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Using Proprioception to Support Menu Item Selection in Virtual Reality

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Declaration

I declare that the Masters dissertation, which I hereby submit for the degree MIS (Multimedia) at the University of Pretoria, is my own work and has not been previously submitted by me for a degree at another university.

27 July, 2023

Kwan Sui (KSD) Ka　　　　Date

Abstract

There is an abundance of literature that informs menu system design, specifically for the context of a two-dimensional flat monitor display. These guidelines that are used to inform menu system design used in two-dimensional flat monitor displays were reconsidered to identify criteria that can inform the design of a menu system used in a three-dimensional (3D) virtual environment that makes use of immersive virtual reality technology. Considering the immersive nature of such technologies, it can be hypothesized that proprioception, a sense used to establish awareness of objects and space in a physical environment, can be transferred into the virtual environment to guide menu item selection.

Various properties of menu system design were investigated to identify properties that can be used together with proprioception to support menu item selection. Further investigation to understand the usage of proprioception in a 3D virtual environment revealed that spatial awareness and memory needs to be established first. Therefore, criteria that inform the design of menu item selection to be supported by proprioception needed to take this fact into consideration as well.

Consequently, a menu system was designed and developed based on the identified criteria to test its feasibility to inform the design of a menu system in a 3D virtual environment that enables users to rely on non-visual senses to guide their selections. The system was designed and developed using commercially available hardware and software to ensure that the findings of this study can be accessible to the general public.

The results of this study identified that participants were able to establish spatial awareness and develop familiarity with the 3D virtual environment, therefore enabling them to make use of proprioception, along with their visual senses and haptic feedback, to improve their ability to select menu items. The results also revealed that participants had varying levels of relying on visual guidance for menu item selection and that the varying levels of reliance were based on personal preference.

Keywords

virtual reality, menu system, spatial awareness, proprioception, 3D interaction, eyes-off interaction, selection technique, usability testing, user experience.

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1. Introduction

Menus are helpful tools that provide access to various functions within a system. Some examples include the Start Menu on a Microsoft Windows computer which allows the user to access and use various software that are installed on the computer, such as calculators, file managers, web browsers, and word processors; and in the context of creating a text document, a menu bar provides options for formatting, styling, reviewing, referencing, and many other functions. Much research has been conducted to establish a set of criteria to aid in the design of menu systems, specifically in the context of a computer screen where the user-interface (UI) is flat (Bailly, Lecolinet & Nigay 2016; Sharp, Preece & Rogers 2019:202–205; Hirsch 2021; Jiang & Chen 2022). In more recent years, technology has transformed the design of UI to allow for engagement with interactive virtual environments (IVEs) in a way that allows users to feel that they are part of those environments (Sharp, Preece & Rogers 2019:212; Buck 2021). Menu systems for these IVEs have also been explored to take advantage of its engaging nature (Salomoni et al. 2017). Such IVEs are presented through virtual reality (VR) technologies that are commercially available such as the Sony Playstation VR (Sony Interactive Entertainment LLC 2020), the HTC Vive (HTC 2018) and the Oculus Quest 2 (Oculus 2020a) in which they all make use of motion tracked head mounted displays (HMDs) and sometimes handheld controllers.

Using these VR technologies, users can interact with the IVE in a more natural way because the virtual space and objects within the IVE can be interacted with in a similar way to physical space and objects (Mine, Brooks & Sequin 1997; Mendes et al. 2019). In a physical space it is possible to have a general awareness of the space and the objects that occur in that space through a sense of awareness is known as proprioception (Stillman 2002; Taylor 2009). Proprioception provides a sense of the size and proximity of objects in space, which includes perceiving the size and position of one's own body parts relative to oneself (Stillman 2002) and because users can feel part of an IVE through VR technology, they should also be able to have a level of awareness of virtual space and objects relative to their own body in the IVE (Eriksson 2016:17; McAnally & Wallis 2021). Studies about proprioception have been done to inform interactions within IVEs (Boeck, Raymaekers & Coninx 2006; Eriksson 2016)but proprioception has not been specifically investigated to support interactions with menu systems within IVEs.

This study investigated criteria for designing a menu system that allows users to take advantage of proprioception to interact with menu items within an IVE. Menu items typically represent functions to be used to complete a task. In order to take advantage of proprioception, a level of familiarity with a specific menu system is required which comes from exposure and practice with the menu system. A good menu system should thus support users in becoming familiar with the menu system by having a design that is easy to learn and remember, and once a strong enough level of familiarity is achieved, proprioception supports locating and selecting menu items to be used. Interacting with the menu system can then be done absentmindedly while focusing on completing a different task, possibly without even looking at the option selected.

The goal of the current study was to produce a set of criteria that can be used to inform menu system design for use in IVEs in a way that allows users to take advantage of proprioception. These criteria allow the design of menu systems in VR to be used in such a way that requires low mental and physical effort to interact with.

1.1 *Background to this study*

IVEs have been created to present a simulated experience for various reasons, including training (Aziz et al. 2014; Murcia-López & Steed 2018; Shi et al. 2018), therapy (Krijn et al. 2004; Feng et al. 2019), travelling (Oculus 2020b; Immersion VR UK 2020), and entertainment (Amir et al. 2016; Valve Corporation 2016a; Oculus 2020a). Being able to interact with the virtual space and objects within these VEs allows the experience to be more engaging, especially when presented through VR technologies (Gigante 1993; Bowman & McMahan 2007; Slater 2018) because users feel part of the IVE and feel that they have an influence on the IVE (Lombard & Ditton 1997; Brade et al. 2017). Studying the usage of menu systems within IVEs, i.e., 3D IVEs, can contribute to improving the experiences in the above-stated uses of IVEs.

Menu systems provide access to functionality in a structured manner (Bowman & Wingrave 2001; Wang, Hu & Chen 2021), allowing functions to be used to complete a task by allowing the user to access functionality whenever they need it. Without good structure, these functions may be difficult to locate or assumed absent. For example, a well organised toolbox results in tools being easy to both locate and access. Similarly, menu systems should be well structured so that the available functions are conveniently located and accessible. Menu systems are thus a means to an end when accomplishing a goal and are not the goal in and of themselves (Bailly, Lecolinet & Nigay 2016).

Existing literature regarding interactions within IVEs, i.e., 3D virtual environments, primarily investigates the interaction with virtual objects that are visually represented (Argelaguet & Andujar 2013; Serafin 2015; Besançon et al. 2019; Lee & Park 2020). If a user wants to pick up a virtual object, then they will typically rely on visual representations by first looking at the virtual object and thereafter interacting with it because visual representation provides a way of perceiving the virtual space in the IVE (Schramm, Gutwin & Cockburn 2016; Buck 2021). Users could perceive themselves to be directly or indirectly part of the IVE, which helps to develop a level of spatial awareness for that IVE (Poupyrev et al. 1998; Serino & Riva 2015). In the physical world, we generally have an idea of the physical space around us and the objects that occupy that physical space. For example, when looking to sit on a chair in a room, it is not necessary for the distance to the chair to be carefully measured, neither is the height of the chair carefully measured before sitting on it. The same is true for actions and objects within proximity of the body due to proprioceptive senses. Proprioception is the ability to sense movement, position of objects, and the surrounding space in relation to the body (Stillman 2002; Taylor 2009). Studies have shown that proprioception can also be used when interacting with an IVE (Mine, Brooks & Sequin 1997; Boeck, Raymaekers & Coninx 2006; Mendes et al. 2019; McAnally & Wallis 2021).

Because proprioception is an ability that can be used in IVEs to help locate virtual objects, this suggests that proprioception can also be used to improve interaction with menu systems within IVEs. If users become familiar enough with a menu system through proprioception, then it may be possible to use the menu system without paying much attention to it and there are two significant user behaviours that indicate when users are paying little attention to something: eyes-off interaction, and multi-tasking (Bowman & Wingrave 2001; Cockburn et al. 2014:3; Bernard et al. 2022). Eyes-off interaction refers to the ability to interact with an object without looking directly at that object (Bowman and Wingrave, 2001) while multi-tasking refers to splitting one's attention by doing a menial task while focusing on a more demanding task (Cockburn et al. 2014:3). These two behaviours indicate that users are not focused on interacting with the menu system, which, in turn, provides evidence that the menu system serves its purpose of being a means to an end to help the user complete their task.

1.2 *Problem statement*

Relying on proprioception has been shown to improve locating and grabbing with virtual objects and moving through the virtual space within IVEs (Mine, Brooks & Sequin 1997; Boeck, Raymaekers & Coninx 2006; Mendes et al. 2019). Therefore, it is possible that proprioception can also be relied on to improve the location and selection with menu items in a menu system within an IVE. Further investigation was conducted to identify how proprioception can improve the selection of menu items with a menu system.

A menu system that allows users to rely on proprioception to interact with menu items is expected to alleviate attention so that users can focus on the task at hand. Various design guidelines for designing good UI and menu systems have been established (Bowman & Wingrave 2001; Dachselt & Hübner 2007; Chertoff, Byers & LaViola 2009; Kulshreshth & LaViola 2014), however, there is no clear set of criteria that encourages reliance on proprioception.

1.3 *Purpose of the study*

The current study explored the use of proprioception to facilitate interaction with menu systems used within IVEs and to do so, a set of criteria was identified by reviewing literature and was thereafter tested to inform menu system design for IVEs that would allow users to take advantage of their proprioceptive senses. Using the identified set of criteria, a menu system was designed with a specific focus on supporting menu item selection through spatial awareness and the comfort of positioning and layout, thus allowing the menu system to be easy to learn. This enabled participants to quickly familiarise themselves with the menu system through their proprioceptive senses, helping them develop the ability to perform eyes-off interactions and multi-tasking. This allowed participants to split their attention so that they can focus on doing the task that the menu system is designed to help them complete. The purpose of the current study was to provide a set of criteria that will support the use of proprioceptive senses for menu item selection, thereby reducing the effort required for using the menu system and allowing more focus to be placed on completing a given task.

1.4 *Significance of this study*

There is significant existing literature that guides the design of UIs for flat display screens (Bowman & Wingrave 2001; Dachselt & Hübner 2007; Chertoff, Byers & LaViola 2009; Kulshreshth & LaViola 2014; Venngren 2021; Nguyen, Sidorova & Torres 2022) and literature about UI design for IVEs with regards to interactions is also emerging, such as selection techniques (Besançon et al. 2019; Lee & Park 2020; Sidenmark et al. 2020), disambiguation techniques (Argelaguet & Andujar 2013; Moore et al. 2019), and retrieval mechanisms (Valve Corporation 2020; Hirsch 2021). This study contributes to UI design for IVEs with a focus on understanding the role of proprioception when interacting with menu systems. Establishing such an understanding is expected to improve the usability of menu systems in IVEs, which can improve the experience for the various uses of IVEs mentioned in Section 1.1.

1.5 Research questions

The goal of this study was achieved by answering the research questions stated below. Each of the sub-questions focuses on a specific aspect of the primary research question and were addressed by answering them with various sources within the study, as indicated in Table 1-1.

1.5.1 Primary research question

How can interactions with menu systems in virtual reality be designed to effectively take advantage of proprioception, thereby helping with menu item selection?

1.5.2 Sub-questions

Table 1-1: Sub-questions that explore various aspects of the primary research question

Question	Description	Source
Which criteria should be used to inform the design of a menu system used in virtual reality that will allow users to take advantage of their proprioceptive senses?	These criteria provide guidelines to identify properties of a menu system that will allow users to take advantage of their proprioceptive senses.	Literature
How effective are the perceptual properties of the designed menu system in supporting users to rely on proprioception to interact with menu systems?	Each property of the menu system was designed and tested with the intention of supporting users in establishing awareness of each menu item so that users can rely on the various properties to trust their own proprioceptive senses.	Empirical data
How can users be supported to become familiar with the menu system?	Proprioceptive senses rely on familiarity with a space and the objects in that space. In the context of the current study, the IVE would be the space and the menu items of the menu system would be the objects. If users struggle to become familiar with the menu system, they will struggle to trust their proprioceptive senses.	Literature and empirical findings

1.6 Research design

Various criteria were identified for informing the design of menu systems by consulting existing literature (discussed in detail in Chapter 2). The intention of the identified criteria are to provide design guidelines for menu systems used in 2D flat display monitors but not for IVEs. The current study combined the various identified sets of criteria to inform a set of criteria that provided design guidelines for menu systems used in IVEs, specifically in VR via motion tracked HMDs and handheld controllers. To test the feasibility of this set of criteria, a menu system for an IVE was designed and developed based on the identified criteria. The current study made use of a user-centred approach, which means that the feasibility of the menu system was primarily measured based on qualitative data in the form of user experience (Sharp, Preece & Rogers 2019:47–49) and quantitative data, in the form of user performance, were also measured but only to triangulate the qualitative findings of user experience with the menu system. Since human experience was used as the primary measurement for the feasibility of the menu system, an interpretivist research paradigm was used to holistically investigate the empirical findings (Stake 2010:95; Pickard 2019:16), this also meant that a primarily qualitative research methodology was adopted for this study (Pickard 2019:16), and because the feasibility of a menu system was tested, usability tests were chosen as the research method (Barnum 2010:111–113).

1.7 Limitations

In this section the limitations of this study are discussed in terms of generalisability, demographic factors, technological aspects, and the software implementation.

1.7.1 Generalisability

This study focused on human experience, which is inherently a qualitative measure and because of the qualitative nature, the results of this study cannot be completely replicated and derived value from understanding various experiences that are unique (Stake 2010:95; Pickard 2019:16). The purpose of conducting usability tests was not to produce replicable results but rather to use the results to measure the feasibility of a design (Sharp, Preece & Rogers 2019:524–533).

1.7.2 Demographic factors

Participants for the current study were identified based on factors that were expected to yield valuable and reliable findings. The following factors were used to identify participants:

- Geolocation: participants were required to be able to travel to a specific physical location to participate in the usability tests. This is because the current study made use of specialised equipment in that location.
- Technological literacy: participants were required to have some experience with IVEs in the form of videogames. Having this prior experience meant that they would be familiar with similar technology and any instructions given to them for engaging with the IVE. The prior experience would, therefore, ensure that they were not overwhelmed nor distracted by the novelty of engaging with an IVE and the use of technology to participate in the usability tests, as discussed in Section 3.3.2. This prior experience would ensure that any data collected from participants was focused more on their interactions with the menu system and not the technology used to present the IVE.

- Physical ability: this current study also focused on the usage of both hands to interact with the menu system, which meant that users must have two functioning hands. The current study also investigated hand dominance with regards to the efficiency of making selections from a menu system.

1.7.3 Technological aspects

The set of criteria identified in this study are only applicable for VR technologies that make use of a head-mounted display (HMD) and two handheld controllers (one for each hand), in which all three pieces of equipment are motion tracked. Specifically, the menu system that was created to test the set of criteria was developed for the HTC Vive (HTC 2018) and this technology was chosen for implementation primarily due to availability, as discussed in Section 4.1.

There is a possibility that the identified set of criteria can also be used for augmented reality (AR) technology that uses motion tracked equipment, but this was not tested in this current study.

1.7.4 System implementation

To develop the IVE that encompasses the scenario and the menu system, a decision was made to use a specific implementation software (game engine) based on the fact that the chosen game engine is popularly used for developing IVEs. The results of this study have only been tested with a specific combination of the chosen game engine and the hardware used to develop the IVE. These design choices are discussed in more detail in Chapter 04 (Section 4.2). It is possible that different results may be produced with an implementation that varies from the combination of the software and hardware used for this study.

1.8 Summary of chapters

This chapter provided an introduction for the study that covers a background, the problem identified and informed by literature, the means to addressing the problem, the limitations of this study, and the research questions along with sources to provide answers.

Chapter 2 provides a foundation for understanding previous research related to menu system design for IVEs. Using this foundation, different sets of criteria were identified and consolidated to inform the design of a menu system that was then tested as part of this study.

Chapter 3 presents the research methodology of this study by describing the details of the methodology followed to conduct the study.

Chapter 4 provides a description of the process of implementing an IVE that encompasses the task and the menu system. Design decisions for the menu system are also detailed in

Chapter 4 along with results from an informal pilot study that helped inform changes to the menu system.

Chapter 5 covers the details of the results from the data collection with participants.

Chapter 6 discusses answers for each research question and suggests topics for further research.

1.9 Summary

This chapter discussed an overview of the current study, which highlighted a knowledge gap with regards to menu system design for IVEs. Based on identifying a knowledge gap, research questions were then identified to provide focus on specific aspects that would contribute to filling the knowledge gap and the research approach for executing the current study was then outlined.

The next chapter provides a literature review that discusses existing work with regards to menu system design. This includes exploring the following concepts: understanding IVEs, spatial awareness, interactions within IVEs, and selection techniques. Based on the understanding of these concepts, sets of criteria were investigated and consolidated to inform a menu system within an IVE that allows reliance on proprioceptive senses.

2. Literature Review

In this chapter, existing literature is investigated to establish what has been done to provide design criteria for menu systems. Some of these criteria that were initially intended for menu systems used in an interface of a two-dimensional (2D) flat monitor display were included to develop a set of criteria to inform the design of menu systems used in a three-dimensional (3D) virtual space. The reason for including these criteria were because they provided a standard for general usability. Interactions used in a 3D virtual space were also investigated, which included exploring the immersive nature of virtual reality technology, selection techniques, and body-relative interactions. Menu items in a 3D virtual space are commonly represented as 3D virtual objects and it is therefore valuable to investigate common methods for interacting with virtual objects in a 3D virtual space. Exploring existing literature helped to investigate taxonomies and categorisation of interactions in 3D virtual spaces as well as identifying design guidelines that can inform the design of a menu system used in a 3D virtual space.

2.1 *Importance of menus*

A menu is an element of a graphical user-interface (GUI) (Sharp, Preece & Rogers 2019:197) that is used to provide a list of options for the user to select from to execute a command, a function, or for starting up software (Bowman & Wingrave 2001). Before GUIs, making use of computers required users to manually input and memorise various commands, which was strenuous, tedious, and easy to input erroneous commands (Jansen 1998). The GUI provided an interface that provided users with a way of issuing precise commands with specified constraints, reducing the room for error and putting less mental strain on the user through the use of graphical elements (Norman 2013:3). The first generation of the GUI were known as a WIMP, which stood for Windows, Icons, Menus, and Pointers (Sharp, Preece & Rogers 2019:197) and modern GUIs have variations of these elements, such as the pointer being replaced by a finger touch in a touch screen. While menus are still a key element to the GUI, interacting with a menu is not the goal of a task, but a tool to help users complete a task (Chertoff, Byers & LaViola 2009; Bailly, Lecolinet & Nigay 2016:7) and if the menu system is designed well, it should enhance the user's ability so that they can focus on doing a task therefore, the interaction with the menu system is only a means to an end.

2.2 *Design criteria for 2D menus*

Previous research investigated the usability of menu systems in a 2D user interface (UI), e.g., desktop computers and smartphones which resulted in many design guidelines for menu systems that are used on a flat monitor display. These design guidelines are discussed below.

Existing design guidelines indicate that good menu design for 2D UIs avoids making the selection process within menus frustrating or distracting and aim to make the selection process to be as low-effort as possible so that users can focus on the task (Bowman & Wingrave 2001; Steed 2006; Eriksson 2016).

For a menu to prove useful it needs to make the user's life easier without causing any significant discomfort, enhancing their ability to do a task efficiently and accurately (Bowman & Wingrave 2001; Bouzbib et al. 2021). Any discomfort in using a tool would immediately discourage a user from continuing to use the tool. Discomfort can be caused by menu items being difficult to find because they are hidden in layers, difficult to reach because they are awkwardly positioned, or have confusing representations that result in functions being misinterpreted or obscure (Jacoby & Ellis 1992; Lediaeva & LaViola 2020). Menus should have a limited number of items, which helps a novice user to not feel overwhelmed (Foley, Wallace & Chan 1984; Bailly, Lecolinet & Nigay 2016) and anything that is too complicated for a user to comprehend will make a user feel out of control, which is not helpful.

