statistical summary of participant #6 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	102	34.000	64.667	8.042
	#2	3	103	34.333	89.556	9.463
	#3	3	93	31.000	130.667	11.431

Sketch Score	#1	3	11	3.667	0.889	0.943
	#2	3	15	5.000	0.000	0.000
	#3	3	15	5.000	0.000	0.000

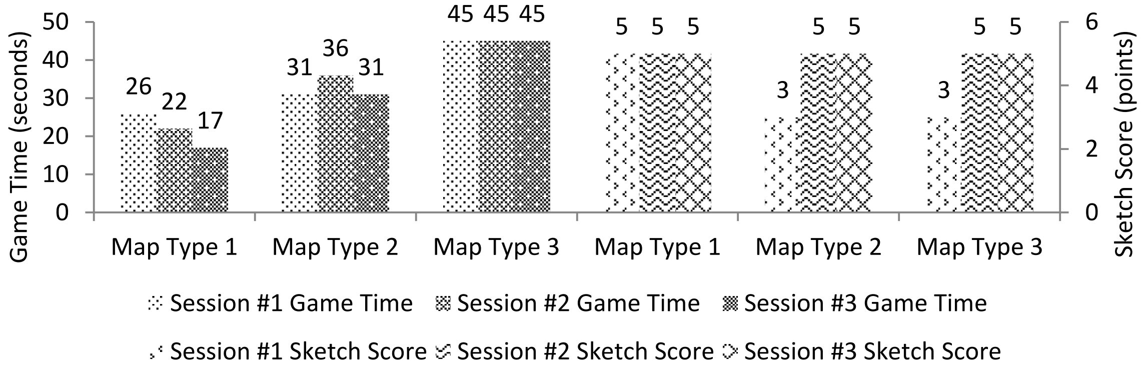

Figure 27: Participant #6 game time and sketch score.

4.10.7 Participant #7

Participant #7 was a 22-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 28 and Table 32 respectively. For the first session (M = 44.333, SD = 14.384) the participant took a longer time to complete the assessment levels compared to the second session (M = 41.333, SD = 10.625). In the third session (M = 37.667, SD = 13.474) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 4.667, SD = 0.471) the participant had a similar sketch score as the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #7, he had a total domain score of 11 and a lifestyle score of 7 with an overall VROOM score of 18. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He travelled to known places beyond the local community. He travelled independently beyond home but if he got lost, he could usually work it out. His vision had its limitations, but he knew how to work with it. He knew where to find people and was linked in with some people or groups. He was aware of his own limitations, but limited his travel rather than learning new skills. He needed non-visual skills sometimes because his vision does provide some extra information. His current mix of activities was not quite right but he was not yet ready to change it. He could see a body moving past but could not tell who it was and would sometimes collide. His vision was limited or frustrating and was often more trouble than it was worth.

Table 32: Statistical summary of participant #7 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	133	44.333	206.889	14.384
	#2	3	124	41.333	112.889	10.625
	#3	3	113	37.667	181.556	13.474
Sketch Score	#1	3	14	4.667	0.222	0.471
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

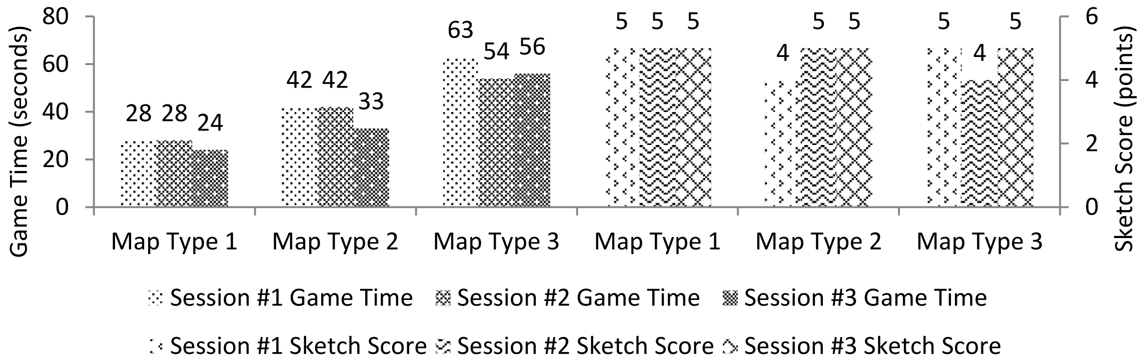

Figure 28: Participant #7 game time and sketch score.

4.10.8 Participant #8

Participant #8 was a 28-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 29 and Table 33 respectively. For the first session (M = 42.000, SD = 13.928) the participant took a longer time to complete the assessment levels compared to the second session (M = 40.000, SD = 10.614). In the third session (M = 40.000, SD = 11.045) the participant completed the assessment levels within the same duration as the second session. During the first session (M = 1.333, SD = 1.886) the participant obtained a higher sketch score than the second session (M = 1.000, SD = 1.414). At the final session (M = 1.333, SD = 1.886) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #8, he had a total domain score of 10 and a lifestyle score of 5 with an overall VROOM score of 15. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He met with people regularly and generally felt welcomed and included. He was aware of his own limitations, but limited his travel rather than learning new skills He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He could not rely on his vision when he was doing things. He relied on his guide cane. He could not see a body moving and would sometimes collide.

Table 33: Statistical summary of participant #8 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	126	42.000	194.000	13.928
	#2	3	120	40.000	112.667	10.614
	#3	3	120	40.000	122.000	11.045
Sketch Score	#1	3	4	1.333	3.556	1.886
	#2	3	3	1.000	2.000	1.414
	#3	3	4	1.333	3.556	1.886

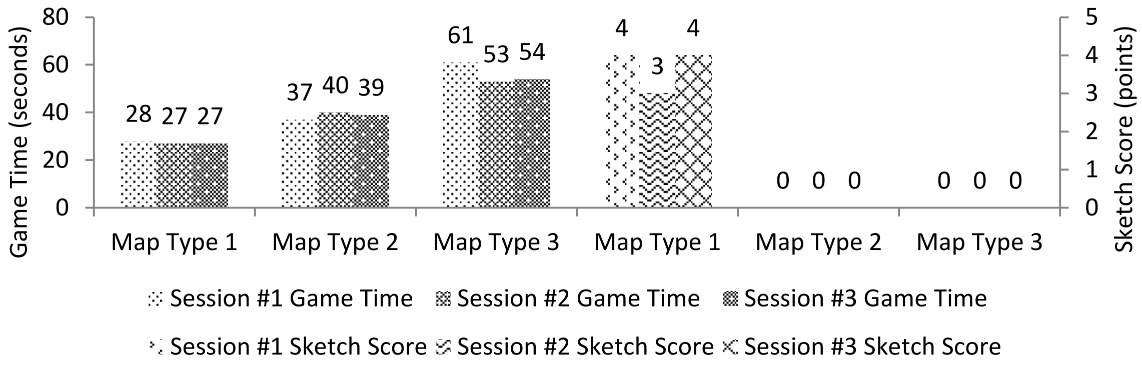

Figure 29: Participant #8 game time and sketch score.

4.10.9 Participant #9

Participant #9 was a 49-year-old female volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 30 and Table 34 respectively. For the first session (M = 44.333, SD = 11.441) the participant took a longer time to complete the assessment levels compared to the second session (M = 41.000, SD = 6.683). In the third session (M = 43.000, SD = 12.083) the participant completed the assessment levels slower than the second session. During the first session (M = 3.000, SD = 2.160) the participant sketch score was lower than the second session (M = 4.667, SD = 0.471). At the final session (M = 4.333, SD = 0.471) the participant sketch score was worse when compared to the previous session.

Table 34: Statistical summary of participant #9 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	133	44.333	130.889	11.441
	#2	3	123	41.000	44.667	6.683
	#3	3	129	43.000	146.000	12.083
Sketch Score	#1	3	9	3.000	4.667	2.160
	#2	3	14	4.667	0.222	0.471
	#3	3	13	4.333	0.222	0.471

Based on the VROOM analysis of participant #9, she had a total domain score of 8 and a lifestyle score of 0 with an overall VROOM score of 8. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. She was satisfied with her current mix of activities. She met with people regularly and generally felt welcomed and included. She could find the way at home but beyond home, she needed a companion or she would get lost. She needed travel restrictions because she was not always aware of what was safe and what was not.

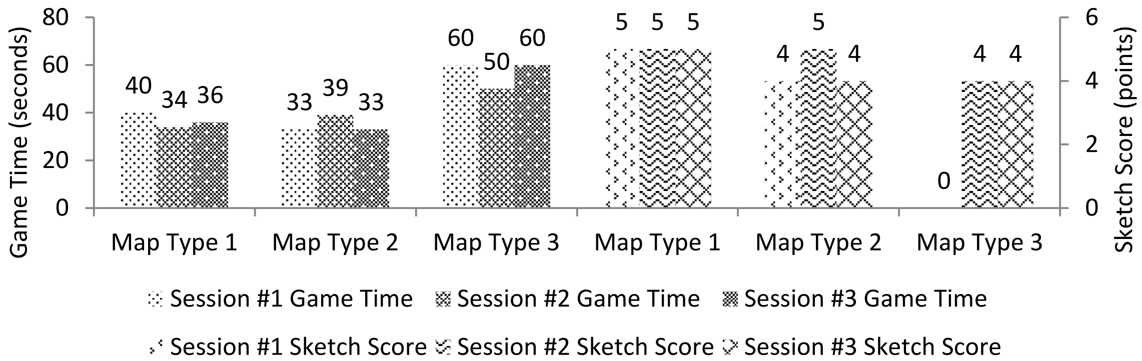

Figure 30: Participant #9 game time and sketch score.

4.10.10 Participant #10

Participant #10 was a 20-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 31 and Table 35 respectively. For the first session (M = 44.000, SD = 12.754) the participant took a longer time to complete the assessment levels compared to the second session (M = 40.000, SD = 11.045). In the third session (M = 42.667, SD = 13.021) the participant completed the assessment levels slower than the second session. During the first session (M = 4.000, SD = 0.816) the participant had a similar sketch score as the second session (M = 4.000, SD = 0.816). At the final session (M = 3.667, SD = 0.943) the participant sketch score was worse when compared to the previous session.