Menus must also provide a visual structure for users to select options from (Dachselt & Hübner 2007; Bailly, Lecolinet & Nigay 2016) as structure helps novice users learn to use the menu because it allows users to rely on that structure to find menu items when needed again, thus helping them commit the location of the menu item to memory in relation to the structure (Shneiderman et al. 2009; Shneiderman et al. 2018a). Options provided by a menu should behave in a transient and quasimodal manner, which respectively refer to temporarily providing the necessary options when needed, and menu options remaining available but being easily dismissible when they are no longer needed (Raskin 2000; Bowman & Wingrave 2001; Jakobsen & Hornæk 2007; Bailly, Lecolinet & Nigay 2016). An example of a menu being transient is when styling the text in a word processor, right-clicking on a selected portion of text will open a menu that provides various options to style the text like size, colour, font, and many others. An example of a menu being quasimodal is the fact that this menu of styling the text should remain open while the user is still busy but must disappear when the user wants to dismiss it, otherwise the menu for styling will become an obstruction and an annoyance (Raskin 2000; Bailly, Lecolinet & Nigay 2016).

2.3 *Interactive virtual environments*

Technology has allowed users to experience a 3D virtual environment where the user feels a part of the 3D virtual environment and has some level of control and interaction within the experience (Brooks 1999; Burdea & Coiffet 2003:2; Iachini et al. 2019). For the context of the current study, a 3D virtual environment that is interactive will be referred to as an interactive virtual environment (IVE). Interacting with an IVE can be supported in various ways such as movement, or locomotion, (Carbotte 2016; Lang 2017; Cherni, Métayer & Souliman 2020) as well as selection (Steed 2006; Perrault et al. 2015; Mutasim, Batmaz & Stuerzlinger 2021). Because interaction is possible there is a reason to provide that interaction in a structured and convenient way, such as through a menu system (Dachselt & Hübner 2007; Bailly, Lecolinet & Nigay 2016; Oulasvirta et al. 2020). Before going into detail about menu systems for an IVE, it is important to establish an understanding of an IVE itself.

The virtual environment can be understood as various areas perceived by the user namely (Argelaguet & Andujar 2013):

- **Virtual space**: the whole virtual environment that is presented by technology, which the user experiences.
- **Visual space**: the part of the virtual environment that is visible to the user in their direct line of sight. The field of view is what the user sees within this space and is indicated by the funnel shape in Figure 2-1.
- **Room scale**: the dimensions of the physical room where the virtual environment is experienced.
- **Motor space**: the virtual space in which the user can move around in the virtual environment but limited to the dimensions of the physical room where the virtual environment is experienced.
- **Control space**: the virtual space that is within reach of the human body's physical dimensional limitations, regardless of the user's visual space, i.e., within an arm's reach of the user.

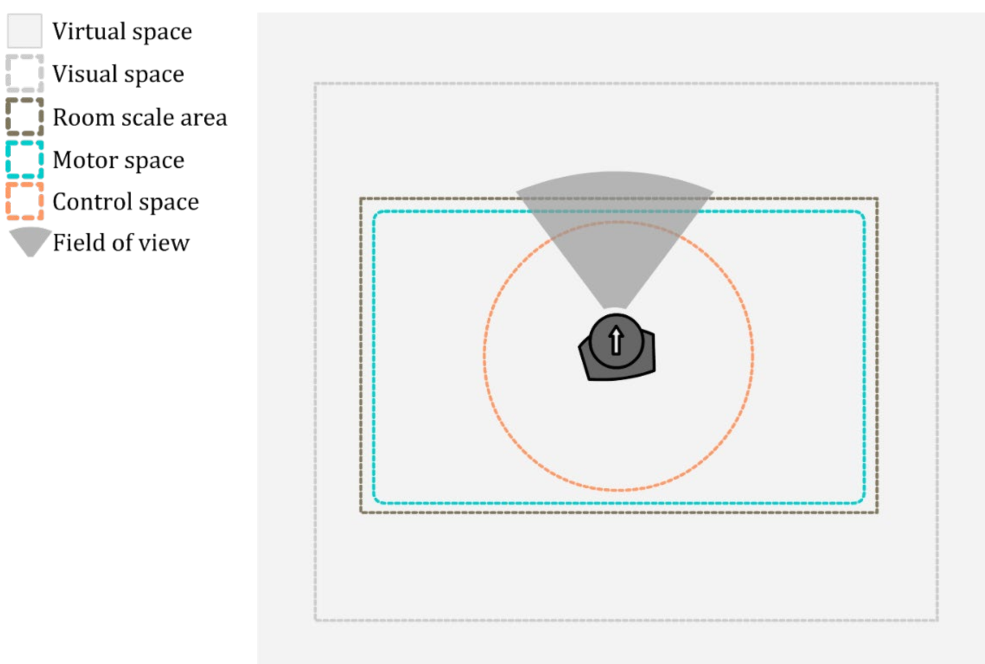


Figure 2-1: An adapted visual representation of the various areas in a virtual environment as described by Argelaguet and Andujar (2013)

The limitations of the physical dimensions of the room and the human body are often limiting factors for selections as well. For example, in “The Lab” (Valve Corporation 2016b), a player may choose to take part in a VR experience where they are placed on the top of a mountain with a view of the surrounding area. In this case, the physical room used to present a virtual experience of climbing a mountain would not be able to directly match the size of the mountain, thus the edge of the virtual mountain will not be the edge of the floor that is in the physical room. The user cannot grab a piece of rock that is below the edge and it is therefore out of reach because the physical floor will be in the way, even though there are no virtual boundaries or obstacles. The user is also not able to grab a piece of rock if it is beyond their physical arm’s reach. Several studies have been conducted to find ways of overcoming the limitations for selecting items in a virtual environment presented with VR technology, i.e., HMDs and controllers (Ren & O’Neill 2013; Argelaguet & Andujar 2013; Eriksson 2016). These studies focused on selecting items beyond the control space by virtually extending the reach distance of the virtual hands (Poupyrev et al. 1996) as well as various adaptions of virtual pointers (Liang & Green 1994; Bezerianos & Balakrishnan 2005; Baloup, Pietrzak & Casiez 2019; Sidenmark et al. 2020).

A broad understanding of IVEs has been established above, however it is important to understand how users perceive their actions to have an effect on an IVE so that these actions can be performed accurately and efficiently with the help of a well-designed menu system. A user’s perspective of the IVE influences how they would visually perceive interacting with objects in that IVE, e.g., videogames are presented from different visual perspectives. The following examples of different perspectives are taken from videogames because they are well known, commercially accessible, and usually require similar hardware and software as those used for creating IVEs. However, it is important to clarify that IVEs are not limited to those found in videogames, since they can also be used for training simulations (Shi et al. 2018), tourism (Immersion VR UK 2020), therapy (Feng et al. 2019), and many other uses. Three common perspectives of viewing IVEs found in videogames are:

- **First-person perspective**: the user views the IVE through the perspective of adopting a character as themselves. For example, a player of “Counter-Strike: Global Offensive” (Valve Corporation 2012) would be playing from a first-person perspective because they are controlling a character as themselves and they can see the character’s arms as their own arms (Figure 2-2).

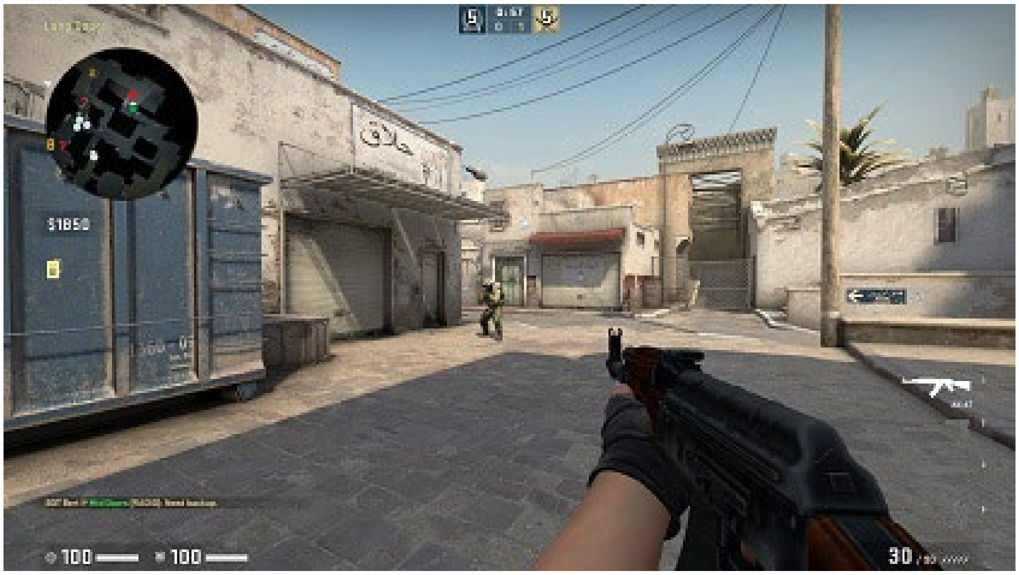


Figure 2-2: First-person view example: A screenshot of the gameplay from "Counter-Strike: Global Offensive" (Valve Corporation 2012)

Image source: https://en.wikipedia.org/wiki/Counter-Strike:_Global_Offensive

- **Third-person perspective**: the user views the IVE as controlling a character with an over-the-shoulder viewpoint, like a puppet master. For example, a player of "The Legend of Zelda: Breath of the Wild" (Nintendo 2017) would be playing from a third-person perspective because they are controlling the on-screen character "Link" from an external viewpoint where the character is fully visible (Figure 2-3).

Figure 2-3: Third-person view example: A screenshot of the gameplay from "The Legend of Zelda: Breath of the Wild" (Nintendo 2017)

Image source:
https://en.wikipedia.org/wiki/The_Legend_of_Zelda:_Breath_of_the_Wild

- **"God's eye" viewpoint**: the user overlooks a large area in the IVE and controls multiple characters by issuing commands as some form of overseeing authority. For example, a player of "StarCraft II: Wings of Liberty" (Blizzard Entertainment 2010) would be playing from a "God's eye" viewpoint because they are overlooking and controlling an army of characters (Figure 2-4).

Figure 2-4: "God's eye" viewpoint example: A screenshot of the gameplay from "StarCraft II: Wings of Liberty" (Blizzard Entertainment 2010)

Image source: https://starcraft2.com/en-us/media

Controlling virtual characters from these various visual perspectives influences how the user interacts with the objects within an IVE which can be identified as an interaction metaphor that refers to the perceptual understanding of possible actions that can affect the IVE (Poupyrev et al. 1998). Interaction metaphors can be categorised as (Klatzky 1998; IVAN Poupyrev & Ichikawa 1999; Fabroyir & Teng 2018):

- egocentric
- allocentric (also known as exocentric or geocentric)

An egocentric metaphor is where the focus is on the user, with regards to how they are related to the objects around them, they have a direct influence on the objects around them, and they are part of the world that the objects are in (IVAN Poupyrev & Ichikawa 1999; Fabroyir & Teng 2018). Referring to Figure 2-5 below, the user performs an action that directly affects the triangular virtual object. For example, a user in the videogame "Counter-Strike: Global Offensive" (Valve Corporation 2012) would interact with an egocentric metaphor and would adopt the role of a character as themselves to pick up weapons.

The allocentric metaphor focuses on the objects with regards to how these objects are related to one another, and the user has an indirect influence on these objects but they are outside of the world that the objects are in (Klatzky 1998; Poupyrev et al. 1998; Fabroyir & Teng 2018). An investigation around the terminology used for interaction metaphors indicated that the exocentric, allocentric, and geocentric metaphor are often used interchangeably (Klatzky 1998; IVAN Poupyrev & Ichikawa 1999). However, since the term “allocentric metaphor” is used in more recent studies (Burgess 2006; Serino & Riva 2015; Fabroyir & Teng 2018), the current study will use the term “allocentric metaphor” as well. In Figure 2-5 below, the user performs an action that affects the square virtual objects by interacting with the triangular objects. For example, users in a videogame interacting through an allocentric metaphor would control characters and objects to interact with other objects, such as the third person perspective used in “The Legend of Zelda: Breath of the Wild” (Nintendo 2017) where the player controls the in-game character (Link) to attack enemies. Another example is the “God’s eye” viewpoint used in “StarCraft II: Wings of Liberty” (Blizzard Entertainment 2010), where the player selects a group of military units and commands them to engage in combat with enemy units.

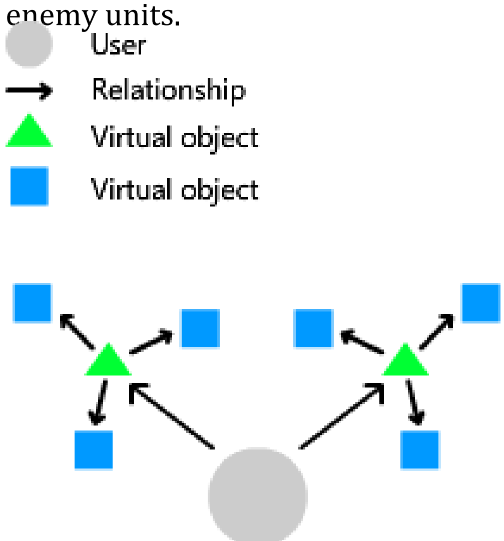


Figure 2-5: A visual representation of the relationship between the user and objects, i.e., interaction metaphors as described by Poupyrev et al. (1998)

VR technology allows users to experience an IVE in a way that is engaging (Gigante 1993; Slater 2018) and provides them with the option to take on a role that has an influence on the IVE; whether it is taking on a role as themselves, as a puppet master, or as an overseeing authority. For the experience to be believable, the IVE would need to be presented in a way that allows the user to feel immersed through VR technology.

2.4 *Immersion and presence*

Immersion can be understood as the capability of technology to stimulate the senses of users in a way that convinces them to believe that they are part of an encompassing and detailed virtual reality whereas presence refers to the user’s level of acceptance for the stimulus that convinces them to be part of the IVE (Slater & Wilbur 1997; Slater 2018; Slater et al. 2022).

From these two definitions above, it can be understood that immersion and presence are two complimentary descriptions (Cummings & Bailenson 2016).

The use of VR technologies provides an engaging experience because it allows the user to feel virtually transported to an environment different from the one that they are physically present in (Gigante 1993; Calleja 2011:18). For an experience within an IVE to be engaging, users would need to be willing to suspend their disbelief of virtually being in a different environment from their physical location (Slater 2018). This suspension of disbelief allows users to accept the illusion of being part of the IVE so that they can believe that they have an influence on the IVE and thus the IVE requires a level of immersion and presence to be experienced. The influence of a user includes interacting with virtual objects that form part of a menu system. Lombard and Ditton (1997) provide a different definition that describes presence as immersion, which is the objective indication of how technology stimulates the user's senses and how users subjectively experience the stimulations in their engagement with an IVE through the technology. The two definitions differ in that:

- According to the definition by Slater and Wilbur (1997), also used in his later publications (Slater 2018; Slater et al. 2022), immersion is considered as the measurement of objective technological provision for an engaging experience but is as a separate yet closely related concept to presence where the subjective acceptance of the experience within an IVE is accounted for.
- Lombard and Ditton (1997) describes immersion as a component of presence where both the objective measurement of provision for an engaging experience through technology to stimulate the user's sense and the subjective acceptance of the user's experience is taken into account.

There is a known debate within the literature of immersion and presence regarding what constitutes the most accurate definitions for these concepts. However, the purpose of the current study was not to contribute to this debate but rather to use definitions of immersion and presence to understand an experience of feeling transported into a different environment in an engaging way. Both descriptions share the notion that immersion can be objectively measured by how the technology engages with the various senses of the user in a way that lets them feel part of an IVE and this may subjectively differ between individuals. Both descriptions ultimately share a common understanding that immersion and presence are both required for a user to find the experience within an IVE engaging.

The current study adopted the understanding of immersion and presence as two separate but complimentary concepts (Slater & Wilbur 1997; Slater 2018). The reason for this adoption was because the current study focused on enhancing interaction with an IVE through a menu system. Although there is no emphasis on any particular VR technology, it was used to present an IVE to the user in a way that was engaging. The user would have needed to accept that there were virtual objects to interact with, in this case the menu items, which requires the user to feel a sense of presence in the IVE.

Lombard & Ditton (1997) also describe presence as both realism and transportation, which is helpful to understand how users perceive their influence on an IVE:

- Presence as realism is the acceptance of how the virtual environment looks and behaves in a way that is believable (Lombard & Ditton 1997; Calleja 2011:2). This means that virtual objects in the IVE can be picked up by physically reaching out and interacting with the virtual object. A tool, e.g., a coloured paintbrush, can be used to change the property, e.g., colour, of an object that it is applied to.
- Presence as transportation allows users to experience an IVE in a way that allows the user to be virtually transported to a different location from their physical location or to interact with virtual objects that are not physically there (Lombard & Ditton 1997; Calleja 2011:2). Presence as transportation allows users to experience an illusion that is not bound by physical limitations, such as travelling (Bulchand-Gidumal & William 2020) or practicing surgery on a digital twin (Laaki, Miche & Tammi 2019).

Based on the understanding that technology can immerse the user's senses in a way that allows them to experience virtual presence in IVEs, users can also establish a sense of awareness of the virtual space and commit that awareness to memory.

2.5 *Spatial awareness and memory*

Spatial awareness within an IVE can be understood as world awareness, where the user is aware of the position of objects, the position of other users, and the structure of the world (García et al. 2008). The user is also aware of self-location, which means that they perceive to take up space in the IVE because of their presence, i.e., they are not just an external observer but rather a presence that has an influence on the IVE and the virtual objects in it (Buck 2021).

Through the awareness of self-location, it is possible for a user to relate to the virtual objects in terms of themselves from the perspective of either the egocentric or the allocentric metaphor, as discussed in Section 2.3. Because of this awareness and perspective, a user can associate the function of virtual objects with an area of their own body (Ängeslevä et al. 2003), e.g., a virtual paintbrush, used for changing colours of other virtual objects, can be associated with one side of the hip, where it could be stored like on a utility belt in the physical world.

Spatial awareness does not only help users to understand the world around them but can also be used to support memory (Burgess 2006) by using spatial awareness to link multiple objects to one another in terms of their location so that they can be remembered collectively and be individually recalled from memory in relation to one another (Perrault et al. 2015). For example, instead of trying to recall individually numerous objects in a room, it would be easier to recall what objects were placed on top of a table and how far apart they were from one another in that room. It is easier to remember numerous objects by focusing on the relationship between these objects, and this technique can also be used to support interactions with virtual objects within an IVE (Burgess 2006; Perrault et al. 2015; Yan et al. 2018).

Users can be supported by user-interfaces (UIs) in terms of memory by designing for recognition over recall (Johnson 2020:105). This means that a UI can be designed in a way that helps users to remember how to perform an action by relying on the UI, e.g., a paintbrush reminds the user that a tool is for changing colours because the visual representation of a paintbrush reminds the user of the tool's function (Johnson 2020:105). The design of UIs can also support memory by designing with consistency in mind, so that the learning and memorising process can be supported when interacting with the elements of a UI (Sharp, Preece & Rogers 2019:26–31). Users familiar with the layout of UI elements become reliant on consistency to predict, locate, and interact with the object (Scarr et al. 2011; Scarr et al. 2013; Cockburn et al. 2014).

Any changes to the locations of UI elements would require users to readjust their spatial memory, which results in a temporary dip in performance (Scarr et al. 2013; Cockburn et al. 2014), therefore, any changes that need to be made to the UI, can be provided by customisation to help users adapt to the changes by ensuring that the changes are noticeable, gradual, and within the control of the user (Scarr et al. 2013). In the context of an IVE, if users were able to control the location of objects that were placed virtually in a space, users were able to easily recall the location of these objects that were placed relative to themselves in that space, even when these objects were no longer visually perceivable (Schipor & Vatavu 2018). As the user becomes more experienced with the UI, their user behaviour would change so that their focus becomes progressively less on learning and memorising the UI and more on becoming efficient in completing a task through the use of the UI (Fitts & Posner 1967:8–25).

2.6 *User behaviour in relation to expertise*

Referring to the difference in the level of expertise for using a system, users can be separated into three categories: novices, intermittent users, and expert users where novices are those that have no experience with the system, intermittent users are those that have some experience, and expert users are those that can use the system with maximum performance and low effort (Shneiderman et al. 2009:66–69). While these categories of expertise were not created for VR technology, they are still applicable because the development of any skill requires practice and experience in order to show improvement (Fitts & Posner 1967:8–25).