Based on the VROOM analysis of participant #10, he had a total domain score of 13 and a lifestyle score of 10 with an overall VROOM score of 23. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He travelled independently beyond home but if he got lost, he could usually work it out. He was aware of his own limitations, but he planned ahead, sourced information, and got help with his travel skills. His vision had its limitations, but he knew how to work with it. He knew where to find people and was linked in with some people or groups. He explored in his local community and liked to try different routes. He needed non-visual skills sometimes to provide some extra information. He could recognise people by their shape, colours, size, or gait, which allowed him to usually avoid collisions. His vision was useful for some things, but not for others. If he was close enough, he could identify large signs by text, size, shape, or colour.

Table 35: Statistical summary of participant #10 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	132	44.000	162.667	12.754
	#2	3	120	40.000	122.000	11.045
	#3	3	128	42.667	169.556	13.021
Sketch Score	#1	3	12	4.000	0.667	0.816
	#2	3	12	4.000	0.667	0.816
	#3	3	11	3.667	0.889	0.943

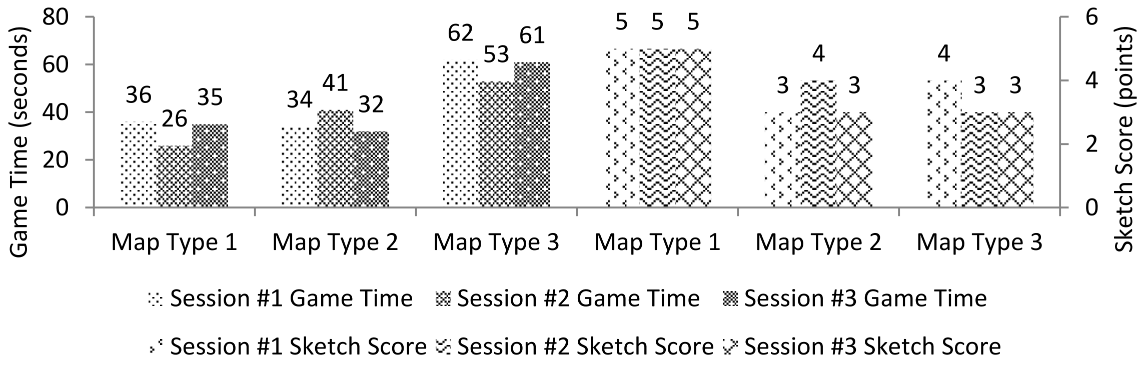

Figure 31: Participant #10 game time and sketch score.

4.10.11 Participant #11

Participant #11 was a 24-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 32 and Table 36 respectively. For the first session (M = 40.667, SD = 14.659) the participant took a longer time to complete the assessment levels compared to the second session (M = 40.333, SD = 12.284). In the third session (M = 40.667, SD = 16.680) the participant completed the assessment levels slower than the second session. During the first session (M = 2.667, SD = 2.055) the participant sketch score was lower than the second session (M = 3.333, SD = 2.357). At the final session (M = 3.000, SD = 2.160) the participant sketch score was worse when compared to the previous session.

Table 36: Statistical summary of participant #11 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	122	40.667	214.889	14.659
	#2	3	121	40.333	150.889	12.284
	#3	3	122	40.667	278.222	16.680
Sketch Score	#1	3	8	2.667	4.222	2.055
	#2	3	10	3.333	5.556	2.357
	#3	3	9	3.000	4.667	2.160

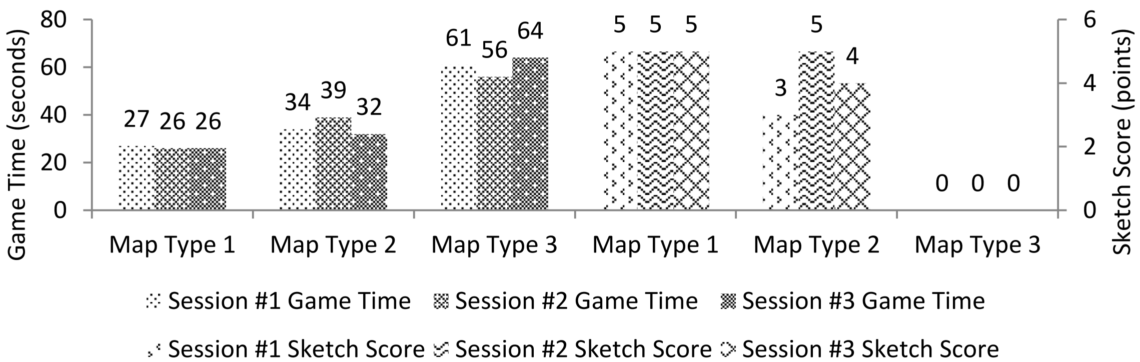

Figure 32: Participant #11 game time and sketch score.

Based on the VROOM analysis of participant #11, he had a total domain score of 15 and a lifestyle score of 10 with an overall VROOM score of 25. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He met with people regularly and generally felt welcomed and included. He travelled to known places beyond the local community. He travelled independently beyond home but if he got lost, he could usually work it out. He was aware of his own limitations, but he planned ahead, sourced information, and got help with his travel skills. His vision had its limitations, but he knew how to work with it. He needed non-visual skills sometimes and his vision does provide some extra information. He could recognise people by their shape, colours, size, or gait, which allowed him to usually avoid collisions. His vision was useful for some things, but not for others. If he was close enough, he could identify large signs by text, size, shape, or colour.

4.10.12 Participant #12

Participant #12 was a 32-year-old male volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 33 and Table 37 respectively. For the first session (M = 38.667, SD = 14.055) the participant took a shorter time to complete the assessment levels compared to the second session (M = 39.333, SD = 11.842). In the third session (M = 38.333, SD = 14.974) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant obtained a higher sketch score than the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #12, he had a total domain score of 11 and a lifestyle score of 10 with an overall VROOM score of 21. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He was aware of his own limitations, but he planned ahead, sourced information, and got help with his travel skills. His vision had its limitations, but he knew how to work with it. He could go without a mobility aid, but it gave him confidence, relieved fatigue, and expanded his options. He knew where to find people and was linked in with some people or groups. He travelled independently beyond home but if he got lost, he would rely on help from other people. He could recognise people by their shape, colours, size, or gait, which allowed him to usually avoid collisions. His vision was useful for some things, but not for others. He did routine travel but only in well-known local areas.

Table 37: Statistical summary of participant #12 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	116	38.667	197.556	14.055
	#2	3	118	39.333	140.222	11.842
	#3	3	115	38.333	224.222	14.974
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

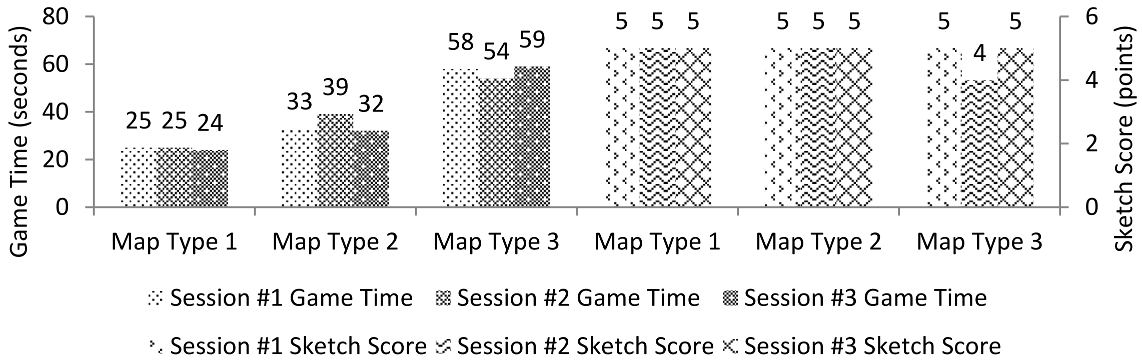

Figure 33: Participant #12 game time and sketch score.

4.10.13 Participant #13

Participant #13 was a 49-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 34 and Table 38 respectively. For the first session (M = 39.333, SD = 11.898) the participant took a shorter time to complete the assessment levels compared to the second session (M = 41.667, SD = 13.072). In the third session (M = 40.667, SD = 14.659) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 4.000, SD = 0.816) the participant obtained a higher sketch score than the second session (M = 2.667, SD = 1.886). At the final session (M = 4.333, SD = 0.943) the participant achieved a better sketch score compared to the previous session.

Table 38: Statistical summary of participant #13 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	118	39.333	141.556	11.898
	#2	3	125	41.667	170.889	13.072
	#3	3	122	40.667	214.889	14.659
Sketch Score	#1	3	12	4.000	0.667	0.816
	#2	3	8	2.667	3.556	1.886
	#3	3	13	4.333	0.889	0.943

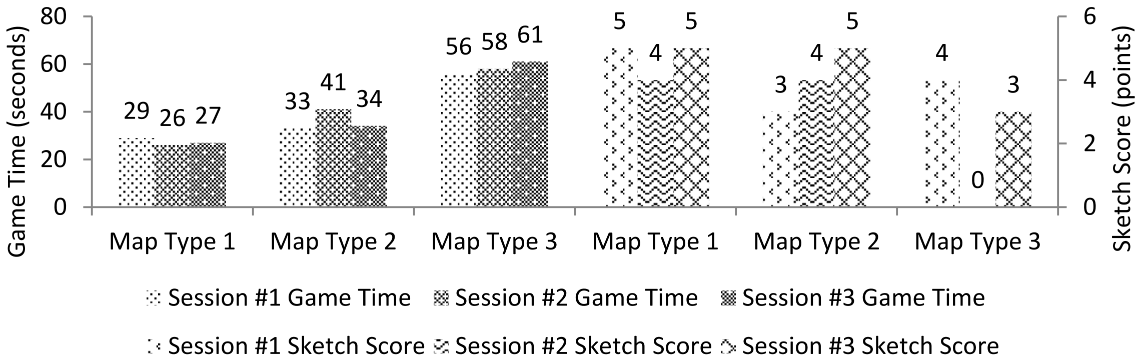

Figure 34: Participant #13 game time and sketch score.