To become more skilled in using a system, a user has to go through the following three stages: cognitive, associative, and autonomous (Fitts & Posner 1967:8–25).

Novice users in the cognitive stage focus on gaining knowledge for what needs to be done and are focused on every action they take (Fitts & Posner 1967:8–25; Shneiderman et al. 2009:66–69). A user in this stage requires instructional guidance to complete an action and it is done slowly with a lot of attention given because they are actively learning (Fitts & Posner 1967:8–25; Ericsson & Harwell 2019). The user can be easily interrupted because their actions are still untrained. All of this results in only being able to perform one action at a time (Fitts & Posner 1967:8–25; Ericsson & Harwell 2019).

Intermittent users in the associative stage have some established knowledge, thus they focus more on how the interaction is done (Fitts & Posner 1967:8–25; Shneiderman et al. 2009:66–69). The goal of users at this stage is to adjust their actions so that their skills can be improved. Due to the possibility that there would be multiple adjustments to be made at this stage, many users of complex systems remain in the associative stage (Cockburn et al. 2014:4–5; Ericsson & Harwell 2019).

When users reach the autonomous stage, they can be considered expert users because their actions are done out of reflex and are carried out in a habitual manner through extensive practice (Fitts & Posner 1967; Schneider & Shiffrin 1977)where little attention is required, meaning that well-practiced tasks can be carried out quickly while focusing on a different task, that is, to multi-task (Cockburn et al. 2014:3). Although experts require little effort to perform a well-practiced task, they typically are also more deliberate in finding ways to become more efficient (Ericsson & Harwell 2019).

2.6.1 Facilitating learning

There are several factors that hinder users from transitioning to become expert users. One hindrance is that users are not aware of a more efficient method for accomplishing tasks (Cockburn et al. 2014:19). Another hindrance is "the paradox of the active user", which refers to users having preference of known techniques over new techniques, regardless of whether the new method would increase performance (Carroll & Rosson 1987). When switching to a new method of executing an action, e.g., using shortcut keys instead of using a function through a dropdown menu, there is usually a temporary short-term loss of performance that discourages some users from adopting the new method, even though the short-term loss of performance will be exchanged for an increased performance in the long term (Cockburn et al. 2014:21). Users also get discouraged because they underestimate their ability to become efficient with the new method (Cockburn et al. 2014:19). To remedy the problem of being discouraged from the temporary loss of performance, Malacria et al. (2013) provided users with a "skill-o-meter", which was an on-screen gauge that provided visible indication of their efficiency in terms of the new method compared to other known methods and the results reinforced the notion that users can be encouraged to adopt new methods if there is a perceivable improvement.

For users to improve in their expertise of using a system, their learning can be facilitated through two methods (Cockburn et al. 2014:10):

- Those that can help users by using elements that are part of the system, e.g., understandable visual representations.
- Those that are external to the system, e.g., training courses.

The current study focused on supporting users in improving their expertise on their own. Therefore, methods of facilitating learning by using elements that are part of the system were implemented.

2.6.1.1 Support for a primary action

For users to improve their expertise on their own, they would need to be supported to learn to perform a specific interaction to make use of a menu system and to familiarise themselves with the functions and navigation of the menu system.

Helping users to learn and refine a specific interaction can be done by providing support for intramodal improvement, which refers to improving the performance by focusing on one specific method of interaction used for one specific function (Cockburn et al. 2014:11), e.g., using direct manipulation to control a virtual hand that is used for selection. Focusing on supporting intramodal improvement for users can help users to refine a specific interaction for using a system, which leads to autonomous user behaviour (Fitts & Posner 1967:8–25; Shneiderman et al. 2009:66–69).

2.6.1.2 Support through exploration

Learning can be done through active experimentation, a method that allows users to establish understanding by doing an action and observing the relationship between the cause and effect of their actions (Morris 2020:1064–1077)which can be supported by providing users with constraints, e.g., only one UI element can be selected at a time, and making use of consistencies, e.g., the layout of the UI will always be the same (Sharp, Preece & Rogers 2019:29–29, 119). Constraints and consistencies guide users as they explore because these help users to know what to expect, which they can use to their advantage (Sharp, Preece & Rogers 2019:29–29, 119).

Allowing users to learn on their own by relying on elements within the system can be done by providing reliable task mapping which ensures that (Cockburn et al. 2014; Bailly, Khamassi & Girard 2021):

- The location of a function can be found where it is expected.

- The association between the representation and the function is obvious.

Exploration can be complemented by providing reliable task mapping that implements constraints and consistencies, in which users can learn to know what to expect (Sharp, Preece & Rogers 2019; Morris 2020:1064–1077). They can then rely on these expectations and commit them to memory given more time and experience.

2.6.1.3 Supporting memory

Memory plays an important role for learning and practicing a specific interaction that helps navigation to elements in a UI that were already committed to memory, enabling rapid target acquisition within an interface for experienced users (Fitts 1954; Besançon et al. 2019; Wickens et al. 2021). To commit details of the task to memory, a user would need to look carefully at every action so that careful attention can be given, which is referred to as visual guidance. Novice users rely on visual guidance as they learn and explore, resulting in doing tasks slowly but as they become more familiar, and thus more confident in their actions, they progressively rely less on visual guidance to achieve higher performance because they rely more on memory as well as other senses, e.g., haptic feedback, instead of visual confirmation. For example, when a smartphone vibrates the user can distinguish between a message and a phone call by the length of a vibration, instead of checking on the screen (Shneiderman et al. 2009:62–65; Schramm, Gutwin & Cockburn 2016). The fact that users rely less on visual guidance as their level of expertise increases indicates that the change in expertise can be observed based on this change in user behaviour (Bailly, Lecolinet & Nigay 2016; Bailly, Khamassi & Girard 2021). Experts are more prone to perform eyes-off interaction, i.e., without looking directly at what their hands are busy with, such as typing without looking directly at the keyboard (Bowman & Wingrave 2001). One principle for good UI design regarding memory encourages designing for recognition over recall which refers to allowing users to rely on hints to help them remember how to use a function (Johnson 2020:105), e.g., looking at a paintbrush icon and remembering that it is a tool used for colouring. This is different to having users fully rely on their own memory to know how to use a function of a system, e.g., remembering command codes to fill in values required by the function, as designing for recognition over recall takes the strain off the user and results in a more gradual learning curve (Johnson 2020:105).

2.6.2 Change in user behaviour

As discussed above, experts typically exhibit specific user behaviours to increase efficiency, such as multi-tasking and performing eyes-off interactions. Providing customisation allows users to finetune a system to their own preference, which can help them become familiar with that system (Shneiderman et al. 2009:64). The desire for customisation is more prominent in users with more experience, while novices prefer to have a default layout because it provides a frame of reference for them to learn from (Shneiderman et al. 2009:64).

Because willingness to explore customisation is prominent in users with more experience, this user behaviour can also be observed as an indication of progression in expertise. Users can also benefit from establishing awareness of their surrounding space and their body in relation to the context of that space as they progress through the various stages of expertise (Cockburn et al. 2014:3).

2.7 *Body-relative interactions*

In the physical environment, the human body can retrieve items from a pocket, such as a pen, without having to look at the item because the item's location is identified relative to the body as well as through the sense of touch (Stillman 2002). In the context of a UI on a touchscreen, it is also possible to locate items relative to the hand without looking if aided by haptic feedback (Bernard et al. 2022) and reliance on spatial awareness of the user's body in relation to virtual objects has helped to perform selections in the context of an IVE as well (Mine, Brooks & Sequin 1997; Yan et al. 2018).

This kind of interaction is known as "body-relative interaction" and it consists of three forms, namely (Mine, Brooks & Sequin 1997):

- direct manipulation
- physical mnemonics
- gestural actions

Direct manipulation uses a sense of one's body to aid the controlling of objects by having virtual objects behave in a way that is relatable to the user's actions, e.g., grabbing a piece of rock in the IVE by leaning down and reaching out with a hand (Sharp, Preece & Rogers 2019:85–86). Interacting with virtual objects in an IVE through direct manipulation provides a satisfying interaction because virtual objects respond to the physical actions performed by the user in a way that is familiar (Shneiderman et al. 2018a) which makes this type of interaction easy to understand, further discussed in Section 2.8.

Physical mnemonics refers to a method of relating memories, e.g., actions, events, and information, to specific body parts so that they can be remembered later, e.g., creating items of a list by counting on fingers (Mine, Brooks & Sequin 1997). The process of commitment and retrieval of memories can also be aided by relating the memories to virtual locations around the body (Ängeslevä et al. 2003; Perrault et al. 2015).

Gestural actions are commands given based on body-relative actions, e.g., holding out a hand and closing it into a fist to take a photo with a smartphone. Research for controlling a camera during surgery (O'Hara et al. 2014) and item selection for a menu used in an IVE (Ren & O'Neill 2013) have benefitted from making use of gestural actions due to its hand-free nature, allowing the user to quickly switch between interacting with technology and using their hands for a different function.

By using body-relative interactions for engaging in an IVE, three advantages are provided: users have a frame of reference, users have a sense of control, and users can potentially perform eyes-off interactions (Mine, Brooks & Sequin 1997). Additionally, providing a transference of familiar interaction from the physical environment into a virtual environment allows the interaction to be easier to accept for novices (Sharp, Preece & Rogers 2019:85–86).

Proprioception is a general sense of movement, position of objects (sometimes out of sight), and the physical environment relative to the body of an individual, which is perceived through the nervous system to help with motor skills (Stillman 2002; Taylor 2009). Using proprioception helps to establish a sense of awareness in a physical environment but can also be used to do the same for an IVE (Yan et al. 2018). By supporting the use of proprioception in an IVE, it increases spatial awareness, which leads to a decrease in the effort of learning to interact with IVEs because it is similar to interacting with objects in the physical environment (Shneiderman 1983; Mine, Brooks & Sequin 1997; Shneiderman et al. 2018a:92). For proprioception to be used in the virtual environment, the users would need to have a sense of their body relative to movement, the virtual objects, and the virtual environment. which can be achieved with the body ownership illusion.

Body ownership illusion is a sensation that enables a user to perceive a virtual body as their own due to self-location, discussed in Section 2.5 (Makin, Holmes & Ehrsson 2008; Petkova & Ehrsson 2008). Technology that successfully stimulates the senses of proprioception, vision, and touch is able to induce an experience for the body ownership illusion because the technology is responsive to the users' interactions (Botvinick & Cohen 1998; Petkova & Ehrsson 2008; Matamala-Gomez et al. 2019). A well-known psychological experiment for body ownership illusion is the rubber hand illusion (RHI), which works as follows (Botvinick & Cohen 1998): participants sat with a rubber hand placed in front of them while one of their real hands was hidden. The hidden hand and the rubber hand would be stroked by a soft brush simultaneously. After a while, only the rubber hand would be stroked by a soft brush, but participants reported that they still felt the stroke on their real (but hidden) hand. The RHI experiment is still a topic of research today, with various research successfully replicating illusion in VR by adopting a virtual hand instead of a rubber hand (Riemer et al. 2019; Kanayama, Hara & Kimura 2021) which suggests that proprioception can be used for interaction in IVEs to support the selection and retrieval of virtual objects (Eriksson 2016; Yan et al. 2018).

2.8 *Interaction techniques*

For the context of the current study, interaction refers to the user selecting or deselecting virtual objects contained in an IVE and performing an action with the object, such as grabbing, dropping, throwing, changing colours, changing sizes, etc. Interaction provides the ability to influence the IVE and makes the experience more believable because the experience is from the perspective of an active participant instead of a passive audience (Slater 2018).

Interactions that mimic the natural movement of hands and body as a way of engaging with an IVE allow the user to experience a sense of familiarity, which makes the interaction technique easier to understand (Shneiderman et al. 2018a:92)and exploring an interaction technique that allows the user to use what is familiar to them, i.e., natural body movements in the physical environment for engaging with an IVE, was beneficial to the current study.

2.8.1 Direct manipulation

Direct manipulation refers to an interaction technique that receives input from the user through movement and responds to this movement that directly translates in the IVE (Sharp, Preece & Rogers 2019:85–86), e.g., waving a motion-tracked controller results in a virtual hand waving in the IVE. This interaction technique allows the user to engage with virtual objects in a way that feels familiar and natural (Shneiderman 1983; Shneiderman et al. 2018a:92), making the interaction technique easy to understand and control due to three properties (Shneiderman 1983; Shneiderman et al. 2018a:92):

- continuous representation of objects,
- actions in the IVE mimics actions that are done in the physical environment,
- actions are reversible with immediate feedback.

Given that menu systems offer a structured approach to making selections, with selecting menu items being the primary form of interaction (Bowman & Wingrave 2001), it is crucial to conduct an investigation into the usability guidelines of selection technique. As a part of this investigation, Argelaguet and Andujar's (2013) set of usability guidelines was found to provide a basis for defining a selection technique used in an IVE, which are as follows:

- The selection technique must be able to provide rapid selections.
- The selections must be accurate and error-proof.
- The selection technique needs to be easy to understand and control.
- The selection technique needs to produce low levels of fatigue.

Through this investigation, the three properties of direct manipulation was found to overlap with Argelaguet and Andujar's (2013) set of usability guidelines which can help to facilitate a selection technique that is easy to understand and control because the continuous representation allow users to establish a correlation between their actions having a direct effect on virtual objects; these actions can also be reversed, which can be used to rectify erroneous actions (Shneiderman 1983; Shneiderman et al. 2018a:92). For example, virtual objects in an IVE can be grabbed, moved, dropped, and thrown and through these various interactions, the virtual object can be placed back in their original positions to reverse the action, allowing mistakes to be immediately rectified. Because direct manipulation allows the user to interact with an IVE in a way that mimics actions performed in the physical environment, it also allows the user to establish spatial awareness within the IVE, which allows them to rely on proprioception as well, as discussed in section 2.5.

However, there is one contrast between the properties of direct manipulation as an interaction technique and Argelaguet and Andujar's (2013) set of usability guidelines for selection techniques. This contrast refers to performing selections through direct manipulation because this method of interaction may cause higher levels of fatigue than some other existing selection techniques. This is due to the movement mimicking natural movements, e.g., crouching down to grab a virtual object that is on the floor in the IVE, that uses larger muscle groups compared to a less natural movement, e.g., pressing a series of buttons. A natural interaction such as direct manipulation that mimics movements of the physical environment, e.g., reaching down and clasping a hand closed to grab a virtual object, usually proves to cause more fatigue and is less efficient than non-natural interaction techniques, e.g., pressing a button to grab a virtual object. However, in spite of causing more fatigue and being less efficient, direct manipulation is still preferred because users feel more in control with natural interactions, resulting in a more satisfying experience (McMahan et al. 2010).

2.8.2 Target selection

Since the choice of a selection technique is important when considering the interaction with the menu system in an IVE, it would be helpful to understand a selection technique as a collection of sub-actions to ensure that the selection is supported at a granular level for facilitating the ease of learnability and adaptability for users (Bowman & Hodges 1999; Argelaguet & Andujar 2013). These sub-actions can be identified as follows:

- **Objection indication**: identifying the object of interest, i.e., pointing at the object or cycling through a list of objects until the indicator sits on the object.
- **Confirmation of selection**: performing an action to select the object of interest, i.e., pressing a button.
- **Feedback**: the system that facilitates the selection responds to the selection to indicate that the selection was performed, e.g., the UI changes to a different layout or the object of interest is placed in the user's hand and becomes available to use.

A study by Besançon et al. (2019) provided an update on Argelaguet and Andujar‘s (2013) set of usability guidelines for selection, which included multiple target selection and region of interest (ROI) selection. However, the current study focused on single target selection and therefore kept with Argelaguet and Andujar‘s (2013) prescribed set of usability guidelines.

2.8.3 Selection refinement

When selecting a single target within a group of other virtual objects, there is difficulty in accurately selecting the target, which results in the need for some method to refine the selection. Argelaguet and Andujar (2013) investigated the need for the refinement of target selection and defined these methods as disambiguation mechanisms.

Disambiguation mechanisms not only enable the user to adjust the selection shape for a more refined selection (Besançon et al. 2019), but also provides the possibility of selecting objects that are obscured behind another object, e.g., by temporarily making the obscuring object transparent (Argelaguet et al. 2010; Lee & Park 2020).

Three disambiguation mechanisms have been identified to help refine selection for increased accuracy (Argelaguet & Andujar 2013):

- Manual disambiguation relies solely on the user's ability to select an item.
- Heuristic disambiguation has items ranked according to an established heuristic with a higher ranked item being more likely to be selected based on the proximity of the selection to various nearby items.
- Behavioural disambiguation is similar to heuristic disambiguation except that it also learns from the user's previous attempts of selection to make a better estimation for the desired item.

Since selections for the current study employed single target selection that is within arm's reach, exploring disambiguation mechanisms for virtual hands, i.e., virtual representations of hands in the IVE, was beneficial. Disambiguation for virtual hands has been investigated by Moore et al. (2019), who motivated that existing methods, when simplified, are variations of the following three methods of disambiguation:

- **Closest intersected**: selection is refined to the object that is closest to the virtual hand when selecting from multiple objects that are touching the virtual hand, e.g., in Figure 2-6 the grey virtual hand is closest to the green triangle, based on the distance between the centre of the hand and the green triangle. Therefore, the green triangle will be selected.
- **First intersected**: selection is based on the object that was the first to be touched by the virtual hand when selecting from multiple objects that are touching the virtual hand, e.g., in Figure 2-6 it is assumed that the objects were touched by the virtual hand

in the following order: first the blue circle, then the green triangle, and lastly the orange square. According to that order, the blue circle will be selected even if it is not the closest virtual object.

- **Last intersected**: selection is based on the object that was the last to be touched by the virtual hand when selecting from multiple objects that are touching the virtual hand, e.g., in Figure 2-6 it is assumed that the objects touched in the following order: first the blue circle, then the green triangle, and lastly the orange square. According to that order, the orange square will be selected even if it is not the closest virtual object.

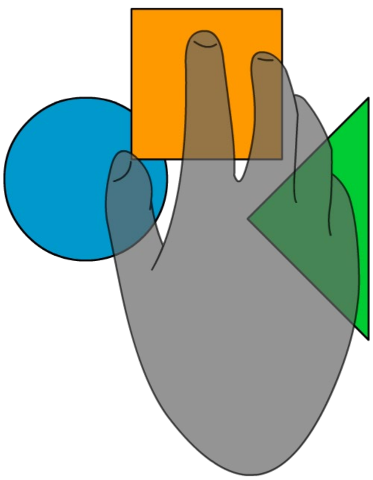


Figure 2-6: An adapted visual representation of a virtual hand position relative to virtual objects (blue circle, orange square, green triangle), as described by Moore et al. (2019)

By investigating disambiguation mechanisms for virtual object selections, menu items can be selected in less time and with more accuracy without users needing to be very precise (Lu, Yu & Shi 2020), further allowing users to focus on the task at hand.

Exploring selection techniques is important to facilitate the interaction of virtual objects that are accessible, but in an IVE it is possible for virtual objects to be inaccessible for selection due to their location being beyond the reach of the user. The user may also be unable to move towards the virtual object because the virtual space can be bigger than the physical space, i.e., the virtual object is beyond the control space for the user, as discussed in Section 2.3 above. In some cases, it is because the user has thrown the virtual object beyond the control space, and they may want to reverse this action to regain access to the virtual object, which requires a method to retrieve the virtual objects back into the control space.

Methods for retrieving these virtual objects have been explored in literature such as the Go-go interaction (Poupyrev et al. 1996) and PRECIOUS (Mendes et al. 2017), as well as in commercial implementations in the form of a virtual pet from “The Lab” (Valve Corporation

2016b), and gravity gloves from "Half-Life: Alyx" (Valve Corporation 2020). Still other studies have investigated methods for virtual object retrieval by combining them with disambiguation techniques (Lu, Yu & Shi 2020), as well as eye-tracking (Yan et al. 2018; Khamis et al. 2018; Sidenmark & Gellersen 2019; Hirsch 2021).