Based on the VROOM analysis of participant #13, he had a total domain score of 8 and a lifestyle score of 0 with an overall VROOM score of 8. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He knew where to find people and was linked in with some people or groups. He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He needed travel restrictions because he was not always aware of what was safe and what was not.

4.10.14 Participant #14

Participant #14 was a 22-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 35 and Table 39 respectively. For the first session (M = 35.000, SD = 13.367) the participant took a shorter time to complete the assessment levels compared to the second session (M = 35.333, SD = 12.658). In the third session (M = 36.000, SD = 13.367) the participant completed the assessment levels slower than the second session. During the first session (M = 2.333, SD = 1.700) the participant had a similar sketch score as the second session (M = 2.333, SD = 1.700). At the final session (M = 2.667, SD = 2.055) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #14, he had a total domain score of 8 and a lifestyle score of 0 with an overall VROOM score of 8. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He knew where to find people and was linked in with some people or groups. He did routine travel but only in well-known local areas. He could find the way at home but beyond home, he needed a companion or he would get lost. He needed travel restrictions because he was not always aware of what was safe and what was not.

Table 39: Statistical summary of participant #14 game time and sketch score.

Data Type	***Session***	***Count***	***Sum***	***Average***	***Variance***	***Std. Deviation***
Game Time	#1	3	105	35.000	178.667	13.367
	#2	3	106	35.333	160.222	12.658
	#3	3	108	36.000	178.667	13.367
Sketch Score	#1	3	7	2.333	2.889	1.700
	#2	3	7	2.333	2.889	1.700
	#3	3	8	2.667	4.222	2.055

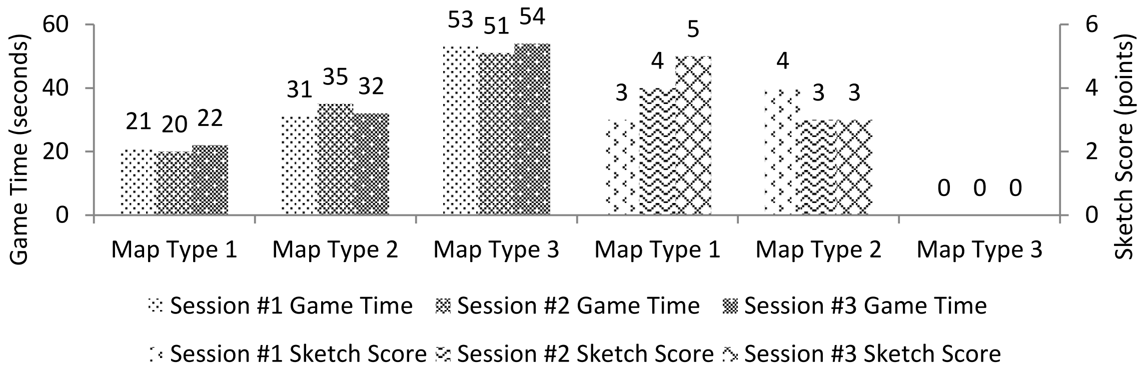

Figure 35: Participant #14 game time and sketch score.

4.10.15 Participant #15

Participant #15 was a 65-year-old male volunteer from SSB with visual impairment with no vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 36 and Table 40 respectively. For the first session (M = 65.667, SD = 20.726) the participant took a shorter time to complete the assessment levels compared to the second session (M = 71.333, SD = 13.275). In the third session (M = 56.000, SD = 8.524) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 1.333, SD = 1.886) the participant sketch score was lower than the second session (M = 1.667, SD = 2.357). At the final session (M = 1.667, SD = 2.357) the participant had the same sketch score as the previous session.

Based on the VROOM analysis of participant #15, he had a total domain score of 11 and a lifestyle score of 0 with an overall VROOM score of 11. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. He was satisfied with his current mix of activities. He knew where to find people and was linked in with some people or groups. He explored in his local community and liked to try different routes. He travelled independently beyond home but if he got lost, he would rely on help from other people. He was aware of his own limitations, but limit his travel rather than learning new skills.

Table 40: Statistical summary of participant #15 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	197	65.667	429.556	20.726
	#2	3	214	71.333	176.222	13.275
	#3	3	168	56.000	72.667	8.524
Sketch Score	#1	3	4	1.333	3.556	1.886
	#2	3	5	1.667	5.556	2.357
	#3	3	5	1.667	5.556	2.357

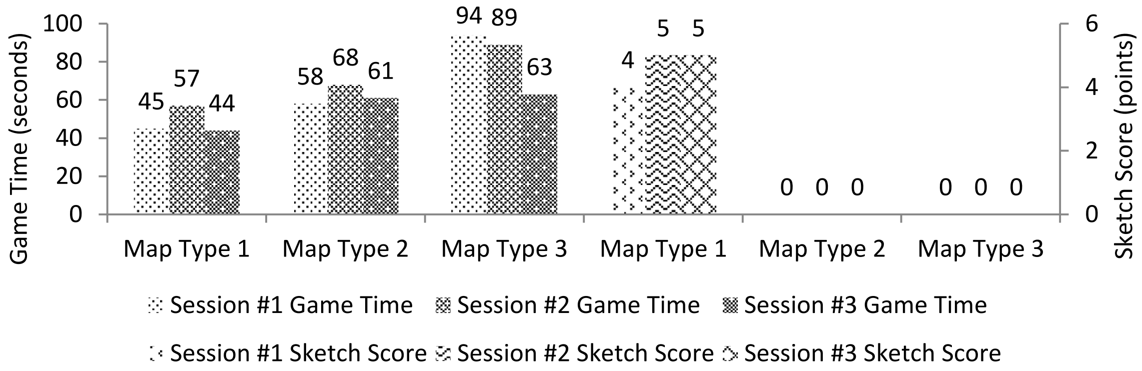

Figure 36: Participant #15 game time and sketch score.

4.10.16 Participant #16

Participant #16 was a 25-year-old female volunteer from SSB with visual impairment with low vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 37 and Table 41 respectively. For the first session (M = 36.667, SD = 12.120) the participant took a longer time to complete the assessment levels compared to the second session (M = 36.333, SD = 11.842). In the third session (M = 35.667, SD = 12.392) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant obtained a higher sketch score than the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session.

Based on the VROOM analysis of participant #16, she had a total domain score of 17 and a lifestyle score of 10 with an overall VROOM score of 27. The following VROOM analysis was based on the participant's experience within the past month from the experiment evaluation date. She found her current mix of activities challenging and enriching. She could go anywhere independently and with her, mental mapping skill was rarely disorientated for long. She met with people regularly and generally felt welcomed and included. She travelled to known places beyond the local community. She was aware of her own limitations, but she planned ahead, sourced information, and got help with her travel skills. Her vision had its limitations, but she knew how to work with it. She could see faces, but not details and sometimes missed some social cues. She needed non-visual skills sometimes because her vision does provide some extra information. Her vision was useful for some things, but not for others.

Table 41: Statistical summary of participant #16 game time and sketch score.

Data Type	***Session***	***Count***	***Sum***	***Average***	***Variance***	***Std. Deviation***
Game Time	#1	3	110	36.667	146.889	12.120
	#2	3	109	36.333	140.222	11.842
	#3	3	107	35.667	153.556	12.392
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

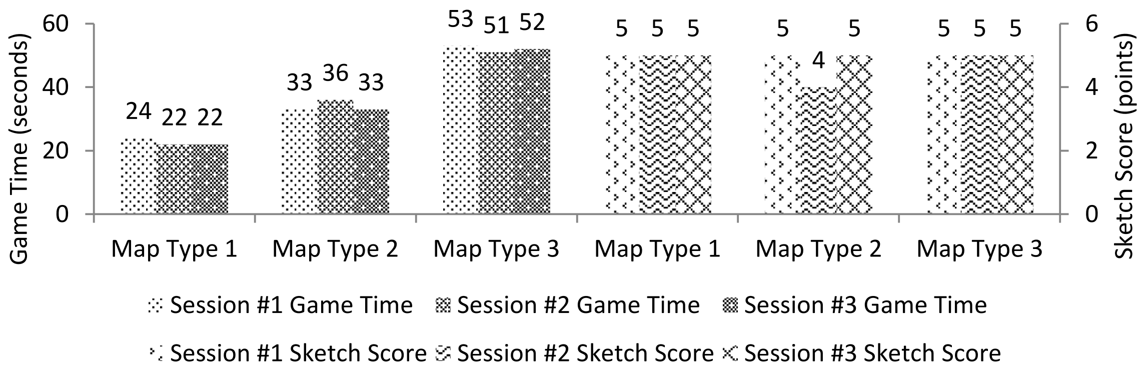

Figure 37: Participant #16 game time and sketch score.

4.10.17 Participant #17

Participant #17 was a 21-year-old female volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 38 and Table 42 respectively. For the first session (M = 53.000, SD = 13.880) the participant took a longer time to complete the assessment levels compared to the second session (M = 51.000, SD = 12.193). In the third session (M = 46.000, SD = 14.765) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant obtained a higher sketch score than the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 42: Statistical summary of participant #17 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	159	53.000	192.667	13.880
	#2	3	153	51.000	148.667	12.193
	#3	3	138	46.000	218.000	14.765
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

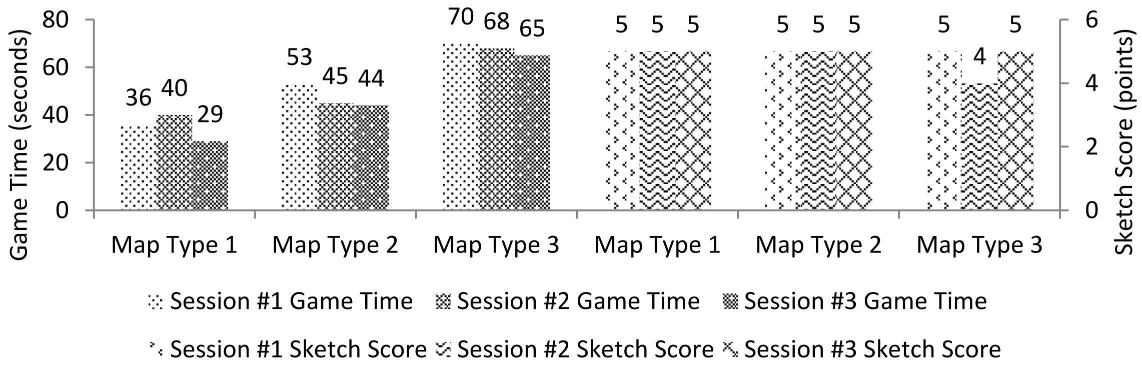

Figure 38: Participant #17 game time and sketch score.