These methods of retrieving virtual object beyond the control space for the user are used to facilitate reversible action in an IVE, conforming to the properties of direct manipulation, as discussed in Section 2.8.1 above. However, the current study focused on target selection that is within an arm's reach; therefore, these methods of retrieval were considered to be beyond the scope of the current study.

2.8.4 Hand usage

Interactions in an IVE can facilitate the use of both hands since VR technology typically features two controllers by design (HTC 2018; Oculus 2020a) and is therefore important to consider how users will use both hands to interact with virtual objects since most activities that humans perform require two hands, regardless of whether each hand serves a similar function (Guiard 1988; Yamagami et al. 2022). Even when the activity is presumed to be one-handed, the activity may still require the non-dominant hand for stability and orientation (Guiard 1988), e.g., holding a piece of paper in place while writing, resulting in the use of both hands. Using both hands to perform an activity is known as bimanual interaction (Hinckley et al. 1997).

Bimanual interaction can be performed either as symmetrical, where both hands are used for the same function, e.g., picking up a table, or as asymmetrical, where the functions of each hand are independent, e.g., opening a door with one hand while texting with the other hand (Balakrishnan & Hinckley 2000). For a bimanual interaction to be considered symmetrical, the action performed by both hands is not restricted to being completely identical but may include using both hands for an identical function, but separate targets, such as typing on a keyboard. A bimanual interaction that is asymmetrical is also not restricted to activities where the function of each hand is independent, e.g., browsing the web on a computer by using the mouse with one hand while pressing keys on the keyboard with the other hand. A few studies have investigated how bimanual interaction in virtual reality can support training in applications where bimanual interaction is inherent to the task, such as surgery (Meli, Pacchierotti & Prattichizzo 2014; Power et al. 2015) as well as practising and building in assembly tasks (Vélaz et al. 2014; Carlson, Vance & Berg 2016; Murcia-López & Steed 2018). In the physical environment, bimanual interactions are often symmetric due to weight and size, e.g., picking up a table.

Due to technological capabilities, virtual objects in an IVE are weightless (Ye 2021) so any weight perceived by the user that relates to virtual objects would be the weight of the physical VR technology used to present the IVE. With virtual objects being weightless, the use of bimanual interaction changes because any object that is unwieldly would no longer be difficult to hold and instead there is more focus on actions that require stabilisation, e.g., resting one hand on the other hand to accurately point a laser towards a target that is far away (Steed 2006).

The lack of perceived weight of virtual objects provided by technology can result in a less immersive IVE, resulting in a lack of presence experienced by the user (Ye 2021) but it can also allow asymmetric bimanual interaction to be used for dual-attention tasks, i.e., to carry out a well-versed task while focusing on a more mentally demanding task (Rosen 2008). One concern about multi-tasking that should be considered when designing for asymmetric bimanual interaction is that multi-tasking is easier when the various tasks are closely related (Sharp, Preece & Rogers 2019:105–106).

Another factor that affects asymmetric bimanual interaction is handedness, which refers to the preference to use a specific hand for certain tasks, typically for more delicate tasks like writing (APA Dictionary of Psychology 2021). For asymmetric bimanual interaction in the physical environment, there is an assumption that the dominant hand is more likely to be used for a primary action, while the non-dominant hand is used to support the action of the dominant hand. Selections related to handedness also tend to have the following results: the dominant hand is more efficient, and the non-dominant hand experiences more fatigue (Lou, Feng & Shi 2020) but the level of impact that handedness has on user performance is dependent on the method of input. Habibi & Chattopadhyay (2021) conducted a study that investigated the impact of handedness with touchless input, e.g., air-based gestures and motion-tracked controllers and they found that there was less performance difference between hands when using touchless input compared to the use of a computer mouse or a touchscreen stylus, specifically for tasks like pointing at a target and dragging items between two positions.

2.8.5 Hand movement in 3D space

To take advantage of the ability to perform bimanual interactions in an IVE, a controller that allows for six degrees of freedom (6DoF) should be used (Mine, Yoganandan & Coffey 2014; Cabral 2017) where the first three (1-3) degrees refer to manipulation by disposition (Figure 2-7) and the next three (4-6) degrees refer to manipulation by rotation (Figure 2-8) (Mine, Yoganandan & Coffey 2014; Cho & Wartell 2015; Niehorster, Li & Lappe 2017). A 7th DOF is discussed by Cho and Wartell (2015), which refers to the resizing of elements in a virtual environment. Resizing is a useful property for virtual objects because objects can be resized to be small for easier storage, e.g., menu items around the body, and later be returned to their intended size for selection and usage.

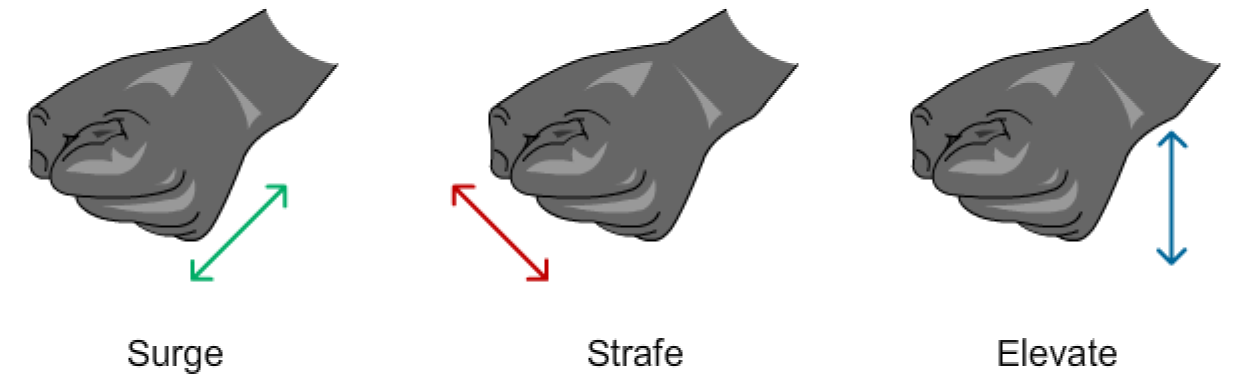


Figure 2-7: An adapted visual representation of a hand's risposition degrees of freedom (DoF) as described by Mine, Yoganandan, and Coffey (2014)

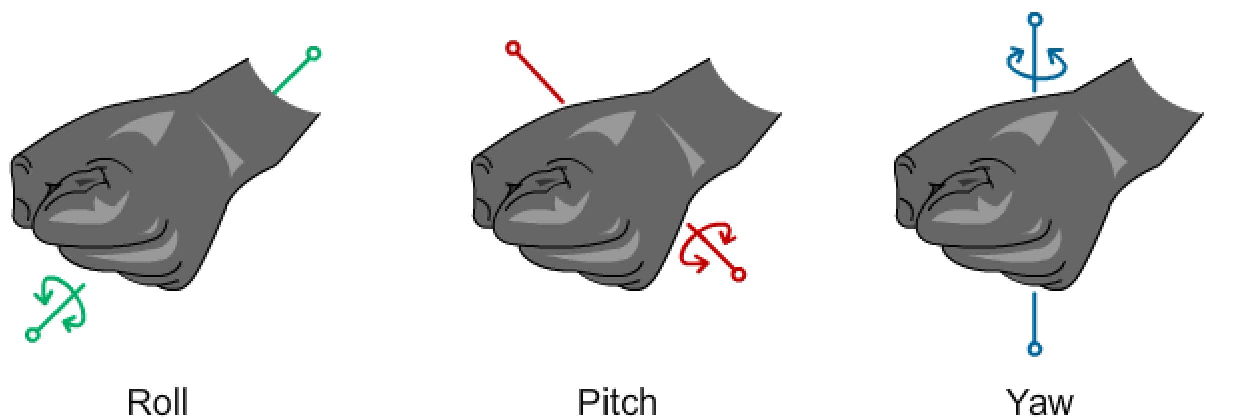


Figure 2-8: An adapted visual representation of a hand's rotation degrees of freedom (DoF) as described by Mine, Yoganandan, and Coffey (2014)

2.9 *Menu properties for IVEs*

Within the studies of menus, the concept of mnemonics refers to a form of shorthand to quickly select an item in a menu by pressing a key on a keyboard that matches the underlined letter in an on-screen menu (Bailly, Lecolinet & Nigay 2016) . This is in different to physical mnemonics that, for the context of the current study, refers to the memory technique discussed in Section 2.7 above and in the context of menus, physical mnemonics can help users remember where virtual objects are located (Mine, Brooks & Sequin 1997).

2.9.1 Structure and layout

Various interaction techniques for selection of virtual objects have been explored to allow users to optimally interact with virtual objects in an IVE (discussed in Section 2.8 above) and once this is established, the user can interact with a collection of virtual objects that is placed in a structured manner, such as a menu system (Dachselt & Hübner 2007; Bailly, Lecolinet & Nigay 2016).

Menus in an IVE pose various issues that need to be reconsidered for a 3D space, such as learnability, visual representation of menu items, and physical fatigue caused by the use of larger muscle groups when interacting through direct manipulation in the IVE (Bowman & Wingrave 2001). Menu layouts determine the position of menu items relative to each other within a menu system resulting in various menu layouts to be considered when optimising the selection process of items in menus to address the aforementioned issues, such as linear menus, radial and rotary hand menus, and diegetic menus.

A linear menu is a menu layout that provides various options within a vertical or horizontal list, e.g., a dropdown menu which is an easily understandable structure for how to view and select items but requires more travel distance to items further down in the list (Komerska & Ware 2004; Chertoff, Byers & LaViola 2009). To equalise the travel distance, menu items can be placed around the point of activation, i.e., selecting a virtual object to bring up a menu for more options; this layout is referred to as the radial menu, or a pie menu. Placing menu items around the point of activation retains an easily understandable structure, like the linear menu, while also reducing the average distance to reach each item, resulting in reduced effort and increased accuracy and speed for selections (Komerska & Ware 2004; Ren & O'Neill 2013). Additionally, with enough practice users can perform eyes-off interaction with the radial menu (Chertoff, Byers & LaViola 2009) and without the need to move the head to look at every interaction, fatigue caused by head movement can be reduced as well (Bowman & Wingrave 2001; Eriksson 2016). Similar to a radial menu, a rotary menu refers to a layout that is the same as the radial menu but selection is done by rotating the wrist to cycle through selections, although this selection method is limited by the rotational ability of the wrist (Chertoff, Byers & LaViola 2009).

Menus can consist of multiple hierarchical layers for grouping menu items together and reducing clutter (Kim et al. 2000; Bailly, Lecolinet & Nigay 2016) but this can undesirably cause menu items to be lost or hidden in these layers. To remedy this occlusion, a flat menu structure can be used, which refers to having fewer hierarchical layers and more items visible at a time which eases the searching process (Scarr et al. 2011); however, this can be overwhelming for novice users if there are too many menu items, which once again becomes visually cluttered.

Contextual menus refers to a menu dynamic layout that is dependent on the objects that activated the menu, i.e., the contextual menu activated by selecting a virtual toolbox would be different to the menu activated on a virtual vehicle (Bailly, Lecolinet & Nigay 2016:13; Sharp, Preece & Rogers 2019:204). In relation to a layout that is dynamic, morphing menus provide a list of items where each item dynamically increases in size the more an item is used, which could result in more clutter (Bailly, Lecolinet & Nigay 2016). A different approach was used with the Finger Counting menu where usage of large muscle groups are reduced through the use of touching finger tips with the thumb which also provided an interaction that is familiar to novice users through gesture-based recognition (Kulshreshth & LaViola 2014). However, this interaction requires multiple layers of submenus if items exceed more than five items, which can be confusing and increase difficulty of searching for specific menu items hidden in layers of submenus.

2.9.2 Representation of menu items

The visual representation of menu systems should align with the context of usage, e.g., the icons on the menu tabs in a word processor all have a similar style, so that users are not distracted by the misalignment (Salomoni et al. 2017). In the context of engaging in an IVE, the user's experience of presence should not be interrupted by any visual misalignments.

Diegetic menus use a visual representation that narratively aligns with the context of the IVE that the menu is used in (Salomoni et al. 2017), e.g., menu options for a timer should be placed in a clock or a wristwatch, instead of arbitrary floating controls. Diegetic menus in stereoscopic interfaces, such as the HMD in VR technology used in the current study, can be presented as a global control interface that is persistently available, a property that allows users to always have access to functions that are contextually and functionally relevant to the task (Salomoni et al. 2017). The representation of a menu item should also provide an intuitive clue to the user to indicate the function, which is known as an affordance (Sharp, Preece & Rogers 2019:26–31) and should be taken into consideration when making use of 3D representations for menu systems as well so that the menu items can be better aligned to the 3D nature of IVEs.

2.10 *Using proprioception for supporting menu system interaction in VR*

Menu system design is a problem that is not new to interaction design and there are findings that inform good usability guidelines for flat screen displays of varying sizes, from monitors for desktop computers, smart television, tablets, smartphones, to smart watches, as discussed in Section 2.2. However, the design of menu systems used in a 3D virtual environment needs to be reconsidered to make use of the immersive nature that VR technology provides. Therefore, existing design guidelines that were developed for the intention of a flat screen were carefully considered to determine their applicability for a 3D environment.

Designing for a 3D virtual environment comes with the advantage of allowing interactions that make use of motor skills similar to the physical environment, i.e., direct manipulation, which is easy to learn, as discussed in Section 2.8.1. These motor skills used for interaction and movement in the physical environment rely on proprioceptive senses, which, as studies have demonstrated, can also be used for guiding interaction in the virtual environment as discussed in Section 2.7. However, the reliance on proprioception has not been explored in the context of menu design; therefore, the current study investigated the potential for users to rely on proprioception for menu item selection.

Reliance on proprioception typically stems from users becoming familiar with their physical and virtual environments due to establishing spatial awareness, as discussed in Section 2.7. This level of familiarity is more prominent in expert users and may lead to progressively less visual reliance, as discussed in Section 2.6.1.3, resulting in the potential to exhibit two user behaviours: eyes-off interaction and multitasking and because these can be used as indications of expert user behaviours, they are considered with particular interest in the current study.

With these considerations in mind regarding the interactions in a 3D virtual environment, the current study explored various concepts to inform the interaction with a menu system used in an IVE in a way that enables reliance of proprioceptive sense to select menu items.

2.10.1 General usability considerations

The following considerations are used to generally inform support for usability regarding various contexts and are not limited to menu systems nor for usage in IVEs.

Six usability goals are commonly used for guidance when designing a system that results in users being facilitated to complete a task and finding the system to be satisfying to use (Sharp, Preece & Rogers 2019:19–22). These six usability goals, prescribed by Sharp, Preece & Rogers (2019), have been used for informing design decisions for educational games (Cezarotto & Chamberlin 2021), establishing frameworks for designing and assessing UX (Adikari, Mcdonald & Campbell 2011), and designing UI that is more accessible for emotionally vulnerable groups (du Preez, Coleman & Smuts 2022). This is an indication that the usability goals are generalisable to many applications. Therefore, the design of a menu system intended to be used in an IVE can benefit from taking these usability goals into consideration as well.

The usability goals provide guidance to produce a system that is:

1. Effective: the system must help the user to accurately complete the task.
2. Efficient: the system must help the user to complete the task quickly.
3. Safe to use: support for error prevention and to prevent data loss must be provided.
4. Have good utility: supporting features for completing the task must be provided.
5. Easy to learn: the system must help novice users to easily use the system.
6. Easy to remember: the system must be easy enough to remember how to use it.

To support users to understand how to interact with a system, five design principles have been prescribed by Sharp, Preece & Rogers (Sharp, Preece & Rogers 2019:26–30). These five design principles have been used for informing the design of a learning management system (Shanmugasundaram & Chidamabaram 2020), the interface design for mobile e-books (Wang & Huang 2015), and for designing UI for emotionally vulnerable groups (du Preez, Coleman & Smuts 2022). This suggests that these design principles are applicable to a wide range of use cases. Therefore, the current study also used these design principles to inform the design of a menu system for an IVE.

The five design principles prescribed by Sharp, Preece & Rogers (2019:26–30) are as follows:

1. Visibility: interactions required from the user, as well as the system status, should be clearly communicated visually.
2. Feedback: the system should respond to the user's interaction.
3. Constraints: limitations provided by the system should be used to guide the user to complete their task.
4. Consistency: functions and UI elements that are similar should be designed in a way that indicates this similarity.
5. Affordance: hints of how to use the system should be provided in a simple and logical manner.

Both sets of criteria above have been used to inform the design of various products and were therefore used in the current study to inform menu system design for IVEs as well.

2.10.2 Usability guidelines specific to menu system design

The following three sets of usability guidelines were used to inform specific aspects of a menu system. This was to ensure that the menu system supports the user's ability to complete tasks, specifically by enabling users to rely on proprioception for menu item selection.

<u>Guideline 1:</u> Concepts from various studies were synthesised into a list of four characteristics that a menu should embody. A menu system that conforms to these four characteristics ensures that it will maintain its function and behaviour (Bailly, Lecolinet & Nigay 2016).

1. Menus should provide a list of items for a user to select, which represent functions that facilitate users in completing a task (Foley, Wallace & Chan 1984).
2. Menus should present the list of items in a visually structured manner (Dachselt & Hübner 2007).
3. Menus should be transient, with information temporarily displayed and easily dismissed (Jakobsen & Hornæk 2007).
4. Menus should be quasimodal, with the menu kept in place through some constant action on the part of the user (Raskin 2000).

Guideline 2: The five requirements listed below provide an appropriate goal to determine what should be expected from a new menu system (Bowman & Wingrave 2001):

1. Users should perform at least as well as when using other menu types, if not better, in terms of efficiency and accuracy.
2. No significant discomfort should be experienced while using the new system.
3. The menu system should not obstruct the user from interacting with the virtual environment.
4. Novice and experienced users should find the new system to be usable.
5. With enough experience, users should be able to do eyes-off interaction.

Guideline 3: Guidelines for selection techniques (Argelaguet & Andujar 2013) were followed since the selection process is crucial to menu interaction.

1. The selection technique must be able to provide rapid selection.
2. It must be accurate and error-proof selection.
3. The selection technique needs to be easy to understand and control.
4. It must produce low levels of fatigue

In combination, these three sets of guidelines served as a benchmark to ensure that a menu system meets the requirement for providing support for the user to complete tasks. This was done by supporting users to develop awareness and familiarity with the menu system to rely on proprioception for selections.

2.11 *Summary*

This chapter discussed the importance of menu systems as a UI element that supports interaction for engaging in an IVE and highlighted the significance for providing a menu system that is diegetic to a 3D space due to the immersive nature of VR technology. There are various existing design guidelines that inform menu system design on a flat monitor display and so, this chapter investigated the possibility of using some of these existing design guidelines to inform a menu system used in an IVE. Additionally, various interaction techniques used in IVEs were also taken into consideration regarding interaction with a menu system in a 3D space. The lack of design guidelines that utilise proprioception was highlighted and guidelines for the design of a menu system to make use of this were provided. The next chapter addresses the research methodology that was followed for the current study.

3. Research design and methods

This chapter discusses the choices surrounding the research approach for the study of proprioceptive menu systems used in an IVE.

The goal of the current study was to identify and test criteria that can be used to inform good design for menu systems, particularly those used in IVEs that are presented with VR technology. The criteria were compiled based on various concepts from existing literature, which was discussed in Section 2.10 as design considerations which were identified with the intention of including perceptual properties that will support the ease of learning the menu system and enable reliance on the proprioceptive senses for menu item selection. The feasibility of the criteria will be determined by whether a menu system that was designed based on these criteria is able to support users in this reliance of proprioception. based on these criteria, a menu system, called the Belt Menu, was designed and developed to test the feasibility of the identified criteria. The Belt Menu was thereafter assessed through usability testing.

The success of a menu system can be measured by how it supports the user to complete a task in an effective and efficient way. However, effectivity and efficiency are only two aspects that affect the experience of using a menu system. If a user is satisfied with a menu system, it not only allows them to perform well with a task, but they would enjoy using the menu system as well. Therefore, user experience was used as the primary factor that determines how well-designed a menu system is and is triangulated with user performance. Investigating user experience was expected to provide perspective on whether participants would find the reliance on proprioceptive senses to be supportive of their interactions with the menu system when completing a task which was especially important as proprioception has not specifically been explored as support for menu system interactions.