4.10.18 Participant #18

Participant #18 was a 22-year-old male volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 39 and Table 43 respectively. For the first session (M = 47.333, SD = 8.957) the participant took a longer time to complete the assessment levels compared to the second session (M = 43.667, SD = 12.499). In the third session (M = 43.000, SD = 11.860) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 4.667, SD = 0.471) the participant had a similar sketch score as the second session (M = 4.667, SD = 0.471). At the final session (M = 5.000, SD = 0.000) the participant achieved a better sketch score compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 43: Statistical summary of participant #18 game time and sketch score.

Data Type	***Session***	***Count***	***Sum***	***Average***	***Variance***	***Std. Deviation***
Game Time	#1	3	142	47.333	80.222	8.957
	#2	3	131	43.667	156.222	12.499
	#3	3	129	43.000	140.667	11.860
Sketch Score	#1	3	14	4.667	0.222	0.471
	#2	3	14	4.667	0.222	0.471
	#3	3	15	5.000	0.000	0.000

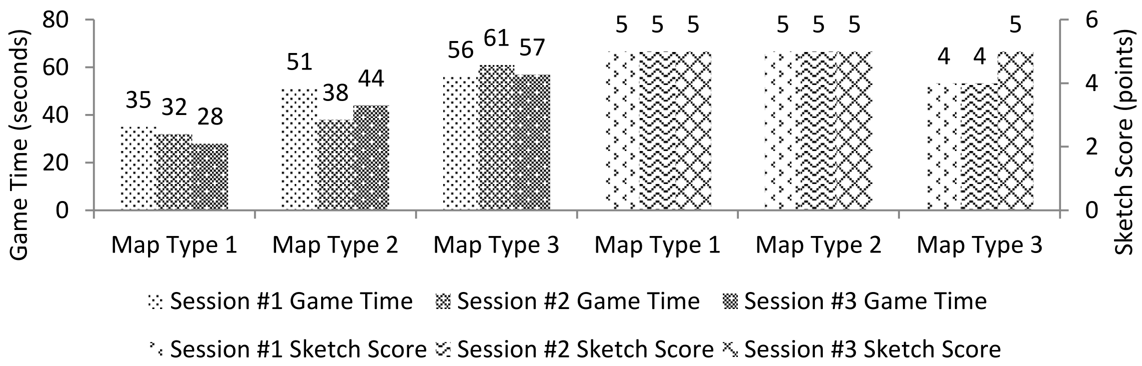

Figure 39: Participant #18 game time and sketch score.

4.10.19 Participant #19

Participant #19 was a 22-year-old female volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 40 and Table 44 respectively. For the first session (M = 52.333, SD = 11.585) the participant took a longer time to complete the assessment levels compared to the second session (M = 44.333, SD = 9.877). In the third session (M = 45.333, SD = 11.025) the participant completed the assessment levels slower than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 5.000, SD = 0.000) the participant had the same sketch score as the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 44: Statistical summary of participant #19 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	157	52.333	134.222	11.585
	#2	3	133	44.333	97.556	9.877
	#3	3	136	45.333	121.556	11.025
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	15	5.000	0.000	0.000

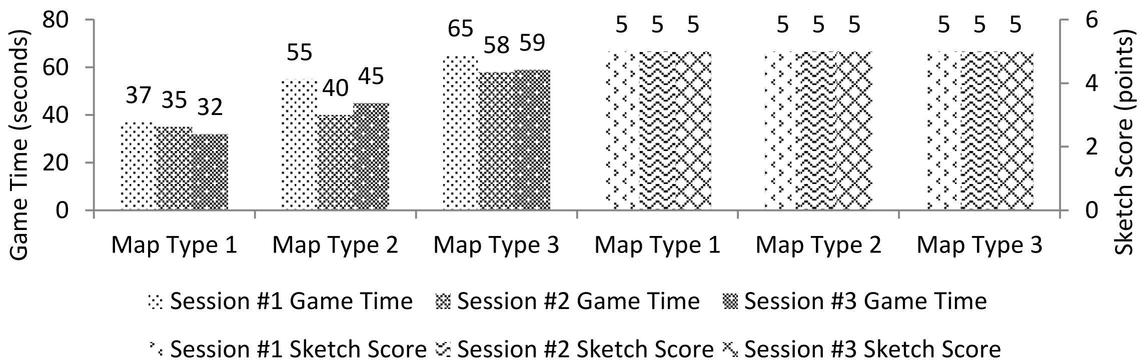

Figure 40: Participant #19 game time and sketch score.

4.10.20 Participant #20

Participant #20 was a 21-year-old female volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 41 and Table 45 respectively. For the first session (M = 48.000, SD = 9.201) the participant took a shorter time to complete the assessment levels compared to the second session (M = 51.667, SD = 13.719). In the third session (M = 51.333, SD = 9.978) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 4.667, SD = 0.471) the participant sketch score was worse when compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 45: Statistical summary of participant #20 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	144	48.000	84.667	9.201
	#2	3	155	51.667	188.222	13.719
	#3	3	154	51.333	99.556	9.978
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	14	4.667	0.222	0.471

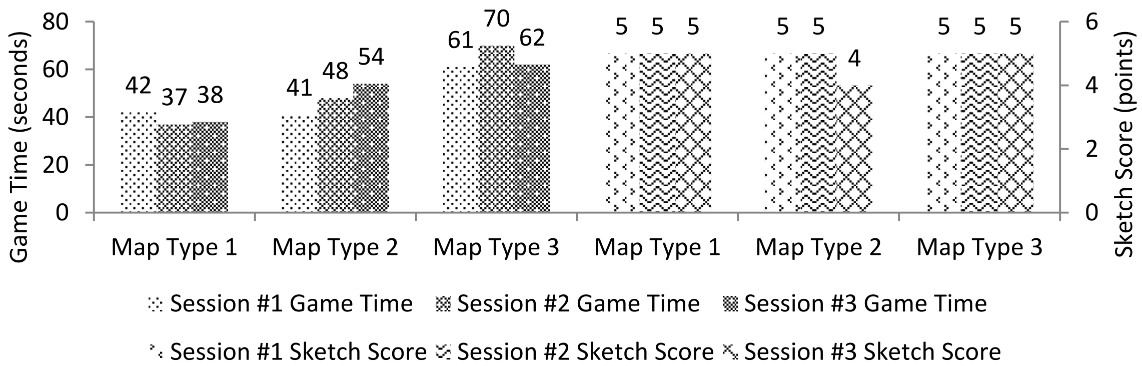

Figure 41: Participant #20 game time and sketch score.

4.10.21 Participant #21

Participant #21 was a 25-year-old male volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 42 and Table 46 respectively. For the first session (M = 64.333, SD = 13.912) the participant took a longer time to complete the assessment levels compared to the second session (M = 55.333, SD = 14.885). In the third session (M = 51.667, SD = 6.018) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 4.667, SD = 0.471) the participant sketch score was worse when compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 46: Statistical summary of participant #21 game time and sketch score.

Data Type	***Session***	***Count***	***Sum***	***Average***	***Variance***	***Std. Deviation***
Game Time	#1	3	193	64.333	193.556	13.912
	#2	3	166	55.333	221.556	14.885
	#3	3	155	51.667	36.222	6.018
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	14	4.667	0.222	0.471

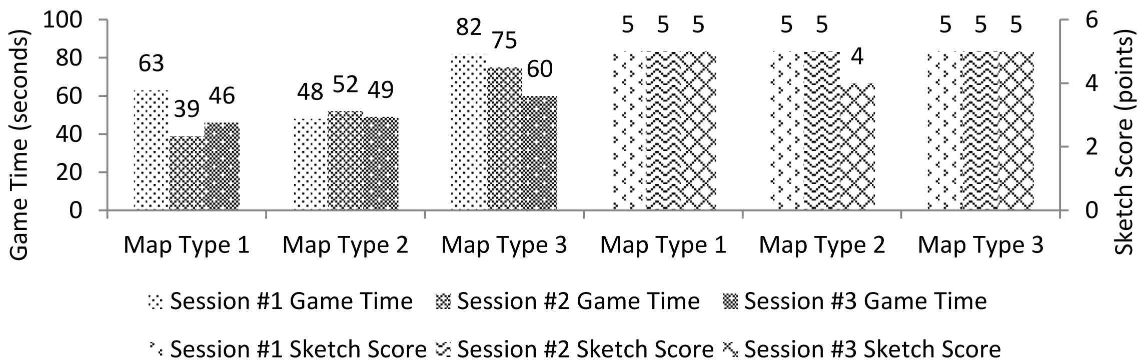

Figure 42: Participant #21 game time and sketch score.