3.1 *Research Paradigm*

Humans naturally perceive the world around them in a subjective manner and assume that others have the same perception of the world as they do. Therefore, human perceptions are based on subjective interpretations of their own personal experiences. Such assumptions result in a perspective that is largely influenced by how they base their perceptions on subjective interpretations of their personal experiences, this understanding for human perception is based on the perspective of phenomenology (Sundler et al. 2019). Accepting this perspective creates an understanding that experience is subjective and should therefore be intentionally studied to find in-depth understanding.

The interpretation and understanding of the users' experiences must be carefully investigated to ensure that the intended meaning and the researcher's understanding match each other. The interpretivist paradigm is a research approach that aims to understand the meaning individuals give to their own actions as well as to the actions of others (Given 2008:459) and this research paradigm takes the stance that there is no single reality that everyone experiences identically but rather, the multiple realities of individuals are discussed collectively to help find meaning (Pickard 2019:12). Because this research paradigm takes this stance, comparing multiple subjective experiences of the same context allows for interpretations to be identified, regardless of whether they are similar or different (Merriam & Tisdell 2015:196). The goal in identifying these interpretations in multiple experiences is not to reach a consensus, but rather to acknowledge all interpretations that provide a holistic understanding of how the shared phenomena were experienced (Stake 2010:95). Furthermore, acknowledging all interpretations takes the stance that the researcher's own interpretation is included as well because their interpretation is ultimately used to report on the understanding of the participants' experiences (Given 2008:462). Because of this inclusion, it is important to be aware of, acknowledge, and accept that the researcher's own assumptions will influence the resulting understanding of the participants' experiences (Sundler et al. 2019).

During the data collection phase of the current study, both the researcher and the participants gained insight through each other's experiences and observations. Therefore, the research activity of testing a menu system resulted in gained knowledge that influenced all involved parties (Pickard 2019:12). The approach of the interpretivist paradigm extracts a holistic meaning through acknowledging the subjective nature of experiences from all involved parties, i.e., both the participants and the researcher (Pickard 2019:13) and was therefore considered as the most suitable approach for the current study. Adopting this approach enabled basing the understanding of the current study on an understanding of the participants' experiences based on interpretations from each participant's own perspective, the perspectives of other participants, and the perspective of the researcher. Having multiple perspectives allows all involved individuals to reflect further on their own experience by comparing it with the experiences of others, resulting in a more holistic understanding that also provides self-understanding and perceptual experiences for all parties involved (Given 2008:462).

3.2 *Research Methodology*

The criteria identified in Section 2.10 were used to inform the design of a menu system, called the Belt Menu which was then tested by having participants use it to complete a task. To determine how these criteria can be used to inform menu system design for IVEs, the participants' experiences were employed as the primary measurement. An investigation into their subjective experiences aided in understanding how the menu system influenced the ability of the participants to complete a given task and the investigation was done by comparing the experiences with one another, thereby identifying which aspects of the menu system enabled participants to rely on their proprioceptive senses to perform menu item selections.

Extracting meaning and value from the participants' subjective experiences required a qualitative approach to be adopted as the methodology for the current study (Merriam & Tisdell 2015:24; Pickard 2019:16). In addition, user performance was recorded as quantitative data to supplement the findings and verify the subjective experiences.

3.2.1 User experience

When using a product, such as a menu system, a user's preference is not determined only by the efficiency that the product provides but also by the user's experience and emotions (Norman 2003). Experience is based on personal judgement, which is greatly influenced by an individual's interpretation of a context (Given 2008:464; Stake 2010:50). Therefore, study aimed at investigating experience involves examining the experience of each participant, since no individual's experience would be identical to another's (Stake 2010:62). Using this perspective, these experiences were investigated to identify the reasoning behind each participant's preferences.

The goal of this study was not to investigate a story or an event through the experience-lens of an individual. Instead, individuals and their experiences were used to investigate the feasibility of the Belt Menu in understanding how menu system design could support users to rely on their proprioceptive senses for menu item selection. The study thus relied on the past experiences of individuals with IVEs and whether these past experiences would impact their experience with the Belt Menu (Stake 2010:48; Goodman & Kuniavsky 2012:506). As such, the current study sought to analyse and understand human experience for a specific context, that is, to use the Belt Menu to complete a task in an IVE. Once those experiences were understood individually and as a group, that understanding was used to investigate the feasibility of a menu system in terms of understanding how proprioception can be used to design for the support of menu item selection. Past experiences will affect the way an individual interprets their current context (Stake 2010:48; Goodman & Kuniavsky 2012:506). It was therefore valuable to spend time to understand the past experiences of these individuals with IVEs that use VR technology, which provided a different perspective and therefore a better understanding of an individual's behaviour when using the designed menu system (Flick 2009:448; Stake 2010:50). The history of an individual was cross-referenced with current tasks to understand the context from the individual's perspective (Merriam & Tisdell 2015:24).

The focus of examining experience meant that this study did not rely solely on subjective data from participants. Good qualitative research focuses on factors that contributed to an event and how it was experienced (Stake 2010:63). The current study made use of subjective experience as the primary measurement for feasibility and the value from this collection of experience was verified when triangulated by supplementary data (Flick 2009:445; Stake 2010:63). Supplementary data were collected in the following ways: observations from the researcher's perspective, quantitative measurements of the participants' performance, and recordings of events, i.e., participants carrying out a task by using the Belt Menu.

3.3 *Research Method*

Usability testing is a method of analysing users while they work with a product to perform set tasks, which provides the opportunity for the product to be analysed for improvement (Holzinger 2005; Barnum 2010:13). Usability testing has an iterative nature (Rubin, Chisnell & Spool 2008:14; Pickard 2019:133) that makes it a commonly-used research method within the field of interaction design (Sharp, Preece & Rogers 2019:501)and this iterative nature of usability testing allowed for multiple phases of design and implementation when creating the Belt Menu which not only helped to define the specifications of the Belt Menu in earlier phases, e.g., informal testing during design and implementation along with pilot testing, but it also helps to identify issues in the design so that Belt Menu can be improved during a pilot study phase.

Usability testing is utilised to generate specifications for a system and is typically conducted in a controlled environment (Pickard 2019:129) and studies performed in a controlled environment allow researchers to control external influences that may affect the participants such as distractions from noise and social influences which can be minimised so that participants can focus on completing the tasks (Sharp, Preece & Rogers 2019:524). Conducting this study within a controlled environment was selected for the current study because it allowed data to be collected with minimal influence from external factors (Barnum 2010:26). Users were studied in a computer lab containing VR equipment, which is known as the "Virtual Reality and Interaction (VRI) Lab". This setting was chosen because of the availability of the VR equipment and because it was a setting that is similar to using VR technology in a natural setting, i.e., a spacious room with a computer and VR equipment. Using a controlled environment to study the participants also enabled data to be captured about participant's subconscious reactions during the test, e.g., body language that may suggest confusion or familiarity, and comments ,e.g., sounds and statements of frustration or surprise (Pickard 2019:127) and a discussion with participants was conducted after the test to gather data about their thoughts, during which such subconscious reactions and comments could be mentioned for reflection and understanding.

There can be various approaches depending on the goal of a usability test, namely: typical, benchmarking, comparison of designs, and competitive evaluation (Barnum 2010:112). The typical structure for a usability test is conducted by presenting participants with tasks to complete and is achieved through using a given product in set scenarios, after which participants provide feedback on their experience (Barnum 2010:112; Sharp, Preece &

Rogers 2019:524). This is usually done to help inform the design of products that are in development (Barnum 2010:112). The benchmarking structure is conducted by testing a product with users to identify various measurements which are then used to create a standard that the product should meet, which is referred to as a benchmark (Barnum 2010:112; Lewis 2014). The goal of this approach is to establish requirements for new products. The comparisons of designs structure is conducted by having participants test more than one design to see what preferences they may have (Barnum 2010:112; Salvendy & Karwowski 2021:981) and the goal of this approach is to identify and explore preferences that users have in the designs of products. Lastly, the competitive evaluation structure is conducted similar to the comparison in designs structure except for two differences: existing products are tested and not just designs, and one of the products being tested was created by the researcher or developer while the other product belongs to a competitor. The goal for competitive evaluation is to compare the researcher's product against competition (Barnum 2010:112; Still & Crane 2017:192).

The goal of the current study was to identify criteria that enabled users to perform menu item selection through the guidance of their proprioceptive senses in an IVE and the identified criteria needed to be tested, which was done by using the criteria to design and develop a menu system. Users then completed a task using the designed system and were then asked to provide feedback on how the various aspects of the designed menu had contributed positively and negatively towards their ability to complete the tasks. This process resulted in establishing requirements for new menu systems. Therefore, the benchmark structure of a usability test was considered to be the most suitable for the current study.

3.3.1 Details of the usability test

Each participant was asked to take part in three separate usability test sessions where they were required to use VR technology that presented the Belt Menu to them within the IVE to complete a set of tasks. Each usability test session per participant was one week apart to observe whether participants can retain their familiarity and proficiency with the menu system over multiple sessions.

Participants could redo any tasks from the same usability test session as practice because this usage of the menu system encouraged learning (Fitts & Posner 1967; Cockburn et al. 2014); however, they were not allowed to do tasks from previous or future sessions. Each time the participant completed the task, they were timed to track the performance of the participant and it was recorded as an attempt. The set of tasks presented to the participants was different for each session, which ensured that any increase in performance would be the result of the participant's familiarity with the menu system and not with the task itself.

3.3.1.1 Pilot studies

Pilot studies are commonly used to help identify and eliminate issues within a study or data collection technique so that problems can be identified and fixed (Pickard 2019:192, 284; Sharp, Preece & Rogers 2019:265). A pilot study consisting of five participants was used for the current study in order to refine the tasks that participants are required to complete, revise the questions asked during interviews, and find more focus on what to observe in terms of the participants' engagement with the Belt Menu. Expert users of VR technology were used for the pilot study due to their familiarity with the hardware which provided the opportunity for them to advise on improvements since they understood the hardware's capabilities. Their input regarding improvements for the interaction method of a menu system used in IVEs were considered valuable because their recommendations were based on their experience with various commercially available IVEs. The use of a pilot study also helped to determine how long of a break, e.g., one day or more, participants needed from VR systems between each session and the result of this was that having a week between sessions would be a good gap, therefore this became a measurement to see how long participants can retain their knowledge of how to use the Belt Menu. Once the pilot study was completed and adjustments applied, the system was ready for user testing.

3.3.1.2 Usability Test Session protocol

A script was implemented to guide the researcher during each usability test session to ensure that the details delivered to each participant were consistent and that all participants were treated the same. Additionally, this was used to prompt the researcher to prepare any equipment used for data collection (Sharp, Preece & Rogers 2019:295). Details of the script included: thanking the participant for their time, explaining what they were required to do, details about the proceedings of the usability test session, and asking them for consent to use their data. It was important to cover these details so that participants had a clear idea of what the study was about, what was expected of them, what data were gathered from them, and how they could help. Providing this information to participants encouraged a level of trust from them that increased the honesty in the data that they provided and also prepared them for these kinds of data to provide or discuss (Sharp, Preece & Rogers 2019:295).

Before participants arrived for the usability tests, they were each given a consent form (Appendix A – Consent form) and a questionnaire (Appendix B – Questionnaire) to be completed beforehand. Thereafter, each participant was presented with the IVE and the Belt Menu through VR technology to complete the set of tasks. The details of the tasks are discussed as part of the system design in Section 4.5. No details were given about how participants were expected to gradually develop expert user behaviour. One hour was dedicated to each session, where 20 minutes was dedicated for participants to use the Belt Menu to complete the task. During this time, participants were required to do the task over two attempts or more so that they could become more familiar with the Belt Menu. The remaining 40 minutes were used to interview participants about their experience with the Belt Menu.

A basic introduction for the VR technology was given if a participant had no experience with it. At the start of the first session for each participant, a brief introduction was given about the Belt Menu and only included details for navigating through the Belt Menu and selecting items which allowed participants to familiarise themselves with the basics of the IVE and the Belt Menu. It was short and simple so that they could familiarise themselves with how the sessions would typically occur and was done to ease the participants into the usability test, aiming to make them feel less anxious and more comfortable (Barnum 2010:131). After this introduction, participants were required to complete a task by making use of the Belt Menu.

The task would become more complex with each progressive session by requiring participants to make use of progressively more menu items from the Belt Menu. The progression of complexities was used to test if participants were able to become more proficient in using the Belt Menu. Details of the tasks for each session are discussed in Section 4.5.

After each session, a semi-structured interview was conducted with the participant to gather more data about their personal experience and their user behaviours were also observed during their experience with the Belt Menu in the IVE to collect data regarding behaviour that they may not be consciously aware of (Barnum 2010:138; Sharp, Preece & Rogers 2019:295–296). Details of the various data collection techniques used in the usability test sessions are discussed in Section 3.4.

3.3.2 Intended Sample

The target population was directed at people who have regular experience with virtual environments through videogames and have an interest in VR technology because they are familiar with technology that presents virtual worlds and with interacting with virtual objects in these virtual worlds. These people would be familiar with button layouts on gaming controllers and would understand communications linked to gaming jargon, e.g., trigger button, generating objects. Due to this familiarity, these people were considered to be less overwhelmed by VR systems, even though they had had varying experiences with VR systems.

Additionally, this population included people with varying levels of experience, from those that had no experience with VR technology that uses an HMD to those who have developed software for VR technology that uses an HMD. The reason for identifying the level of experience each participant has with VR technology was to see if this would affect their potential ability to perform the various tasks given to them through the IVE. Participants were given a questionnaire to ascertain their experience with virtual environments and VR technology, which is discussed in Section 3.4.1.

The university's institutional ethics committee does not allow for the collection of demographic data without clear justification. Since this study is not concerned with the effects of gender or age, there was not enough reason to justify the need for the collection of these data. Other criteria that were used to identify participants include the physical ability to user both hands, and the ability to be at the physical location of usability tests to partake in the study which were discussed in Section 1.7.2. Purposive sampling was used to identify and recruit participants that fit the criteria stated above (Lunenburg & Irby 2008:175; Pickard 2019:64).

With regards to a reliable sampling size for participants to be involved in a usability test, one study provides evidence that three to five users would be sufficient since they are able to identify 80% of usability problems in a UI (Nielsen & Landauer 1993), while another study has found that the using only five participants underestimates the sample size to conclusively detect problems because, even though a variety of problems can be identified, there is not enough data to verify whether these issues are commonly experienced or if they are outlying issues experienced by participants (Cazañas et al. 2017). Therefore, the use of 10 participants would be considered more reliable to ensure that there are enough data collected to verify the issues identified (Lindgaard & Chattratichart 2007). Studies conducted by Hwang and Salvendy (2010) and Faulkner (2003) indicate that involving 10 users is sufficient to identify more than 80% of design issues in a system, which suggests that not much more new data will be discovered if more participants are used. While there are varying opinions with regards to determining the number of participants that should be involved in usability tests, all of these sources agree that data collection should be done until saturation has been reached, i.e., there are no new usability issues that are being identified and that there is enough evidence to verify what has been identified (Lindgaard & Chattratichart 2007; Lewis 2014; Sim et al. 2018). Informed by the fact that 10 to 20 participants are able to identify 90% of the usability issues in a UI (Faulkner 2003; Lindgaard & Chattratichart 2007), it was decided to recruit at least 10 participants with the possibility of including more participants. In total, 17 people that fit the above stated criteria participated in this study.

Participants were recruited via personal contacts and once they confirmed that they would be willing and available, the details of their participation were emailed to them. This included the consent form Appendix A – Consent form and a link to the online questionnaire Appendix B – Questionnaire.

3.4 *Data Collection*

A combination of data collection techniques were used to triangulate the findings and ensure that the findings of this study were reliable (Pickard 2019:102, 230). The various data collection techniques used were as follows:

- An online questionnaire helped establish basic knowledge around each user's background experience with IVEs.
- Observations were done to collect data from the researcher's perspective as a complete observer.
- Interviews were used to understand each participant's experience from their personal perspective.
- Performance data were also recorded to verify the findings from an objective angle.
- Focus groups were used to explore the participants' experiences with one another to gain perspective from a different angle.

Each of these data collection techniques were selected to capture different types of data that inform the participants' experience of using the Belt Menu.

3.4.1 Questionnaire

A questionnaire is a common and reliable method of gathering demographic data from participants that can be completed in their own time (Sharp, Preece & Rogers 2019:278). Therefore, a questionnaire was used to gather demographics about each participant's gaming habits and VR experience and was distributed as the first step of data collection to identify details of their gaming habits and exposure to VR systems. Because this questionnaire was only used to understand each participant's habits and background in terms of gaming and VR experience, closed questions were mostly used but space for participants to elaborate on some of their answers were also provided (Appendix B – Questionnaire). While a notable limitation of using a questionnaire is that an opportunity to speak with the participant is missed (Pickard 2019:207), this limitation did not affect this study as interviews were also used at a later stage. Having information about each participant before the interview allowed the researcher to look over the information and ask questions more relevant to the participant.

A standardised questionnaire would be beneficial for collecting data because it would be from an established source (Barnum 2010:181–184). While there are various questionnaires that exist for investigating presence within VR studies (Lessiter et al. 2001; Graf & Schwind 2020), as well as investigating experience of videogames in terms of play (Norman 2013; Law, Brühlmann & Mekler 2018), these questionnaires do not help to understand the background experience of participants in both videogames and VR systems. Therefore, the questionnaire for this part of the study was created by the researcher (Appendix B –

Questionnaire). An online questionnaire (Google Forms) was used as the platform because it made the process of distribution and data capturing easier (Toepoel 2015:132). While online questionnaires run the risk of excluding individuals who are not technologically inclined or who may have limited or no internet access (Pickard 2019:223), this issue can be discarded as the target population are people who interact with technology regularly.

3.4.2 Observation

Observations are most effective for capturing detail of an activity or event while it is happening while other types of data collection, such as interviews and narratives only provide an account of the past (Flick 2009:222). Conducting the observation as a non-participant allows the observer to study the events from a distance so that they do not influence the event. In a natural setting, observations are typically done without explicit permission or awareness of those being observed to avoid influencing the participants and the activity or event, however, this is usually discouraged as it can be unethical (Flick 2009:223). In contrast, observations conducted in controlled environments often impose some level of discomfort due to a more formal environment (Sharp, Preece & Rogers 2019:295–296) and may cause participants to behave differently because they are aware of being observed.

Since the current study intended to investigate how the participants experienced support from the Belt Menu in helping them to complete the tasks, it was important to observe them using the Belt Menu. For this study, participants were observed in a controlled environment with consent which meant that they might be self-conscious of being observed. However, the expectation was that participants would feel less self-conscious of events in the physical room, including the idea of being observed, due to the immersive nature of IVEs presented with VR technologies, especially because the HMD completely obscured the participant's visibility of the physical room (Blackmon 2003; Bowman & McMahan 2007). This setup allowed the researcher to make observations about participants and measure their performance with minimal interference on their experience.

A common technique used to help understand participants while observing them in usability tests is the think-aloud protocol, which refers to requiring participants to verbalise their thoughts relating to their actions as they complete the tasks, allowing the researcher to better understand the thought process of the participant (Pickard 2019:128; Sharp, Preece & Rogers 2019:296). By having participants verbalise their thoughts, insight from these observations helped to identify reasons behind positive and negative experiences of participants (Barnum 2010:138).

The subsections below discuss details about expected user behaviours in regard to how they responded to the usability of the Belt Menu. However, one of the key strengths of using observations is to capture emergent and unexpected data (Merriam & Tisdell 2015:140–

141). By clearly identifying what would be expected user behaviours, this also provides clarity for what would be considered outliers and can therefore be focused on with more intention since there was an expectation that participants would interact with the Belt Menu in unexpected ways; therefore, there was an increased need for observing participants during the usability test sessions. Unexpected behaviour could be related to user expertise, layout and positioning, hand usage, etc. These provided some insights about the design of the Belt Menu that was not intentionally designed with these behaviours in mind. Additionally, capturing these unexpected behaviours provided evidence that can be used to supplement discussion points in interviews and focus groups (Merriam & Tisdell 2015:139).

By capturing user behaviour while the participant is using the Belt Menu to do the given task, subconscious behaviours could be brought up during interviews and focus groups. This allowed these details to be further discussed for understanding and reflection for the participants and the researcher.

3.4.2.1 Video and audio recordings

With the permission of participants, their experience with the menu system were recorded so that the participants' body language and their tone in speech could be used during analysis. To do so, a mounted video camera was used for recording the video and audio interactions of each participant's experience in the physical room. In addition to video recording the room, Open Broadcaster Software (OBS) was used to capture on-screen activity (https://obsproject.com/). The use of video and audio recordings preserves all details during a usability test session (Merriam & Tisdell 2015:131) and allowed for careful analysis of subconscious and implicit expressions made by the participants, such as body language and tonal differences in their speech (Pickard 2019:200–201), which allowed the researcher to reflect on it during analysis. An interview was conducted directly after the usability test session where the observations were confirmed with the participant to ensure that they were correct. Specific details of conducting interviews are discussed in section 3.4.3 below.

3.4.2.2 Interaction with the Belt Menu items

During the observation section, the researcher observed the participant's interactions, with particular focus on the following details that were discussed in the previous chapter:

- Ease or difficulty navigating through the menu system (Bowman & Wingrave 2001; Bailly, Lecolinet & Nigay 2016).
- Item selection (Ivan Poupyrev & Ichikawa 1999; Bowman & Wingrave 2001; Argelaguet & Andujar 2013)
    - Items are within reach or out of reach (too far or close).
    - Objects representing items to select are understood correctly or incorrectly.
    - Visibility of items and labels.

  - Ease or difficulty of recovering from an erroneous selection (reversing an incorrect action and performing a correct action).
- Ease or difficulty in becoming familiar with the menu over time (Bowman & Wingrave 2001; Shneiderman et al. 2009; Sharp, Preece & Rogers 2019:19–22).
- Levels of comfort and fatigue for using the menu system (Bowman & Wingrave 2001; Argelaguet & Andujar 2013).
- Ability to perform eyes-off interaction (Mine, Brooks & Sequin 1997; Bowman & Wingrave 2001).

To determine how easy or difficult it is to navigate through the Belt Menu, participants were observed for behaviours that express emotions, e.g., frustration, confusion, enjoyment, etc., when searching for specific menu items and submenu items.

Regarding item selection, focus was given to the following user behaviours while they interacted with the Belt Menu:

- Menu items in/out of reach: participants were observed on how they reached for menu items. Some menu items were purposely placed in specific positions to test the limitations of reach.
- Hand usage: this was observed to understand whether they were comfortable to make use of both hands and to understand what purpose they assigned to each hand and the reasoning behind it. The level of dexterity in the dominant hand and the non-dominant hand usually differ, which can affect the level of familiarity and confidence in their selection.
- Spatial awareness and memory: remembering the functions and locations of menu items along with noticing other forms of feedback, e.g., haptic feedback, helps to establish a sense of awareness for the menu system. Any progress for the level of this awareness, whether it is established actively or subconsciously through repetition of selections, contributed towards becoming familiar with the menu system. With enough familiarity, participants may feel comfortable enough to multi-task, e.g., simultaneously making independent selections with each hand, which is considered expert user behaviour.
- Where the participants were looking: taking note of this behaviour allows it to be used to verify the level of attention the participant gave towards interacting with the menu system while attempting to complete the task. Verification can be done by pointing this out during an interview and asking them for the reason behind this behaviour. Progressively relying less on visual guidance while performing selections indicates a progression towards what is considered expert behaviour.
- Error recovery: the way participants responded to and fixed these errors were observed because their attitude towards error recovery is affected by the usability to undo and redo actions.

As participants become more familiar with UI elements, they should become less reliant on visibility for interaction and increased familiarity should instead stem from remembering the position of menu items. The fluid selections should help with this as the motion for selection becomes well-practiced. Therefore, it is expected that at some point they will perform eyes-off interactions when selecting menu items.

While making an observation, focus is placed on a particular element of interest (Stake 2010:90), which implies that elements out of focus will be missed. It is for this reason that other data collection techniques were used. Screen recording was used so that the researcher may focus on details that take place in the physical room during the observation section and to provide an additional angle to help understand any anomalies that took place while analysing other data.

Although there was minimal interference during the participants' engagement with the IVE while being observed, researcher bias would be unavoidable when it comes to assumptions made from the researcher's observations. As much as the researcher may have tried to discard any known bias, what was observed and interpreted by the researcher would be based on their own past experience with IVEs (Merriam & Tisdell 2015:25). This does not compromise the validity of the findings for this study of proprioceptive menus. Rather, interpretations based on the researcher's experience can be treated as a starting point for establishing an understanding and can then be verified or refuted by discussing them with the participants (Stake 2010:126). Other data collection techniques, e.g., interviews, can also be used to verify the findings made from observations (Flick 2009:225).

3.4.2.3 Progression in relation to expertise

There was a particular interest in studying each participant's ability to become proficient with the Belt Menu with an expectation that with each subsequent session participants would become more experienced with the Belt Menu and would therefore interact with the menu system with more expert behaviours.

It was expected that participants would be novice users in session 1 while becoming familiar with the basic interactions of the Belt Menu. By session 2, participants were expected to be familiar with the selection method, as well as easily making associations between main menu items and submenus within the Belt Menu. There was an expectation that participants should be familiar enough to make selections smoothly and effortlessly.

The success of the designed menu system was especially tested in session 3. Participants would have to give their attention primarily to completing the task (matching the shape, colour, and size of the blocks), resulting in the Belt Menu being used as a supporting interaction. This is referred to as automaticity, which is the ability to perform a task with little cognitive effort, which is an indication of expert user behaviour (Fitts & Posner 1967:8–25; Shneiderman et al. 2009:66–69).

3.4.3 Interviews

Interviews are useful for capturing information such as user feedback from the perspective of an individual (Flick 2009:149–175). Using semi-structured interviews provided participants with the opportunity to discuss their own thoughts freely and reduced the need to be prompted to elaborate on specific details. These two benefits helped to explore the topic from each participant's perspective while ensuring that all participants cover the same topics (Flick 2009:156; Barnum 2010:57, 156).

Four limitations should be considered when conducting interviews (Taylor, Bogdan & DeVault 2016:106–107):

1. People say different things in different situations. A participant may state that their reasons for actions were one thing during the interview but this may differ to when the participant was in the scenario.
2. Researchers who rely only on details given in an interview will lack the understanding that comes from the context that they are interested in.
3. Researchers may potentially misunderstand the informant's language. Informants may not know or want to discuss what is considered important to the researcher. Some details can only be extrapolated from the context through observation.
4. Researchers will make assumptions about the details given by the informant, which may be wrong.

To address the first two limitations of interviews listed above, the current study used other data collection techniques to confirm the findings of the interviews. This helped to triangulate a more holistic understanding than relying solely on interviews. The last two limitations of conducting interviews caused by the researcher's potential misunderstandings and assumptions were addressed through member checking, where participants are asked to look over the notes made by the researcher, which allowed the participants to make potential comments or corrections (Stake 2010:126). A common concern for member checking is that most participants are not willing to spend additional time and effort to review the researcher's notes. However, the researcher could verbally go over their notes in the interview, which requires less effort for participants and could make them more willing to engage and make comments or corrections (Stake 2010:126). The accuracy of the account is limited to the interviewee's ability to report the details. However, the same could be true for the observer. By using these data collection methods together, details missed from observations (limited by the observer) can be accounted for from interviews (limited by the participant) and vice versa.

Questions for the interview were developed based on findings from the pilot study (Appendix C). Reflecting during an interview often results in new insight and perspective for both the researcher and the participant (Taylor, Bogdan & DeVault 2016:114). These new insights and perspectives resulted in further reflections and discussions. The interview with each participant was conducted right after the observation phase of each session. The interpretivist paradigm takes the perspective that no participants would have identical experiences when compared to each other, as discussed in Section 3.1. Because of this, it can be expected that discussion points could emerge from the observation phase based on each participant's unique behaviours and comments. Including these discussion points as extra questions would help to verify and understand each participant's experience of using the Belt Menu.

3.4.3.1 Audio recording

Recording equipment always has a chance of malfunctioning or the researcher may simply forget to switch them on (Pickard 2019:200–201). To mitigate these potential issues, the equipment was checked before each usability test session begins and backup equipment was organised. More than one audio recording device was used in case of malfunctions, e.g., faulty equipment, corrupted recording file. Participants were made aware of the fact that recording equipment was being used and may have initially felt uneasy about the presence of the recording equipment (Merriam & Tisdell 2015:131). To minimise this unease, the recording equipment was strategically placed where it was clearly visible but outside each participant's direct line of sight, i.e., placing the recording device to the side of the participant and by using the voice recorder on a laptop. Thus, it was expected that their attention was redirected towards answering the interview questions. The careful consideration for the placement of the recording equipment was to relieve participants of the constant awareness that they were being observed, which may have helped them feel more comfortable. Participants were informed of being recorded and the recording equipment would be pointed out to them at the start of the session. For this study of proprioceptive menus, the recording equipment was not visible to participants because they were wearing the head mounted display (HMD).

3.4.4 User performance

It is common practice to record user performance as part of a usability test (Sharp, Preece & Rogers 2019:524–525). Metrics produced by tracking user performance were not used to measure the user itself, but rather to understand their experience through their performance (Barnum 2010:137; Shneiderman et al. 2018b:192). User performance was measured as follows: overall timing for each task, number of erroneous selections, number of people making the same error, selection identification, selection accuracy, and selection speed. For the task to be completed, a specified number of blocks needed to be correctly selected from the Belt Menu. A selection from the Belt Menu required two selections: one selection from the main menu item and one selection from the submenu item. This produced a finalised selection, resulting in a tool from the Belt Menu, namely a specific block. For example: completing the task in stage 1 requires the participant to produce 10 blocks each of three different shapes. They would need to make two selections from the Belt Menu to produce each block, resulting in 10 blocks of three shapes with two selections for each block giving a total of 60 selections. This total of 60 selections would be considered the minimum number of selections required to complete the task. The details for determining the minimum number of selections for each stage and using it for analysing efficiency are further discussed in Section 5.3.2.1.

The performance of users affects their opinion of enjoying a UI. If participants were able to do the task efficiently by using the Belt Menu, it would contribute towards providing a positive user experience, leading to them to be more willing to use it again (Norman 2003). By recording performance data, both UI elements and areas that cause various emotions could be identified. Identifying these elements and areas allowed better understanding of the user's experience.

The current study measured the feasibility of the Belt Menu through user experience that was also triangulated by the metrics of each participant's performance. It also helped to isolate causes behind the deterioration of proficiency with the Belt Menu.

Table 3-1: Explanations for user performance

User Performance	Source(s)	Reason for the measurement
Overall timing for each task.	Per participant + each participant's overall performance.	Keeping track of overall performance time can help measure a participant's proficiency with the menu system. Decrease in time indicates that they are becoming more proficient, possibly due to having more confidence in successfully making selections. This allows the task to be the primary focus. Making the task a primary activity while interactions with the Belt Menu a secondary activity is a result of multi-tasking, which is a sign of expert user behaviour (Cockburn et al. 2014:3; Ericsson & Harwell 2019).
Total number of selections.	Per participant + each participant's overall performance.	Recording the total number of selections helps to determine how efficient participants are at completing a task. As discussed above, the minimum number of selections required to complete the task for each session was pre-determined. Any selections that deviate above this selection count indicated progressively lower efficiency. It was expected that more selections occurred as the task became more complex, which can be cross-referenced with the number of erroneous selections.
Number of erroneous selections.	Per participant + each participant's overall performance.	This addresses the number of times a participant has selected the incorrect menu item to perform an action. If a participant has more erroneous selections than correct selections, this suggests that the participant is making selections by constant trial and error. More errors would be expected during the early usability test sessions as the participants are still familiarising themselves with the menu system. A decrease in erroneous selections means an increase in accuracy, which builds confidence and could lead to less visual reliance, potentially leading to eyes-off interactions.

User Performance	Source(s)	Reason for the measurement
Number of people making erroneous selections with each menu item.	Each participant's overall performance.	This could help isolate problematic areas of the menu system design. Some menu items are intended to be placed in hard-to-reach positions to test the limitations of user selection. These positions are also outside the direct line of sight to test for eyes-off interaction.
Selection speed.	Per participant + each participant's overall performance.	A certain number of selections will be made in each attempt for completing the task. By comparing the total number of selections with the time taken to complete the task, selections per second (SPS) can be calculated. This would indicate how quickly selections can be made and compare this to selection accuracy. This value would provide a more valid indication of efficiency. The selection speed should also increase as participants become less reliant on visibility and more confident in their selections by using spatial awareness, memory, and proprioception (García et al. 2008; Buck 2021).

Using these empirical measurements ensures that the subjective comments and thoughts of each participant can be verified with performance data. Having these measurements will help isolate the tasks that the participant struggled with and the specific area that caused the struggle.

3.4.4.1 System recordings

The IVE was created with built-in functionality to have a more precise way to keep track of the various aspects of each participant's performance in specific tasks, namely timing and accuracy. Each participant's performance was tracked for each task given to them. A more elaborate explanation of these system recordings is mentioned in Section 4.7. This alleviated the need for the researcher to focus on recording the participant's performance, which allowed more attention to be given towards observing the participant. Using the system to track performance was more accurate as there would be no delays due to starting and stopping timers, as opposed to human reaction times. It also prevents miscounting interactions of each menu item and submenu items.

3.4.5 Focus Groups

Three focus groups consisting of five to six participants were conducted and were scheduled once every participant had completed all three sessions. These focus groups were used to encourage a discussion between participants about similarities and differences in their experiences with the Belt Menu. This was an opportunity for the researcher to understand how participants felt about the Belt Menu and the reasons behind these feelings (Barnum 2010:56). Using focus groups to understand users' opinions and feelings is a good tool for informing a new product or, in this case, a new menu system (Rubin, Chisnell & Spool 2008:17).

This platform also encouraged participants to think deeper about their own experiences, resulting in them sharing greater insights of their experience with the Belt Menu. Participants sharing would influence others so that they can review their own experience from a new perspective (Lunenburg & Irby 2008:92). The goal of using focus groups is not to reach a consensus within each group but rather to reveal different perspectives (Taylor, Bogdan & DeVault 2016:132). If there is a consensus in a group, it is important to make sure that it is not a result of the minority's comments or opinions being drowned out (Taylor, Bogdan & DeVault 2016:132). Even though comments and opinions may come from a minority, it can still prove valuable and credible if it can be triangulated by other data previously collected (Stake 2010:125).

Analysing data from the usability test sessions resulted in themes and topics of interest that were further investigated. Having a focus group after all the other data collection methods were completed provided an opportunity for participants to validate any findings that emerged from the analysis. Focus groups are not good for gauging performance issues but are more useful in understanding a participant's feelings towards a product (Rubin, Chisnell & Spool 2008:17). Therefore, any questions in the focus groups concerning user performance were only asked to supplement what was already observed during the usability tests. A script of the questions asked during the focus groups can be found as Appendix D – Focus group questions.

3.5 *Qualitative and quantitative analyses*

Qualitative analysis is the process of extracting meaning from experiences of events, which is executed by making sense and visualising the details of the events (Pickard 2019:267). The goal of performing this kind of analysis is to identify similarities and differences and to gain new perspectives, resulting in a more holistic understanding of the event than what was previously known and understood (Stake 2010:31). The current study made use of the experiences of participants to investigate the feasibility of the Belt Menu, i.e., the ability to support menu item selection through the guidance of proprioceptive senses. The interpretation of these events relies on a detailed understanding of the context for which the events occur (Stake 2010:51). The context of the current study is that participants needed to complete tasks within an IVE. Having a detailed understanding of this context helped to focus the investigation on the participants' experiences as users.

The analysing of experience already occurs while the data are being collected. As data are collected regarding the observed experience of participants, the researcher interprets their experience through comparison with the researcher's own experiences by identifying related concepts based on tacit knowledge to understand the reasoning behind the way in which the event unfolds (Pickard 2019:17). This tacit knowledge of the researcher originates from their own experience in IVEs and from designing and developing the Belt Menu. Since participants have past experience in IVEs, they also relied on their own tacit knowledge to interpret their own experience, which is why it was important to establish an understanding of their past experiences, as discussed in Section 3.4.1. Doing so provided a more holistic understanding of each participant's experience with the Belt Menu because the results of the questionnaire provided established knowledge of the context from which the participants would draw inspiration to express their own interpretation of their experience.

3.5.1 Interpreting user experience

Before interpreting the experience of others, the researcher needs to acknowledge that their own experience will affect how they interpret the experience of others. This acknowledgement enables the ability to be aware of known bias and assumptions so that the researcher can initially isolate opinions based on personal experience and focus on each participant's experience (Merriam & Tisdell 2015:27). This is done by adopting the assumption that the researcher does not know each participant's experience and seeks to understand the experience with new perspective (Sundler et al. 2019). Ultimately, the findings for this study were produced from the researcher's interpretation of the various participants' understanding of their own experience in using the menu system (Merriam & Tisdell 2015:25).

To interpret experience, qualitative research makes use of microanalysis and microinterpretation (Stake 2010:39). Microanalysis refers to the process of finding meaning from the experience of an individual, where the experience is investigated for finer details and not treated as a single instant and the resulting interpretation of this analysis is referred to as microinterpretation (Stake 2010:39). Multiple microinterpretations were then analysed collectively through comparison to identify anomalies and contradictions, and these identifications were then established as points of interest for discussion. In a group setting with participants, these points of interests were discussed to establish deeper understanding and to gain new perspective. This allowed interpretations to be made regarding the contribution, positive or negative, of various aspects of the menu system to the participants' experiences. Their experiences would assist in building confidence in menu item selection that could lead to reliance on proprioceptive senses for these selections.

3.5.2 Constant comparative analysis

Constant comparative analysis is a method of analysis that involves comparing one segment of data with another to determine similarities and differences (Pickard 2019:267). Data are grouped together on a similar dimension, which in this context refers to any aspect of the menu system that may affect user interactions with the menu system. For example, comments about menu item positioning and layout would be grouped together. The dimension is tentatively given a name and, depending on the frequency in which the dimension is identified in various segments of data and when new insights were identified, may result in becoming a theme (Pickard 2019:271). This process of identifying various dimensions is called coding (Pickard 2019:271). These themes are identified and refined by repeating the coding process over several iterations until no new themes emerge (Taylor, Bogdan & DeVault 2016:164). Recorded videos of each participant's experience, the on-screen activity, and the written notes were analysed to solidify the reliability of the emergent codes. The more information acquired about an experience, the more accurately it can be coded (Pickard 2019:271–273). It is important to investigate a study from more than one approach to ensure validity and to avoid bias (Barnum 2010:260–261; Pickard 2019:22; Sharp, Preece & Rogers 2019:264–265).

The objective of the aforementioned process is to identify patterns in the data, which are arranged in relationships to each other to identify emergent themes that help to create understanding and definition based on the data itself (Merriam & Tisdell 2015:32). Themes and the corresponding relationships between categories and properties are both defined and refined throughout the analysis process. Some themes could be inspired by concepts extracted from literature but the value of constant comparative analysis lies in identifying properties of the data itself that emerge from an iterative process of understanding the data. (Merriam & Tisdell 2015:33).

Each participant's experience during the three sessions was coded based on emergent themes (Pickard 2019:270). It is expected that themes typically fell under either positive or negative experience. These could come in various forms of comments, e.g., "The measuring tape confused me at first, but I get it now." or "The menu was fine, my hand was just clumsy", as well as criticisms, e.g., "The Paintbrush's position was awkward, so I kept making mistakes" or "The one icon was confusing". Specifics about what caused participants to have certain emotions, such as frustration, success, or empowerment, were analysed. These emotions could originate from how participants interacted with the Belt Menu, such as how they selected items, where they looked while making selections, issues with the menu system, and user errors. By analysing the notes taken from the observations, interviews, and focus groups, themes were identified.