4.10.22 Participant #22

Participant #22 was a 22-year-old male volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 43 and Table 47 respectively. For the first session (M = 51.667, SD = 23.697) the participant took a longer time to complete the assessment levels compared to the second session (M = 47.333, SD = 11.842). In the third session (M = 45.667, SD = 12.919) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 4.667, SD = 0.471) the participant sketch score was lower than the second session (M = 5.000, SD = 0.000). At the final session (M = 4.667, SD = 0.471) the participant sketch score was worse when compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 47: Statistical summary of participant #22 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	155	51.667	561.556	23.697
	#2	3	142	47.333	140.222	11.842
	#3	3	137	45.667	166.889	12.919
Sketch Score	#1	3	14	4.667	0.222	0.471
	#2	3	15	5.000	0.000	0.000
	#3	3	14	4.667	0.222	0.471

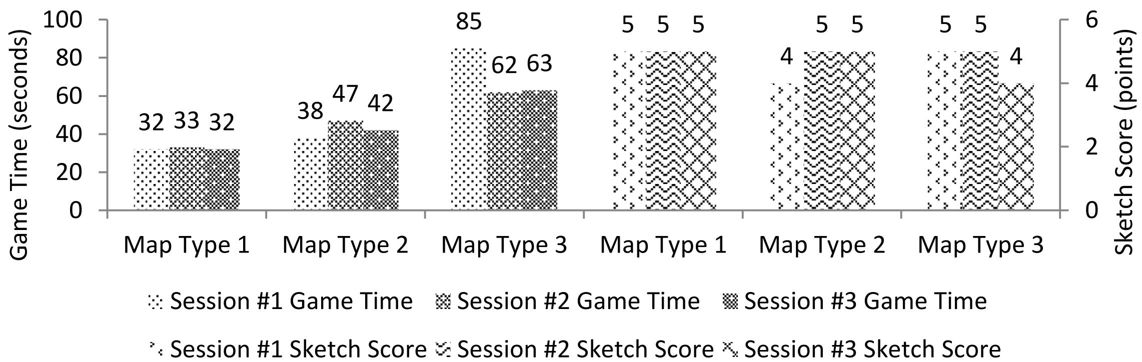

Figure 43: Participant #22 game time and sketch score.

4.10.23 Participant #23

Participant #23 was a 26-year-old female volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 44 and Table 48 respectively. For the first session (M = 63.667, SD = 14.430) the participant took a longer time to complete the assessment levels compared to the second session (M = 56.667, SD = 11.025). In the third session (M = 57.333, SD = 19.568) the participant completed the assessment levels slower than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 5.000, SD = 0.000) the participant had the same sketch score as the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 48: Statistical summary of participant #23 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	191	63.667	208.222	14.430
	#2	3	170	56.667	121.556	11.025
	#3	3	172	57.333	382.889	19.568
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	15	5.000	0.000	0.000

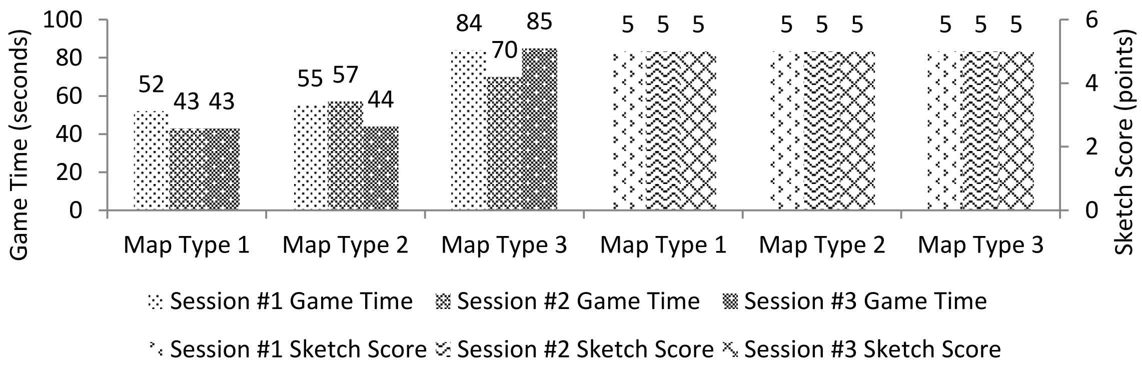

Figure 44: Participant #23 game time and sketch score.

4.10.24 Participant #24

Participant #24 was a 24-year-old male volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 45 and Table 49 respectively. For the first session (M = 63.333, SD = 7.587) the participant took a longer time to complete the assessment levels compared to the second session (M = 52.000, SD = 14.765). In the third session (M = 48.667, SD = 17.442) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 4.667, SD = 0.471) the participant sketch score was worse when compared to the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 49: Statistical summary of participant #24 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	190	63.333	57.556	7.587
	#2	3	156	52.000	218.000	14.765
	#3	3	146	48.667	304.222	17.442
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	14	4.667	0.222	0.471

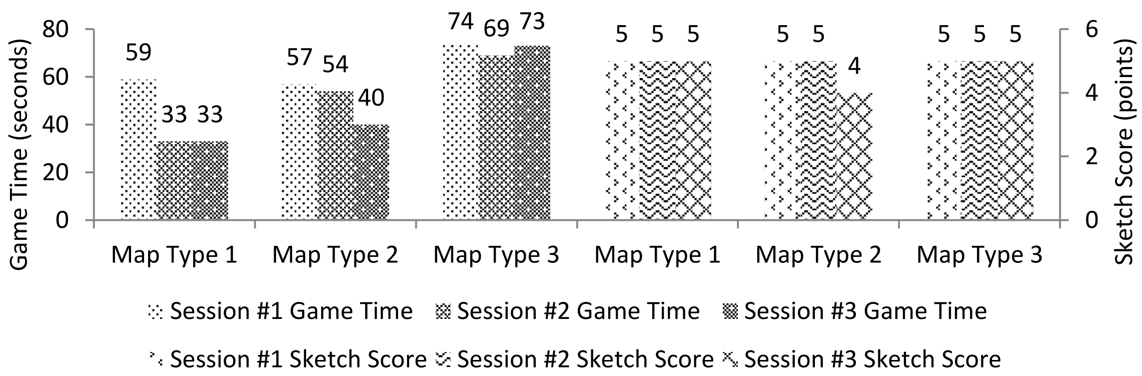

Figure 45: Participant #24 game time and sketch score.

4.10.25 Participant #25

Participant #25 was a 25-year-old female volunteer from SUTSC with normal vision. Data collected from the assessment sessions and its statistical summary as shown in Figure 46 and Table 50 respectively. For the first session (M = 58.333, SD = 12.658) the participant took a longer time to complete the assessment levels compared to the second session (M = 52.667, SD = 11.264). In the third session (M = 49.000, SD = 19.950) the participant was quicker to complete the assessment levels than the second session. During the first session (M = 5.000, SD = 0.000) the participant had a similar sketch score as the second session (M = 5.000, SD = 0.000). At the final session (M = 5.000, SD = 0.000) the participant had the same sketch score as the previous session. This participant was a sighted individual and hence did not partake in the VROOM assessment.

Table 50: Statistical summary of participant #25 game time and sketch score.

Data Type	*Session*	*Count*	*Sum*	*Average*	*Variance*	*Std. Deviation*
Game Time	#1	3	175	58.333	160.222	12.658
	#2	3	158	52.667	126.889	11.264
	#3	3	147	49.000	398.000	19.950
Sketch Score	#1	3	15	5.000	0.000	0.000
	#2	3	15	5.000	0.000	0.000
	#3	3	15	5.000	0.000	0.000

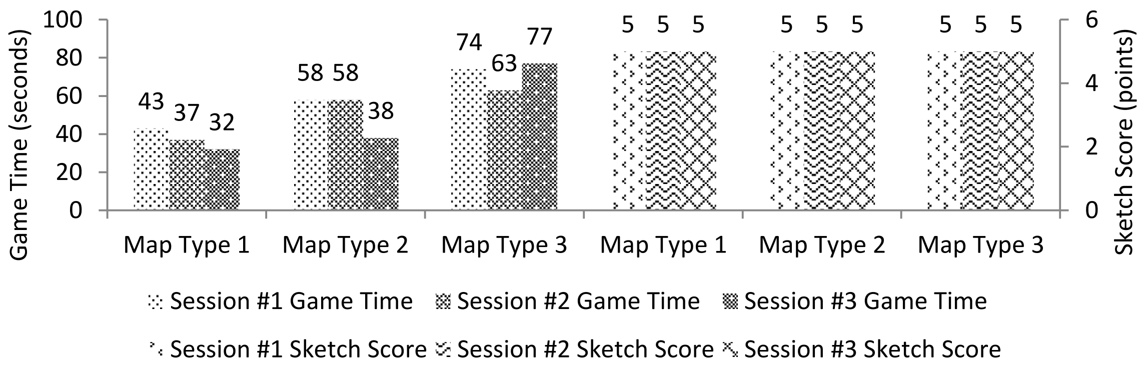

Figure 46: Participant #25 game time and sketch score.

4.11 Summary

Participants for the mental mapping skills assessment tool fall under three groups: those with visual impairments with no vision, visually impaired participants with low vision, and sighted participants. The research experiment was conducted over three sessions for each participant. In each session, the duration taken to complete the assessment tool and the sketch score were recorded. A statistical test called Analysis of Variance (ANOVA) was used to determine if the means of the two populations were equal. This study sought to determine whether a person's mental mapping would improve by repeating test over several short sessions. The null hypothesis states that the results are consistent for both game time and game score throughout the three assessment sessions while the alternative hypothesis states that the results differed for both game time and game score throughout the three assessment sessions.

For the visually impaired participants with no vision, the one-way ANOVA analysis for both the total game time and total sketch score on three separate sessions was not significant, $F(2, 21) = 0.553$, $p > 0.584$, and $F(2, 21) = 0.970$, $p > 0.395$ respectively. The visually impaired participants with low vision showed similar trend for their total game time and total sketch score, $F(2, 21) = 0.204$, $p > 0.817$ and $F(2, 21) = 0.175$, $p > 0.841$ respectively. In the case of the participants who were sighted, the one-way ANOVA for the total game time prove the results were significant, $F(2, 24) = 4.306$, $p > 0.025$. However this was not the case for the total sketch score as the analysis was not significant, $F(2, 24) = 0.667$, $p > 0.523$. When the participants' results were combined, the one-way ANOVA on the total game time was not significant, $F(2, 72) = 1.520$, $p > 0.226$ with a similar analytical conclusion on the total sketch score, which was not significant, $F(2, 72) = 0.355$, $p > 0.703$.

The correlation data showed strong positive average correlation coefficient for the total game time for the visually impaired group with no vision ($r = 0.836$), sighted group ($r = 0.767$), and when all data from participants were combined ($r = 0.864$). The visually impaired group with low vision indicated a moderately strong positive average correlation coefficient for the total game time ($r = 0.740$). The situation was different for the average correlation coefficient for the total sketch score. The visually impaired group with no vision showed a moderately strong positive ($r = 0.623$) average correlation coefficient while the visually impaired group with low vision exhibited a strong positive ($r = 0.895$) average correlation coefficient for the total sketch score. As for the sighted group, the average correlation coefficient for the total sketch score was a weak negative ($r = -0.020$). As a whole, the combined results from all the three groups presented a strong positive average correlation coefficient for the total sketch score.

As a whole, the combined result for all three groups of participant showed a small gain in improvements for both the total game time and total sketch score. Findings by others concluded that vision had an important role to play when updating or representing the spatial information that was encoded through our haptic sense and this have a vital effect on the development of neuronal areas that are involved in spatial memory (Pasqualotto and Newell, 2007; Pasqualotto and Proulx, 2012). This could explain the gained competency by the low vision and sighted participants throughout the assessment sessions as they became more familiar with the procedure of the assessment. The assessment tool presented thus measures the present mental mapping competency of the participants rather than improving it. Comparable findings were concluded by researchers that different types of feedback have a similar effect on spatial memory task for both the visually impaired and blindfolded-sighted participants (Postma *et al.*, 2007; Akpinar, Popović and Kirazci, 2012).

Chapter 5 Conclusions and Future Work

The thesis concludes with this final fifth chapter. The discussion of the results from the experiment and analytical efforts derived from chapter 4 and the limitation and recommendations for future directions are presented here. This thesis had investigated the mental mapping performance between three groups of participants using a computer-based assessment tool. By calculating the total game time and total sketch score of the participants, the results showed that the spatial cognitive skill of the participants did not improve significantly over the course of the experiment. The result was similar to that of earlier research experiments conducted when comparing the performance of sighted participants and age-matched visually impaired Braille readers (Grant, Thiagarajah and Sathian, 2000). The null hypothesis (H_0) was accepted, which stated that the participants' mental mapping skills did not improve even with a computer-based audio assisted assessment tool.

5.1 Overview

The one-way ANOVA result for the visually impaired for both their total game time and total sketch score showed an F value that was lower than its corresponding F critical value as shown in Table 17 and Table 18 for those with no vision while Table 19 and Table 20 showed the results for those with low vision. With a lower F value and the F critical value, this meant the result was not significant, which in turn showed that the developed computer-based mental mapping skill assessment tool did not improve the mental mapping capability of the participant. From past researchers, however, as the next few section will elaborate, the assessment tool developed for this thesis may have some usefulness for measuring or evaluating the mental mapping skills of an individual. In chapter 4, the results for the group with visual impairment with low vision and sighted participants have almost similar result in terms of improvements in their total game time and total sketch score. This can be explained by the findings from researchers on how the performance between sighted participants and age-match visually impaired Braille readers showed no greater advantage in one group or the other (Grant, Thiagarajah and Sathian, 2000; Postma *et al.*, 2007;

Akpinar, Popović and Kirazci, 2012). As for the sighted participants, their total game time showed an F value that was larger than the F critical value (Table 21) but the opposite for the total sketch score (Table 22). This could explain the gained competency of the sighted individual throughout the assessment sessions as they became more familiar with the procedure of the assessment. Previous findings concluded that vision had an important role to play when updating or representing the spatial information that is encoded through our haptic sense and this have a vital effect on the development of neuronal areas that are involved in spatial memory (Pasqualotto and Newell, 2007; Pasqualotto and Proulx, 2012).

When the participants' results were combined, the one-way ANOVA on the total game time was not significant, $F(2, 72) = 1.520$, $p > 0.226$ with a similar analytical conclusion on the total sketch score, which was not significant, $F(2, 72) = 0.355$, $p > 0.703$. In other words, the mental mapping of the participants does not improve over the short testing duration. This was in accordance with findings by researchers (Postma *et al.*, 2007; Akpinar, Popović and Kirazci, 2012) on the effect of different types of feedback on the spatial memory for visually impaired and blindfolded-sighted participants concluded that different types of feedback have a similar effect on spatial memory task for both groups.

However, there was a difference in the results between the first group and the second group of participants as shown in Table 16. In the first group, the participants with visual impairments with no vision had a lower VROOM score (Table 12) on average (M = 9.750, SD = 2.680) compared to the second group (M = 24.625, SD = 4.973), which consists of participants whom were visually impaired but with low vision (Table 13). This variance was noticeable in the in the outcome of the total game time and total sketch score between these two groups. This result was in line with a research study whereby the outcome was that the lack of visual experience might have an impact on executing spatial tasks especially when combinations of inputs are required from different modalities (Pasqualotto and Proulx, 2012).

In the group with no vision, their collective total game time (Table 9) (M = 125.100, SD = 30.320) average was slower than those of low vision (Table 10) (M = 114.300, SD = 10.080). The total sketch score for the no vision group had a lower average value (M = 7.292, SD = 3.335) compared to those with low vision (M = 12.460, SD = 2.798). The better performance in the low vision group could be due to the past or current experience that allows them to identify objects via visual mapping (Pasqualotto and Newell, 2007), which increases their chances of successfully mentally map the 2D virtual map of the assessment tool. For comparison, the sighted participants in the third group achieved a far superior total sketch score (Table 11) among the three groups (M = 14.700, SD = 0.457). In the case of the sighted participants from SUTSC, a majority of them have a total sketch score of 14 points and 15 points. To recap, the highest attainable score for total sketch score on each session was 15 points. Achieving a full score indicates that the participant was able to remember the exact path taken for all level of complexity for every session.

5.2 Contributions

This study extends the usefulness of spatial memory evaluation by implementing Stuart's tactile map test into a digital format. To achieve this objective a computer-based assessment tool developed to model the methodology used by Stuart was presented in this thesis. The 2D map was part of the assessment tool, which captured the game time to determine how fast a participant complete a particular level as well as the game score to check on the number of mistakes that the participant made. The assessment tool implemented a various level of challenging maps that were designed in order to test out the participant's mental mapping skills.

A gamification of the assessment tool was put in place to keep the participant engaged. The software was developed as a game in which the participant needs to navigate a virtual 2D map to reach the destination. With the help of auditory feedback in the game, the participant was guided around the virtual 2D map while attempting to remember the path that was taken. A traffic light system used as a means of distraction was implemented in an attempt to interrupt the participant's attention on the game. The computer-based assessment tool represents only the first part of the research study program. In the other half, the participants were asked to draw out the path that was taken, for that particular level. A scoring system based on Stuart Tactile Map Test was used to evaluate how well a participant recalls the route taken. This, combined with the game time from the assessment tool was used to assess the improvement, if any, on the participant's mental mapping skills over the course of the research program.

The results from the intervention presented in this research study constituted a major part of the contribution. By analysing the game time and game score from the assessment tool as well as the sketch score, two hypotheses were evaluated to find out if either one of them was accepted. One hypothesis (H_1) states that the participant mental mapping skills do improve during the duration of the research study. For this to be true there should be a decrease in the total game time needed to complete each session, along with a better game score, and total sketch points. On the other hand, if no improvements were seen in the analysis of the results, then the null hypothesis (H_0) is not rejected. In this thesis, an assessment tool for mental mapping skill evaluation was introduced. The tool evaluates individual mental mapping skills by measuring the total game time and total sketch points over three sessions.

This thesis makes a number of research contributions regarding the assessment of mental mapping skills with a computer-based software by answering the research questions presented in the earlier chapter. Developing a computer-based mental mapping skills assessment tool was deemed feasible as the software was proven easy to use during the evaluation phase. All that was needed was a laptop and an external keyboard for the input to allow participants to move the virtual character around the 2D virtual map. The game score and game time were tracked by the software, which allowed the recording of the evaluation results with minimum effort. Changing between levels was done within seconds and with a click of a button, literally. This reduces the wait times in between levels and reduces the time wasted to switch between different maps such as the ones encountered by researchers using the 3D physical board (Meyer, Deverell, Stuart, Theng, Hou, *et al.*, 2017).

The criteria for a good computer-based mental mapping skills assessment tool tied closely with the feasibility of having one. The development of the assessment tool should focus on the ease of its deployment and evaluation. Having easy access to the computer-based assessment tool for mental mapping skills is one of the criteria. In order to realize this, the software had low hardware requirements with an easy-to-read user interface. This allows the instructor to carry out the assessment sessions with little interruption. Hence, the criteria for a good computer-based assessment tool for mental mapping skills were for it to be easy to use and efficient to deploy.

Our alternative hypothesis (H_1) states that the participant mental mapping skills improve over the duration of the research study. This was seen in the decreased total game time to complete each session as well as an increase in both the total game score and total sketch points over the same period. As for the null hypothesis (H_0), if the participants' mental mapping skills do not improve after intervention the null hypothesis is not rejected. The results from the assessment tool revealed that the spatial cognitive skill of the participants in our research study remains consistent which did not improve over the sessions. Thus, it answered the research question by confirming that the mental mapping skills of the participant would be consistent over the duration of the assessment that is $H_0: \mu_1 = \mu_2 = \mu_3$.

5.3 Limitation and Future Work

Throughout the research study of this thesis, there were several aspects that limit the current work and one of this, in particular, was the difficulty in recruitment of participants with a wide spectrum of background. Finding visually impaired participants who were willing to volunteer for the research study had proven daunting as the population of visually impaired were scattered all over the city. For future work, it is best to set aside three to four months as the recruitment schedule to identify the participant types and the location of recruitment. In doing so, there would be ample time to plan for the assessment session and the research study would be carried out with minimal interruptions.

The other limitation was in the environment to conduct the experiment, which must be quiet so the participant could hear the auditory feedback given by the assessment tool. A headphone could be provided but bear in mind that this may not be a hygienic option, as it would be shared among other participants. If a headphone or headset were used, it should be cleaned thoroughly after each session for the comfort of the next participant. Earphones are strongly discouraged because these devices are inserted at the opening of the ear canal, which contains wax built-up and thus makes sharing them unhygienic. The current assessment session was fortunately conducted within an environment with low noise pollution, that being the conference room when conducted for the visually impaired participants and the campus discussion room for the sighted participants. Both these sites offer a quiet surrounding to carry out the research experiment.