Identifying the themes of the participants' experience provided a structured perspective that helped to investigate the feasibility of the design considerations in Section 2.10. These could then be used to support menu item selections in an IVE that are guided by proprioceptive senses. The expected participant behaviours mentioned in Section 3.4.2.3. were also used to gauge the feasibility of the designed menu system by analysing whether the progression of the participants' behaviours followed the trajectory towards expected behaviours and comparing expected behaviours to the participants' actual behaviours. The goal of analysing the experience of participants was to identify aspects of the Belt Menu that eased participants into becoming familiar with the Belt Menu in a way that supports reliance on proprioception for menu item selections, thereby addressing the research questions.

3.5.3 Software for qualitative analysis

To analyse all the qualitative data collected from observations, interviews, and focus groups, Atlas.ti was used (https://atlasti.com). This software allowed research articles and transcription documents to be imported. Doing so provided the ability to highlight quotations and add tags to them. These tags were used as themes that were identified from the analysis process and were then refined as more data were processed. Atlas.ti also allowed any annotations, e.g., comments or notes, to be embedded with additional information. Annotations were used to provide definitions for each tag so that the meaning for each tag could be preserved when tagging highlighted quotations. In addition to this, tags could also be linked to specific articles that were imported so that they provide a reference to existing literature. Tags could also be linked to one another through various relationships. This link could then result in a mind map that provided a visualisation of the analysis process. Using this visualisation helped to perceive how all these relationships link to one another, resulting in new insight about the feasibility of the designed menu system as a solution to the research questions.

3.5.4 Simple quantitative analysis

The findings from qualitative data were triangulated by examining user performance data to identify the nature of the event, e.g., the frequency of using a specific hand for selecting a specific menu item. Any report regarding unexpected user behaviour was verified, e.g., reports of feeling overwhelmed could possibly be confirmed by user interactions that have high selections count combined with lower accuracy.

Empirical data (efficiency, accuracy, time) were used to verify why participants would have a certain experience. The empirical data were processed through Microsoft Excel to understand how well participants performed in each session. The number of selections were totalled for all participants according to each of the three sessions. This total was dissected into total selections made with each hand, accuracy of selections, and total selections per menu item and submenu item. The best times taken to complete the task were also processed and compared to observe improvement in terms of efficiency, which supplemented the findings regarding progression of expertise with the Belt Menu. Using the total number of selections with the time taken to complete the task, efficiency was calculated as selections per second (s/s).

3.6 *Ethics considerations*

Collecting data from participants requires them to disclose personal information. It is important to ensure them that their data will be treated with care and confidentiality (Barnum 2010:170–172; Sharp, Preece & Rogers 2019:262–264). In addition to this practice being ethical, it also helps participants to establish a level of trust in their relationship with the researcher. Participants are more willing to share information when they feel that the researcher can be trusted (Merriam & Tisdell 2015:261; Sharp, Preece & Rogers 2019:262–264).

Before participants can share any information for a research topic, they would need to know what kind of information is required from them. They would also need to be informed of how their data will be used for the study. Participants also need to be given details to help them understand what is expected of them, what they will be doing, what details will be asked of them, and if there are any risks involved. Once participants understand these perimeters, they will know how they can be helpful for the research topic (Sharp, Preece & Rogers 2019:262–264). All this information can be communicated through a written consent form (Appendix A – Consent form) that they would need to sign in agreement. Sometimes, participants do not fully understand the details provided in the consent form. This can be resolved by verbally going through the consent form with them so that any ambiguity can be clarified. They were also asked to digitally indicate their consent in the online questionnaire.

The identity of all participants was kept confidential for this study of proprioceptive menus. Each participant was given a unique alias so that the researcher could keep record of their responses, behaviours, etc. Although video and audio recordings were made, none of the participants were identifiable through the footage, since their faces were obscured by the HMD. The video and audio recordings were also not viewed or listened to by anyone except the researcher.

Participants were informed that there would be three phases of participation. In total their participation required about four hours of their time, as discussed in Section 3.3.1.2.

VR technology (HMD and controllers) makes use of 360° motion tracking along with six degrees of freedom (6DoF) to allow for an immersive experience, as mentioned in Section 1.7.3. If there is a mismatch between the tracked body movement and what is presented to the user, the user can potentially experience cyber sickness. Cyber sickness is a temporary side effect that can be experienced when engaged with a VR experience. Symptoms of cyber sickness are like motion sickness, which includes dizziness, excessive sweating, and nausea (Rangelova, Motus & André 2020). Various levels of discomfort can be experienced by different people, even when the same content and technology is used (Chang, Kim & Yoo 2020).

All participants were notified of potential cyber sickness and how to deal with it. Each participant was informed that they should notify the researcher if they start to experience any symptoms of cyber sickness so that they may discontinue their engagement with the VR experience. The participant was given the option to either take a break to recover and resume their engagement or to retract their participation with this study altogether. Participants who chose to take a break were also given the option to schedule another session. Due to the nature of needing each participant to engage with multiple sessions, any data collected from a retracted participant were discarded as well.

3.7 *Summary*

The discussion in this chapter covered the details for the current study of proprioceptive menus in terms of what approaches were used, why they were chosen, and how they were conducted. A list of criteria was compiled to inform the design of the Belt Menu. To do so, user experience was used to measure the usability of the Belt Menu, which infers that the current study was primarily qualitative by nature since experience is inherently subjective. This investigation was done through usability tests, which provided the foundation for collecting data of each participant's experience with the Belt Menu in the form of user behaviour and performance. Analysis of the collected data was performed to extract understanding of each participant's experience. This was used to determine whether the identified criteria that informed the design of the Belt Menu enabled participants to establish awareness of menu items to the extent that they can use proprioception for menu item selection, thus addressing the research questions.

The next chapter discusses the details of developing the Belt Menu, the task, and the scenario used for the usability test. These details cover design choices, technologies used (hardware and software), and the changes based on the results of the pilot tests.

4. System design and implementation

This chapter covers the development process of the menu system, the scenario and the task presented to the participants, as well as the IVE that contained the scenario. The purpose for developing these elements (menu system, scenario, task) and the encompassing IVE was to create a virtual context wherein the menu system could be tested while completing the task. Following the identified criteria in Section 2.10 that are intended to inform menu system design used in IVEs, a prototype of a menu system was designed, called the Belt Menu. In testing the Belt Menu, the identified criteria were tested for their ability to inform menu system design that supports users in relying on their proprioceptive senses for menu item selection. Testing the Belt Menu was done over three separate sessions to investigate the potential progress of participants' familiarity and confidence in their interactions with the Belt Menu. The task in these three sessions was also progressively more complex to investigate progression in the participants' levels of expertise with the Belt Menu. Specifically, the design choices made to inform the selection technique and positioning were intended to support expert user behaviour, such as eyes-off interaction and multi-tasking.

For each of these elements (Belt Menu, scenario, task) and the encompassing IVE, the various design choices are discussed in detail. Additionally, the details for the usage of various technologies (hardware and software) that were needed to develop the IVE are included in this chapter. Data recording that would inform user performance was also built into the IVE, therefore the development of the functions for data recording is included in this chapter as well. Lastly, lessons learnt from informal user testing and pilot testing are also discussed here because these lessons influenced the design of the Belt Menu with regards to being intuitive for people other than the researcher.

4.1 Hardware details

The HTC Vive Pro (HTC 2018) was chosen as the hardware for presenting the IVE in the current study because it was accessible, it provided the adequate display quality required, and technical support was available to the researcher when needed. The HTC Vive Pro (HTC 2018) is a commercial VR system that it is used to present high-end VR experiences. It consists of five components, namely the head mounted display (HMD) (Figure 4-1), two handheld controllers (Figure 4-2, Figure 4-3), and two base stations (Figure 4-4). The HMD and handheld controllers are motion-tracked by base stations and must be tethered to a high-performance computer to be used.

4.1.1 The VR system – HTC Vive Pro

Figure 4-1: HTC Vive Pro - head mounted display (HMD) (HTC 2018)

The HMD is the device that provides visual feedback to the user. It also has built-in audio feedback. The specifications are as follows (HTC 2018):

- Screen: Dual AMOLED 3.5" diagonal
- Resolution: 1440 x 1600 pixels per eye (2880 x 1600 pixels combined)
- Refresh rate: 90 Hz
- Field of view: 110 degrees
- Audio:
    - Hi-resolution certificate headset
    - Hi-resolution certificate headphones (removable)
    - High impedance headphones support
- Input: Integrated microphones
- Connections: Bluetooth, USB-C port for peripherals
- Sensors: SteamVR Tracking, G-sensor, gyroscope, proximity, Eye Comfort Setting (IPD)
- Ergonomics:
    - Eye relief with lens distance adjustment
    - Adjustable Eye Comfort Setting (IPD)
    - Adjustable headphones
    - Adjustable head strap

Figure 4-2: HTC Vive Pro - handheld controllers (HTC 2018)

There are two handheld controllers, one for each hand of the user, which provide the means to interact with the IVE, as well as the ability to provide haptic feedback (HTC 2018). The specifications are as follows (HTC 2018):

- Sensors: SteamVR Tracking 2.0
- Input (see Figure 4-3):
    - Trackpad
    - Grip button
    - Trigger button
    - Menu button
- Use per charge: Approximately 6 hours
- Connections: Micro-USB charging port

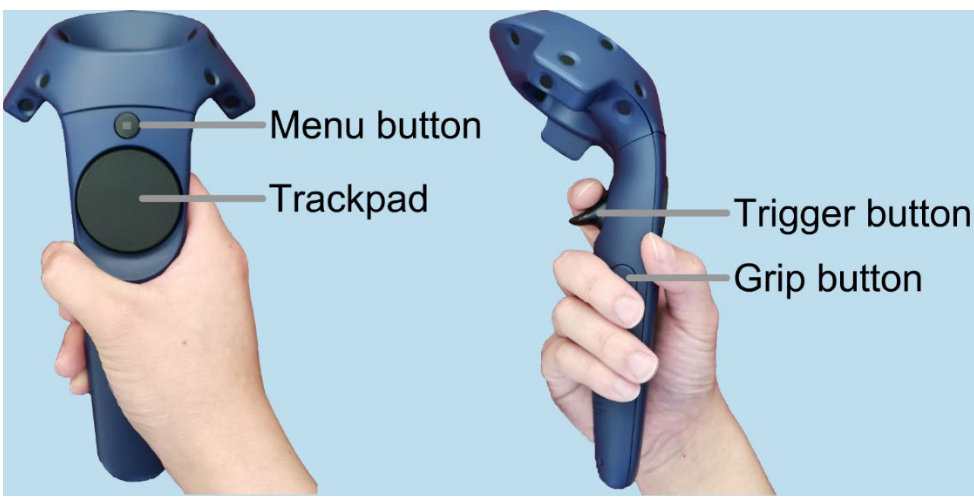


Figure 4-3: Controller buttons (HTC 2018)

Figure 4-4: HTC Vive Pro - base stations (HTC 2018)

The base stations are two laser emitters that come standard with the HTC Vive Pro and are used as sensors to provide accurate motion-tracking for the HMD and the handheld controllers (Figure 4-4). The user does not directly interact with the base stations. These sensors are placed on opposite corners of a quadrilateral, predefined open space for users to freely move in without any obstructions, called the play area (HTC 2018), as indicated in Figure 4-5. Doing so also offers a visual indication to the user in VR of the boundaries for the play area, called the "chaperone system", which is used to prevent users from bumping into physical objects that they may be unaware of due to wearing the HMD that obscures vision from the physical environment. Figure 4-5 is an illustration of the room layout which contains the aforementioned equipment for usability testing.

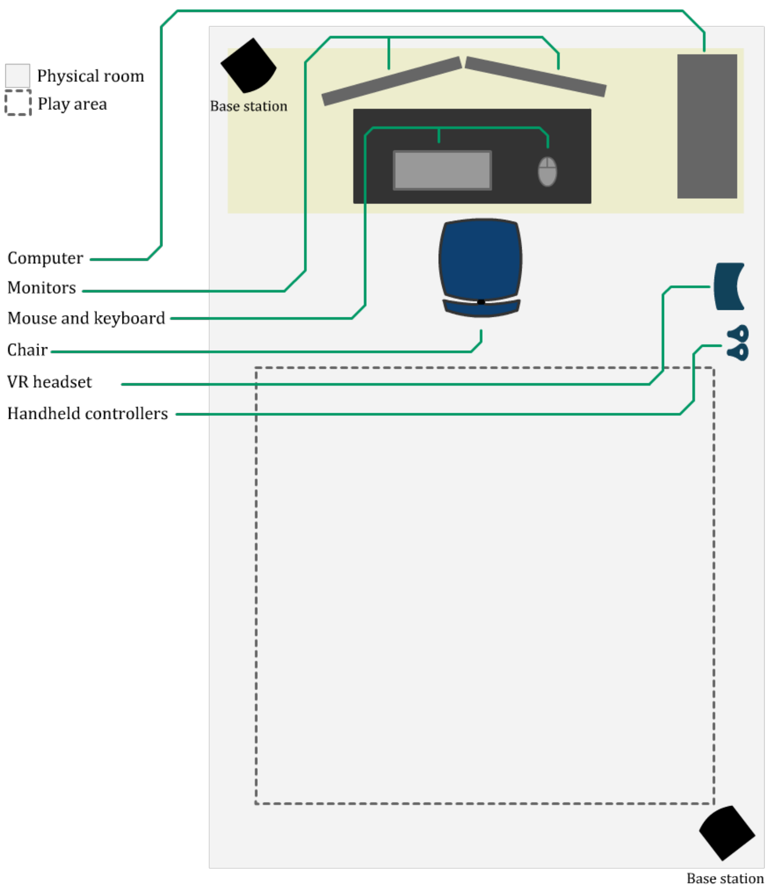


Figure 4-5: Top view of the physical room used to present the IVE

The hardware mentioned above was made available through the VRI Lab at the University of Pretoria.

4.1.2 Testing facilities

The VRI Lab also provided the computer required to run the HTC Vive Pro. Inside the VRI Lab, an area was dedicated to make use of this hardware (see Figure 4-6); the base station (top left), and VR headset and handheld controllers (right) are circled in green. To make use of the VR lab equipment and space, bookings were arranged with the relevant authorities beforehand. Using this dedicated area in the VRI Lab also provided a controlled environment to run usability tests with minimal external interferences, e.g., noise (Pickard 2019:129; Sharp, Preece & Rogers 2019:524).

Figure 4-6: VRI Lab – VR dedicated area

4.2 The interactive virtual environment (IVE)

Currently, there are two platforms (Unreal Engine and Unity) that are freely available and most commonly used by non-commercial developers to create IVEs (Ashtari et al. 2020). These platforms are game engines that are typically used for developing games. Some well-known games developed using Unity include Cuphead (Studio MDHR Entertainment Incorporated 2017), Hearthstone (Blizzard Entertainment 2014), Hollow Knight (Team Cherry 2017), and Ori and the Blind Forest (Moon Studios 2015). Well-known games developed using Unreal Engine include Mass Effect 1-3 (Bioware 2008; Bioware 2010; Bioware 2012), Hellblade: Senua's Sacrifice (Ninja Theory & QLOC 2017), Dragon Ball Fighter Z (Arc System Works 2017), and Borderlands 3 (Gearbox 2019).

While the scope of this study is not to inform menu system design used in a game context, these game engines provide a good foundation for developing an IVE. This is because they have basic mechanics that are already implemented and ready to use. Basic mechanics include engine physics, 3D graphics rendering, interactivity, and a library of development tools (Unity 2015; Shannon 2017:4; Epic Games 2020; Salama & Elsayed 2021). One of these tools is SteamVR (Valve Corporation 2016a), which is used to support VR technology within IVEs. Using one of these game engines avoids "reinventing the wheel" and allows for more time to be spent on the design and development of the testing scenario, the task, and the Belt Menu. Therefore, the IVE for this study was created using a game engine.

Unreal Engine and Unity are both available to be used for this research and both provide adequate support for developing an IVE that uses VR technology. Both have online communities that share knowledge on how to develop an IVE using these respective platforms (Unity 2021; Epic Games 2021) and both platforms would have had adequate support to produce an implementation of the menu system required for the current study. However, there was support available within the researcher's working environment through an experienced VR developer that uses Unreal Engine. Therefore, it was decided that Unreal Engine would be used to develop the IVE for this study. Specifically, Unreal Engine 4.22.3 was chosen for developing the IVE because it was the latest version of the software available at the time of development.

The virtual space of the IVE contained aspects of a world that needed to be defined, e.g., the floor, the walls, lighting, virtual objects. This would then provide a space for the menu system to be tested for its ability to support users with menu item selection through their proprioceptive sense. Participants engaged with this IVE through VR technology, which presented them with the scenario and task for them to complete by using the Belt Menu. The final version of the IVE is shown in Figure 4-7 and Figure 4-8, which includes changes that were made based on insights from the pilot study discussed in Section 4.6.

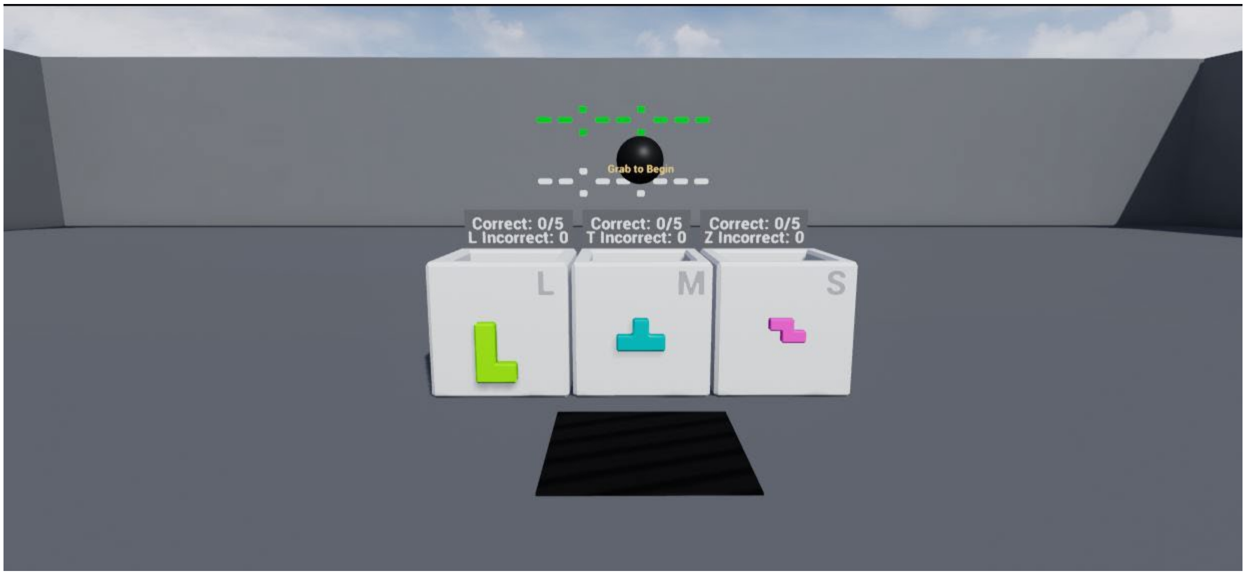


Figure 4-7: Finalised IVE (Front view)

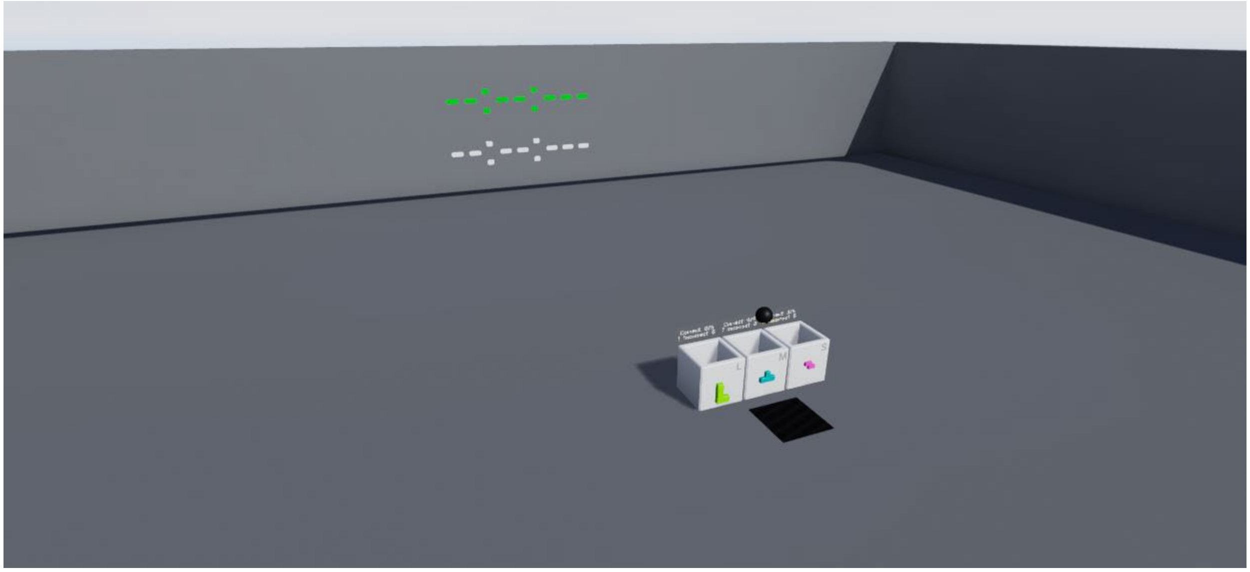


Figure 4-8: Finalised IVE (Perspective view)

The IVE used to present the scenario and task also needed some basic interactivity that would enable users to do the following interactions with virtual objects: pick up, hold, drop, and throw. These interactions and various elements are required to create convincing experiences that are immersive, staying true to the nature of IVEs (Shneiderman 1983;

Shneiderman et al. 2018a:92). Once all these were established, the scenario and task for testing the Belt Menu were designed and developed.