For future work on this computer-based mental mapping skills assessment tool, future researchers should explore the possibility of adding more complex map levels. This will stretch and test the mental mapping skills of those with very high proficiency in the subject area to see the extent to which a human would do. Additional obstacles could be added to make navigating the 2D virtual map harder for the participant. This has a similar effect as the traffic light, which was meant to break the concentration of the participants. The more obstacles that the participant will need to take into consideration, the less likely they are able to focus on the 2D virtual map. The same applies to real life when one is occupied with multiple tasks at hand, it would prove difficult to concentrate on another task as their attention spans are diverted into several areas. The software could also be improved by having a more pleasant user interface, which is purely aesthetic for the better enjoyment of the players. Another area to improve is to have different language options available for the player to choose. Having a wide range of spoken languages will make the assessment tool more accessible to a larger population in other countries where Bahasa Melayu is not one of their spoken languages.

5.4 Summary

For the visually impaired, orientation and mobility training is a form of a recovery program that is intended for recently visually impaired individuals or those with a substantial loss in their vision to improve their cognitive mapping skill or mental mapping. Our reliance on mental mapping is fundamental to help us find our way around an environment but not limited to remembering the location of things that are close by. In the current market, there exists a variety of orientation and mobility devices that an individual with visual impairment can use to assist them in navigating their environment and in the more recent decade, with the advancement of digital technology, researchers were introducing innovations in the virtual world. An example was the Audio-based Environment Simulator software, which lets the participants explore an existing building but in a virtual world, which is set in an action video game metaphor (Connors *et al.*, 2014).

Training exercises conducted in a virtual environment can be used to provide people with visual impairment a place to improve their cognitive navigation skills (Sánchez, Saenz and Garrido, 2010). This aligns with the research topic of this thesis, which is on the assessment of mental mapping skill with Stuart's tactile map test as a base point. Stuart's method was conducted with a physical product (Ian Stuart, 1995; Meyer, Deverell, Stuart, Theng, Hou, *et al.*, 2017; Meyer, Deverell, Stuart, Theng, Ling, *et al.*, 2017) and there is some inherent potential problem with this concept. The first problem is that during the evaluation, keeping track of the maps and swapping them in between sessions may cause delay and even confusion while the sessions were on-going. If the number of maps was to increase, the instructor would need to keep track of them all and with as the maps increase the physical size of the total maps that need to be kept track of would scale with it. Transporting these physical maps from one location to another may cause misplaced or damaged maps. The other problem with physical maps is that they were hard to create or produce when a different layout is needed or if an error is made in one of the design. Having a computer-based version of these maps allowed any addition and modification needed for the map to be conducted with minimum effort. Furthermore, with the setup to retrieve updates over the internet, any changes to the assessment tool could be carried out at any place in the world.

The design and development of the assessment tool, which was used to evaluate the mental mapping skills of an individual were presented in the earlier chapter. The goal of this assessment tool is to evaluate the mental mapping skills of the player. To do this there were two measurements taken in the experiment. The first was the game time that each participant was required to complete the assessment level and for the last step, the participant needs to draw out the path that they have just taken. The sketch path direction needs to match the level path for it to be counted as correct. The assessment tool was designed as a game for the participant to play. The participant was sitting facing opposite the instructor, with the laptop that was used to run the assessment tool facing the instructor. What was available for the participant to interact with was an external keyboard used as an input to the assessment tool.

The assessment tool is a computer-based software that takes place in a virtual 2D environment. The map design was based on Stuart Tactile Maps Test (Ian Stuart, 1995) which was originally developed to test a person's ability to learn spatial information and stay orientated during mobility. It showed the number of attempts a person needs to practice to get it right. The results from Stuart's test can be equated with active coordination skills observed throughout functional orientation and mobility assessment. Each map design was a modification of Stuart's test and it follows the number of paths based on the original map. The main modification was the addition of traffic lights as a method to distract the concentration of the participants. The initial design includes game score as a third measurement variable but after the experiment, it was noted that this was hardly used because a majority of the time the participant scored 100 or the full score of the assessment level. Each map is more difficult than the previous with increasing complexity on the number of lines. With the design of the assessment tool complete, the actual software was realized and ready for implementation. Participants of both those who were visually impaired and sighted were recruited for the research experiment.

The result of this research showed that if an individual had poor mental mapping skills, the results were consistent over an observable duration of time, which in the case of this thesis was within several days. By analysing the game time and game score from the assessment tool as well as the sketch score, two hypotheses were evaluated to find out if either one of them is accepted. The null hypothesis H_0, states that the assessment results do not show any changes for both the total game time and total game score throughout the three sessions. The alternative hypothesis H_1 (1), theorizes that the assessment results would show changes for both the total game time and total game score during the course of the evaluation sessions.

Regardless of the state of visual acuity of individuals, the spatial cognitive memory varies with each individual. Research showed that participants with higher levels of mathematical fluency scored better for spatial thinking efficiency and spatial memory on average, compared to participants of lesser mathematical articulacy (Tikhomirova, 2017). Hence, the null hypothesis (H_0) was accepted because the results indicated the participant's spatial cognitive skill did not change dramatically. The understanding of arithmetic operations and the various aspects of mathematical knowledge could be associated with the performance spatial memory (Zorzi, Priftis and Umiltà, 2002). The alternative hypothesis (H_1) of this study that the participant's mental mapping skills would improve after evaluation with a computer-based audio assisted assessment tool is rejected as the mental mapping skills of an individual depended on their capability and does not improve within a short frame of time. As a conclusion, the mental mapping skills of an individual can be measured using this assessment tool, which was based on Stuart Tactile Maps Test, showing that an individual's mental mapping skills are unique to each.

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Appendices

1. Critical values for the F-Distribution (α = 0.05)

Denominator DF	Numerator, Degrees of Freedom (DF)						
	1	2	3	4	5	6	7
1	161.448	199.500	215.707	224.583	230.162	233.986	236.768
2	18.513	19.000	19.164	19.247	19.296	19.330	19.353
3	10.128	9.552	9.277	9.117	9.013	8.941	8.887
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094
5	6.608	5.786	5.409	5.192	5.050	4.950	4.876
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787
8	5.318	4.459	4.066	3.838	3.687	3.581	3.500
9	5.117	4.256	3.863	3.633	3.482	3.374	3.293
10	4.965	4.103	3.708	3.478	3.326	3.217	3.135
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764
15	4.543	3.682	3.287	3.056	2.901	2.790	2.707
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514
21	4.325	3.467	3.072	2.840	2.685	2.573	2.488
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334
31	4.160	3.305	2.911	2.679	2.523	2.409	2.323
32	4.149	3.295	2.901	2.668	2.512	2.399	2.313
33	4.139	3.285	2.892	2.659	2.503	2.389	2.303
34	4.130	3.276	2.883	2.650	2.494	2.380	2.294
35	4.121	3.267	2.874	2.641	2.485	2.372	2.285
36	4.113	3.259	2.866	2.634	2.477	2.364	2.277
37	4.105	3.252	2.859	2.626	2.470	2.356	2.270
38	4.098	3.245	2.852	2.619	2.463	2.349	2.262

Denominator DF	Numerator, Degrees of Freedom (DF)						
	1	**2**	**3**	**4**	**5**	**6**	**7**
39	4.091	3.238	2.845	2.612	2.456	2.342	2.255
40	4.085	3.232	2.839	2.606	2.449	2.336	2.249
41	4.079	3.226	2.833	2.600	2.443	2.330	2.243
42	4.073	3.220	2.827	2.594	2.438	2.324	2.237
43	4.067	3.214	2.822	2.589	2.432	2.318	2.232
44	4.062	3.209	2.816	2.584	2.427	2.313	2.226
45	4.057	3.204	2.812	2.579	2.422	2.308	2.221
46	4.052	3.200	2.807	2.574	2.417	2.304	2.216
47	4.047	3.195	2.802	2.570	2.413	2.299	2.212
48	4.043	3.191	2.798	2.565	2.409	2.295	2.207
49	4.038	3.187	2.794	2.561	2.404	2.290	2.203
50	4.034	3.183	2.790	2.557	2.400	2.286	2.199
51	4.030	3.179	2.786	2.553	2.397	2.283	2.195
52	4.027	3.175	2.783	2.550	2.393	2.279	2.192
53	4.023	3.172	2.779	2.546	2.389	2.275	2.188
54	4.020	3.168	2.776	2.543	2.386	2.272	2.185
55	4.016	3.165	2.773	2.540	2.383	2.269	2.181
56	4.013	3.162	2.769	2.537	2.380	2.266	2.178
57	4.010	3.159	2.766	2.534	2.377	2.263	2.175
58	4.007	3.156	2.764	2.531	2.374	2.260	2.172
59	4.004	3.153	2.761	2.528	2.371	2.257	2.169
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167
61	3.998	3.148	2.755	2.523	2.366	2.251	2.164
62	3.996	3.145	2.753	2.520	2.363	2.249	2.161
63	3.993	3.143	2.751	2.518	2.361	2.246	2.159
64	3.991	3.140	2.748	2.515	2.358	2.244	2.156
65	3.989	3.138	2.746	2.513	2.356	2.242	2.154
66	3.986	3.136	2.744	2.511	2.354	2.239	2.152
67	3.984	3.134	2.742	2.509	2.352	2.237	2.150
68	3.982	3.132	2.740	2.507	2.350	2.235	2.148
69	3.980	3.130	2.737	2.505	2.348	2.233	2.145
70	3.978	3.128	2.736	2.503	2.346	2.231	2.143
71	3.976	3.126	2.734	2.501	2.344	2.229	2.142
72	3.974	3.124	2.732	2.499	2.342	2.227	2.140

2. VROOM Questionnaires

Domains	Score according to discussion about skills, attitudes and activities **within the past month**	**Comments & Score**
Activities	0 I find activities overwhelming 1 My mix of activities is not quite right. I don't know how to fix it; or I'm not yet ready for change 2 I like some of my activities, but I'm ready for new directions 3 I'm satisfied with my current mix of activities 4 I find my mix of activities challenging and enriching	/4
Connections	0 I feel isolated and lonely; I'm not sure who to connect with 1 I feel quite dependent on others to take me out, or do things for me 2 I know where to find people; I'm linked in with some people or groups 3 I meet with people regularly; I feel welcomed and included 4 I actively contribute; I have mutual friendships; we're there for each other	/4
Life-space	0 I'm house-bound; I rarely go beyond the front gate 1 I do routine travel, only in well-known local areas (e.g., home block, local shops) 2 I explore in my local community; I like to try different routes 3 I travel to known places beyond the local community (e.g. commuting for work, visiting friends) 4 I like to explore beyond the local community, discovering new places	/4
Orientation	0 Even at home, I get lost and need help; I have trouble understanding shapes, angles, & distances 1 I can find the way at home; beyond home, I need a companion or I get lost 2 I travel independently beyond home; if I get lost, I rely on help from other people 3 I travel independently beyond home; if I get lost, I can usually work it out by myself 4 I can go anywhere independently; I use mental mapping and I'm rarely disorientated for long	/4
Agency	0 My travel is managed by other people; I don't make the decisions 1 I need travel restrictions – I'm not always aware of what's safe and what is not 2 I'm aware of my own limitations, but I limit my travel rather than learning new skills 3 I'm aware of my own limitations; I plan ahead, source information and get help with my travel skills 4 I'm in charge; I evaluate my travel and learn from experience as I go; I develop my own skills	/4
RECOMMENDATIONS		Total Score: /20

Part B: Lifestyle	Score together from observations and discussion about activities **within the past month**	**Comments & Score**
Reading	0 I have no useful vision for reading text 1 If I'm close enough, I can identify large signs (e.g., stop sign) by text, size, shape, colour 2 I can sometimes read vehicle number plates & shop signs 3 I can sometimes identify different foods by looking at text and packaging (e.g., types of milk) 4 I can read regular print (i.e., letters, N12)	**/4**
Visual certainty	0 My vision is never useful when I'm moving around; too little, too late 1 I can't rely on my vision when I'm doing things 2 My vision causes hesitation and frustration; it undermines confidence when I'm moving 3 My vision has its limitations, but I know how to work with it 4 My vision is reliable for travel; I don't really have to think about it much	**/4**
Mobility aids (beyond home)	0 I use non-visual skills (cane/dog/guide) beyond home – my vision is useless 1 I rely on my cane/dog/guide – vision provides some extra information 2 I need non-visual skills sometimes (e.g., night travel, fluctuating vision) 3 I can go without it, but a mobility aid gives me confidence, relieves fatigue, expands my options 4 My vision is good enough for travel – I don't need a mobility aid	**/4**
People	0 I can't see people's shapes or movement; or see if a conversation partner moves away 1 I can see a body moving past, but I can't tell who it is; I sometimes collide 2 I can recognise people by their shape, colours, size or gait; I can usually avoid collisions 3 I can see faces, but not details; I do miss some social cues 4 I can recognise faces, read facial expressions and social cues	**/4**
Pleasure	0 My vision is un-motivating; it rarely or never prompts a closer look 1 My vision is limited or frustrating; often more trouble than it is worth 2 My vision is useful for some things, but not for others 3 I can see interesting things; it is usually worth the time it takes to look 4 I can see beautiful or engaging things that bring calm, contentment, excitement, even bliss	**/4**
RECOMMENDATIONS		**Total Score: /20**

3. Ethics Clearance

From:	Astrid Nordmann
To:	Denny Meyer
Cc:	RES Ethics; Lil Deverell
Subject:	SHR Project 2016/316 - Ethics clearance
Date:	Monday, 20 February 2017 8:12:22 AM
Attachments:	image001.png

To: A/Prof. Denny Meyer, FHAD

Dear Denny,

SHR Project 2016/316 – Optimising technology to measure functional vision, mobility and service outcomes for people with low vision or blindness
A/Prof. Denny Meyer *et al* - FHAD
Approved duration: 20-02-2017 to 18-10-2020 [adjusted]

I refer to the ethical review of the above project protocol by Swinburne's Human Research Ethics Committee (SUHREC). Your response to the review, as emailed on 09 February 2016, accords with the Committee review.

I am pleased to advise that, as submitted to date, the project may proceed in line with standard on-going ethics clearance conditions outlined below.

- The approved duration is 20 February 2017 to 18 October 2020 unless an extension request is subsequently approved.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research* and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor, and addition or removal of other personnel/students from the project, requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring and variations/additions, self-audits and progress reports can be found on the Research Ethics Internet pages.

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance, citing the Swinburne project number. A copy of this email should be retained as part of project record-keeping.

Best wishes for the project.

Yours sincerely

Astrid Nordmann
Secretary, SUHREC

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4. Participation Information for Client

Participant Information – Clients

"Optimising technology to measure functional vision, mobility and service outcomes for people with low vision or blindness"

SWINBURNE UNIVERSITY OF TECHNOLOGY

Swinburne-Melbourne Research Team: Prof Denny Meyer (principal investigator, statistics), Dr Lil Deverell (project manager, O&M specialist), Dr Amirul Islam (statistics, research design), Dr Jahar Bhowmik (statistics, research design), A/Prof Andrew Pipingas (research design), Dr Abdullah Al Mahmud (tech design), Dr Chris McCarthy (tech design), Dr Suku Sukunesan (research design). Swinburne-Sarawak: A/Prof Bee Theng Lau (PhD coordinator), Dr Almon Chai (tech design), Dr Pan Zheng (tech design), Aylwin Chai Bing Chun (PhD student)

1. Invitation

You are invited to help test two new assessment tools that measure your functional vision and orientation and mobility (O&M) skills. Both these tools produce a score out of 50, supported by your comments. **VROOM** (Vision-Related Outcomes in Orientation and Mobility) measures your functional vision during travel, and **OMO** (Orientation and Mobility Outcomes) measures your functional O&M skills.

2. What is this project about?

The VROOM and OMO tools measure your skills in everyday situations so that the functional outcomes of training or treatment can be compared. The VROOM and OMO tools are designed for use with anyone, any age, anywhere in the world. We hope to prove that these tools work with all kinds of people, including those who have no vision, low vision, or lots of vision; and those who travel independently, or with the support of others.

Swinburne University is funding this two-year O&M project to promote Digital Health, and so the project has a tech-focus. Researchers are particularly interested in ways that you use technology or would like to use technology to support travel, so that they can design smart-tech solutions that address specific O&M problems.

3. What will your participation involve?

There are no monetary costs involved in participation. At the end of an ordinary O&M assessment you join your O&M professional in a rating conversation where you score your functional vision and O&M skills together using the VROOM and OMO tools. Others who matter to you can join in this conversation too. You are welcome to provide feedback to improve the VROOM and OMO tools. Your VROOM/OMO data will be de-identified before being forwarded to Swinburne for analysis. With your consent, Swinburne plans to record some assessments so that video, audio and photo data can be included in online training for O&M professionals, and in project publications and presentations.

4. Benefits and risks

You will gain a score for your functional vision and mobility skills, and a common language to discuss functional vision and O&M with family, friends, professionals, and others who matter to you. This project will involve no risks to you beyond ordinary functional assessment where you show the assessor the everyday things that you do in the ordinary places that you go.

5. Informed consent and privacy

Participation in this project is voluntary. You can give either written or verbal consent to your assessment data being used. You are free to withdraw from participation, including your data, without question or explanation at any time.

Functional O&M assessment happens in the public domain where privacy cannot be guaranteed. You might be identified from video, audio, or photographs, and so sessions will only be recorded with your documented consent; you can opt out of recording and can withdraw your consent for use of media content at any time. Parents or guardians will need to sign consent for minors or participants under their care, whether or not assessment sessions are recorded.

6. Research output

After the study, the Swinburne team will provide a report to each agency involved. The O&M agencies may use content to review services, make selected findings publicly available, or publish the whole

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professionals, smart-technology to support clients' O&M, and publish findings from the project in media releases, peer-reviewed journal articles, and conference presentations. The data from this project are also likely to be used in future research projects, and contribute towards policy development.

7. Further information

If you would like further information about the project, please do not hesitate to contact:

Lil Deverell, Project Manager
Room ATC931, Swinburne University of Technology
P O Box 218, HAWTHORN VIC 3122
Mobile: 0418 370 312
ldeverell@swin.edu.au

This project has been approved by Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 3845 or +61 3 9214 3845 or resethics@swin.edu.au

5. Client/Participant Consent Form

Client/Participant Consent Form

"Optimising technology to measure functional vision, mobility and service outcomes for people with low vision or blindness"

Principal Investigator: Prof Denny Meyer; **Project Manager:** Dr Lil Deverell

1. I consent to participate in the project named above. I have been provided a copy of the project information statement to which this consent form relates, and questions have been answered to my satisfaction.
2. I acknowledge that:
   - the Swinburne project is for research and not for profit; and
   - my participation is voluntary and that I am free to withdraw from the project at any time without explanation.
3. I understand that assessment data about my functional performance generated in this project will be
   - de-identified before being forwarded to Swinburne;
   - retained, accessed and analysed by Swinburne for the purpose of this project;
   - available for use in future research projects; and
   - I will not be named in publications or otherwise without my express written consent.
4. I understand that,
   - with my prior permission, assessment session/s may be recorded;
   - I might be identifiable in video, audio or photographs from the project, even if not named;
   - I am free to withdraw permission to use media content identifying me, at any time, without explanation;
   - withdrawing media consent, or opting out of recording will have no bearing on my eligibility for O&M services.
5. **Permission**

   In relation to this project, please circle your response to the following:

▪ I agree to participate in O&M assessment/s using the new functional assessment tools.	**Yes**	**No**
▪ I agree for my de-identified assessment data to be used in this project and related research projects.	**Yes**	**No**
▪ I agree to allow my assessment/s to be recorded by electronic device.	**Yes**	**No**
▪ I agree to allow video, audio and photos of me to be used in online training, publications and presentations relating to the project.	**Yes**	**No**
▪ I agree to make myself available for further information if required.	**Yes**	**No**

Name of Participant: ....

Name of Witness: ....

Signature of participant, or signature of witness to verbal agreement **Date:**

....

Participant information and consent forms v2, 20Jan2017