4.3. Interactions and controls

Interactions performed in the IVE were all done with direct manipulation, an interaction technique that mimics the movements and actions done in the physical environment and translates them into the IVE which makes the interaction easy to learn and understand (Shneiderman 1983; Shneiderman et al. 2018a:92). The discussion below defines the terminology used when referring to the various ways of interacting with virtual objects within an IVE. These actions were done using the HTC Vive handheld controllers mentioned in Section 4.1.

Direct manipulation as an interaction type requires big movements with the arms, which causes more energy to be used per interaction compared to other types, e.g., using commands by typing them on a keyboard. This opposes the design guidelines by Argelaguet and Andujar (2013), which states that the selection technique should cause low levels of fatigue. However, VR technology that uses motion tracked controllers, such as the technology used in the current study, typically uses direct manipulation as the primary interaction technique because it feels like natural movement (Eriksson 2016). Natural movement used for interaction is also afforded by motion tracked controls, and in some cases preferred over other interactions that provide better user performance (Bowman & McMahan 2007). That being said, within the IVE menu items were intentionally placed within arm's reach to ensure that these options were readily available as needed instead of having the user to go somewhere specific in the IVE to interact with the menu system. This design choice ensured that no more extra effort was required to interact with the Belt Menu than what is minimally required for performing interactions in an IVE.

4.3.1 Handheld controller usage

The HTC Vive makes use of motion capturing on the HMD and both (left and right) controllers to create an immersive experience as indicated in Section 4.1. To keep the interaction with the virtual reality equipment simple, only the trigger buttons on both controllers were used (see Figure 4-3). This simplicity ensures that participants would spend minimal time learning the equipment so that they can focus their efforts on interacting with the Belt Menu. The trigger button is also the most prominent button when the controller is held in the hand because it clearly protrudes out of the overall shape of the controller. Therefore, the availability of this button is obvious compared to other buttons e.g., the grip button.

For a participant to use the Belt Menu, they would need to be familiar with the following ways of interactions:

- Touch: move the controller in hand so that the controller overlaps the desired virtual object, as shown in Figure 4-9.

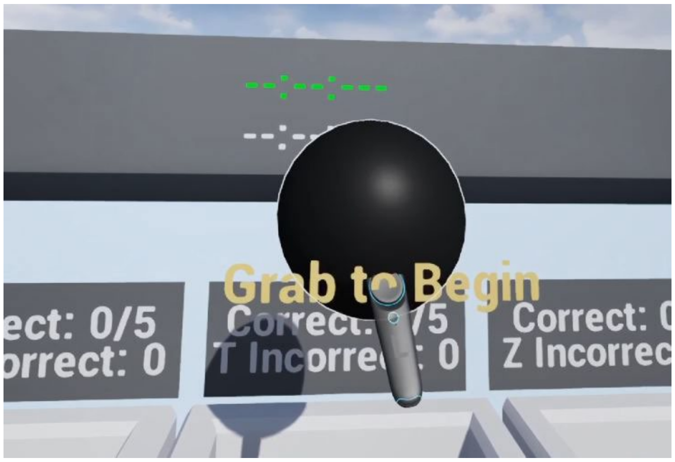


Figure 4-9: Touching the black sphere

- Grab: grabbing is done by selecting a virtual object through touching the virtual object and then pressing the trigger.
- Release: releasing a virtual object is done by letting go of the trigger button.
- Holding: holding can be done by grabbing the virtual object and keeping the trigger button held down (Figure 4-10).

Figure 4-10: Holding the blocks menu item to open submenu options (before and while holding)

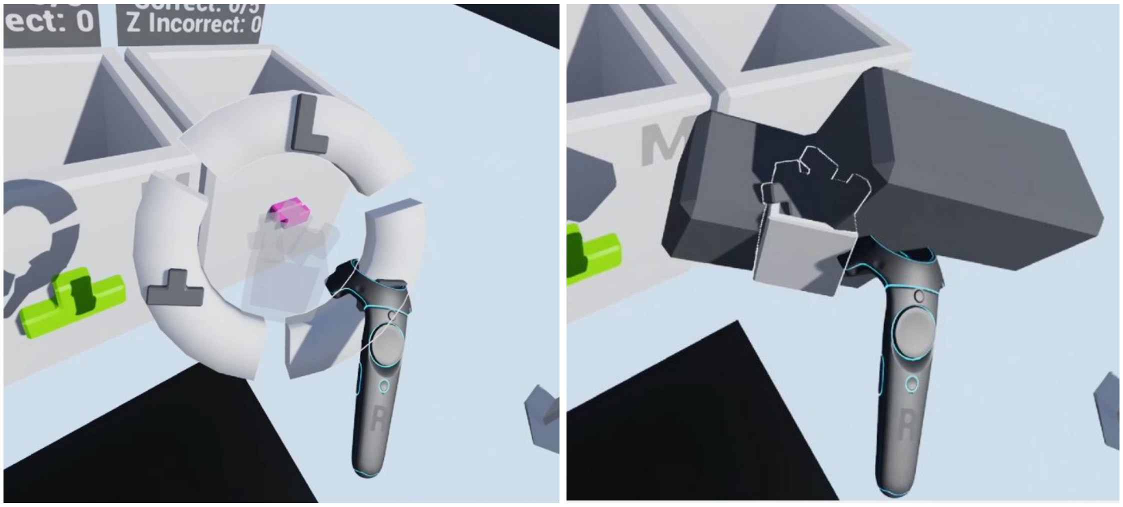


Figure 4-11: Touching Z block submenu option and selecting a Z block (before and after selecting)

- Drop: some virtual objects will become attached to the participant's controller without the user needing to hold the virtual objects, such as the tools, e.g. blocks, coloured Paintbrush, and the plus/minus measure tapes. To drop any virtual objects attached to the controller, the user must press and release the trigger button (grabbing and releasing). The motion controller does not need to be at any specific position to drop an attached virtual object, as indicated in Figure 4-12.

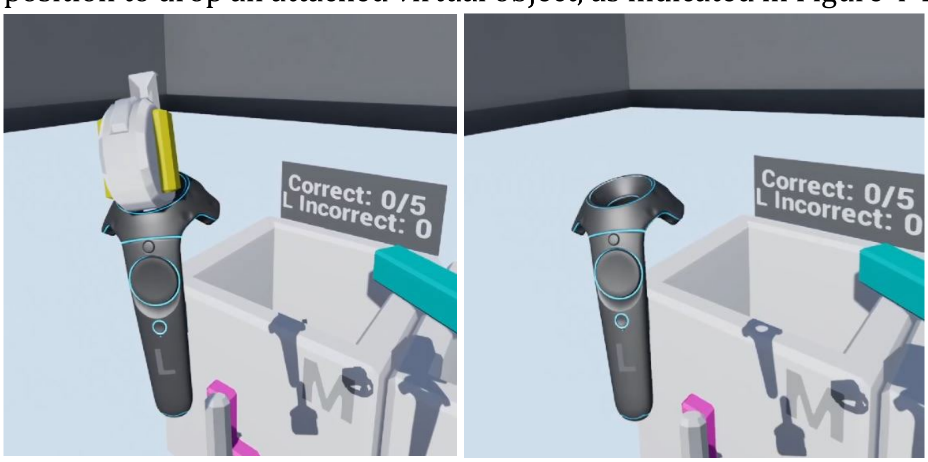


Figure 4-12: Dropping the minus resize tool (before and after dropping)

- Throw: while a virtual object is attached to the controller, move the controller in a similar way to throwing a ball and then press the trigger button to drop, as shown in Figure 4-13.

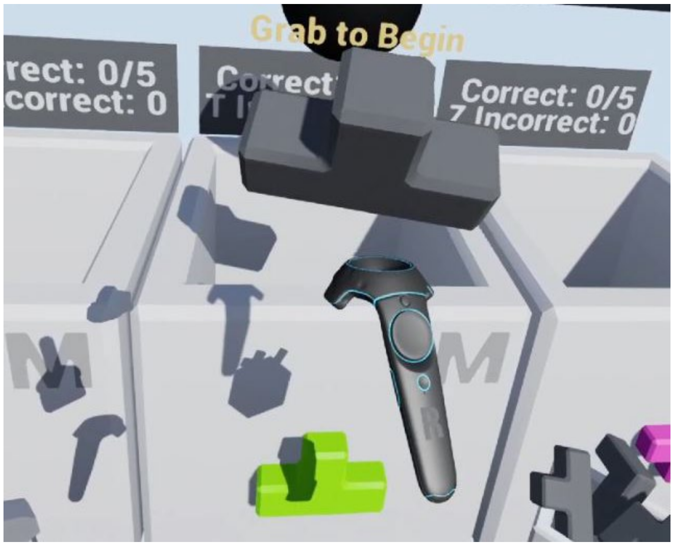


Figure 4-13: Throwing a T block

4.4 Design decisions for the Belt Menu

Every design choice for the Belt Menu needed to be informed and verified by the identified criteria so that the Belt Menu could become a menu system where users may, with practice, rely on proprioception for menu item selection. As such, the prerequisites for a menu system that allowed users to rely on proprioception were simplified to five considerations of providing support for the user's interaction with the Belt Menu:

- Menu items were always accessible.
- The method of selection was easy to understand and to use.
- The visual representation of menu items provided affordance for the function.
- Selections for each layer of menu items, i.e., main menus and submenus, had distinct feedback other than visual feedback, such as haptic feedback.
- Customisation was available and within the user's control.

With these considerations in mind, the details below discuss how each element of the Belt Menu was designed. These elements are discussed as follows: representation and function, layout, and selection method. The specific method of selection is discussed in Section 4.4.4. Any mention of selections before that can be understood as a general action, i.e., choosing a specific menu option that may result in more options to be chosen.

4.4.1 Representation and function

Participants were equipped with five menu options attached around their body (Figure 4-14, Figure 4-15) and collectively they make up the Belt Menu. These five menu items are: Addbox, Paintbrush, Measure tape, Dustbin, and Arrow adjuster, which provide specific functions in a structured manner to support the user to complete a task, adhering to the first two characteristics of a menu system (Foley, Wallace & Chan 1984; Bailly, Lecolinet & Nigay 2016). The visual representation for each menu item was specifically chosen based on commonly known items. This way users had a familiar frame of reference, which was important to help users to have an idea of what the tool is used for, helping them to quickly become familiar with the function. This enables the users to quickly become familiar with the Belt Menu as a whole. Helping users become familiar encourages them to build confidence in their selection, which is an important factor for becoming reliant on proprioception for menu item selections.

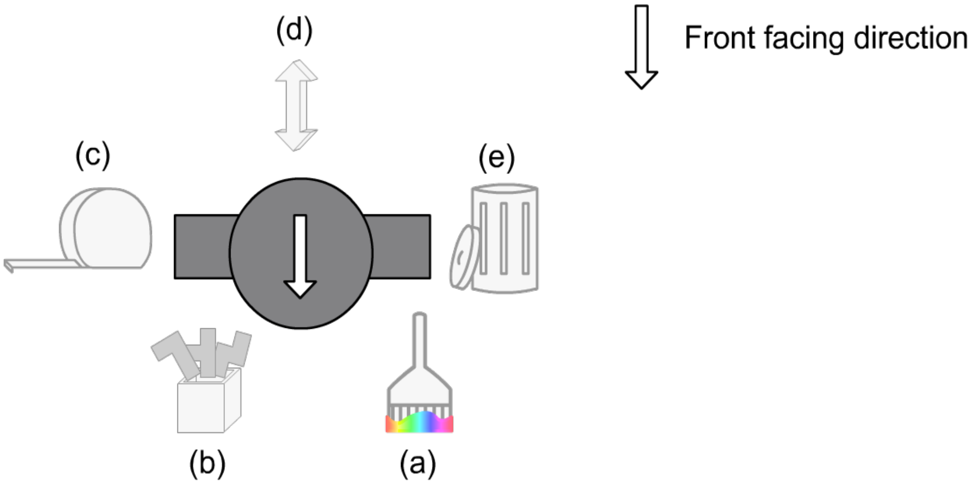


Figure 4-14: Belt menu – top view (a) Paintbrush, (b) Addbox, (c) Measure tape, (d) Arrow adjuster, and (e) Dustbin

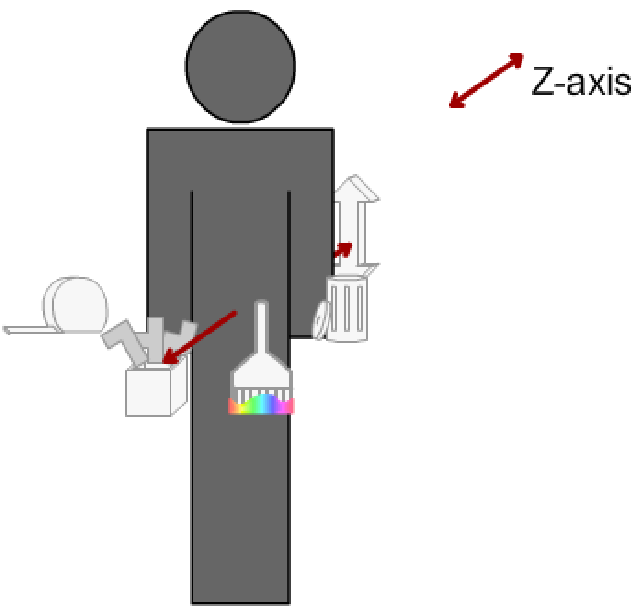


Figure 4-15: Belt menu – side view

4.4.1.1 The Paintbrush

The design for the Paintbrush was chosen to represent a colouring tool. This is because a paintbrush is commonly known for its purpose of applying colour to any surface it touches. Having rainbow coloured paint suggested that there was more than one colour of paint to use. The Paintbrush (Figure 4-14a) presented a submenu in the form of a colour wheel that allowed participants to select from three colours.

The use of a colour wheel derived from commonly understood concepts of choosing colours. Providing three distinct segments indicated that there were three different colours to choose from (Figure 4-16). Selecting one of these segments added a coloured Paintbrush of the selected colour to the user's hand. Touching a block with the coloured Paintbrush changed the block to the same colour as the coloured Paintbrush.

Figure 4-16: Submenu – colour wheel

4.4.1.2 The Addbox

The design for the Addbox came from the idea that all the block shapes were in a storage box. This implied a storage for the blocks and therefore where the blocks could be retrieved from. The Addbox (Figure 4-14b) presented a submenu that allowed participants to select a block of one specific shape from three options (Figure 4-17) and add it to their hand.

The blocks selection (Figure 4-17) was presented to the user when they selected the Addbox menu option (Figure 4-14b). Each shape of blocks was clearly presented, thus indicating three distinct shapes of blocks to select from.

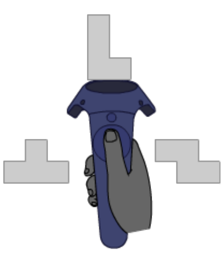


Figure 4-17: Submenu – blocks selection

4.4.1.3 The Measure tape

Measurements are commonly associated with size and therefore the Measure tape represented a tool that was used to change the size of the blocks. The Measure tape (Figure 4-14c) presented a submenu of tools that would increase or decrease the size of the blocks. Blocks could be three sizes (small, medium, and large). By default, blocks were medium-sized.

The resize plus (+) and minus (-) tools (Figure 4-18) were presented to the user when they selected the Measure tape menu option (Figure 4-14c). The plus symbol attached to the plus tool and the minus symbol attached to the minus tool are commonly known for increasing or decreasing values. Using the plus tool on a block increased the size of the block by one scale. For example: a medium-sized block that has been touched with the plus tool will become a large block. The minus tool decreased the size of the block by one scale. For example: a medium-sized block touched by a minus tool will become a small block. To provide the ability to recover from errors (Argelaguet & Andujar 2013), such as accidently increasing or decreasing the size of the block, the user could use the opposite resize Measure tape to fix this error.

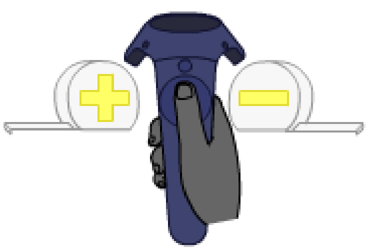


Figure 4-18: Submenu – plus tool (left) and minus tool (right)

4.4.1.4 The Arrow adjuster

A two-sided arrow suggests possible movement in either of the vertical directions. Therefore, when placed with the belt menu, a two-sided arrow was used to represent a tool that moved the belt menu either up or down. The Arrow adjuster (Figure 4-14d) allowed the participants to adjust the height of the belt menu. This was included to provide simple customisation to cater for participants of different heights.

4.4.1.5 The Dustbin

Dustbins are commonly used as a symbol for a place of disposal, e.g., the Recycle Bin in Microsoft Windows (Figure 4-19). The open lid suggested that items could be placed in it and therefore anything placed in the dustbin would be disposed of. The dustbin (Figure 4-14e) provided a method of deleting a block by touching the dustbin with the block that the participant was holding.

Figure 4-19: Screenshot of the Microsoft Windows 10 Recycle Bin

4.4.2 Accessibility

The focus of this study was to investigate whether participants can become more effective and efficient in using the Belt Menu. It is for this reason that all menu options on the Belt Menu were always available and did not change according to the need of the task. Consistency with menus is important so that users can become familiar with the menu (Scarr et al. 2013:3140–3142). Even though the Paintbrush and the Measure tape were not needed for each stage of the task that the participants completed, it was still important that participants knew that these menu options were available. That way, participants were already exposed to, and somewhat familiar with, the Paintbrush and Measure tape when they needed them in stages 2 and 3.

When a selection was made with menu items, visual changes would occur. Selecting a main menu item, e.g., Addbox, triggered submenu items to appear and the main menu item would become transparent, as shown in Figure 4-10. The appearance of the submenu items indicated to the user that there was more to be done in their selection. By making the main menu item transparent while it was selected, the transparency helped to reduce visual clutter so that users could focus on the current selections available, which were the submenu options. Once a submenu item was selected, the submenu items would disappear and a tool would be held in the user's hand, providing the user with a form of feedback so that they know that the menu system was responding to their actions. Designing the menu system to behave in this way adhered to the guideline that menu systems should present transient information and be quasimodal (Jakobsen & Hornæk 2007; Bailly, Lecolinet & Nigay 2016).

4.4.3 Layout

To ensure accessibility, all menu items were placed around the user's body, keeping these options available within the control space as shown in Figure 4-14 and Figure 4-15, i.e., within arm's reach. Specifically, the main menu items were positioned around the waist area, which was inspired by a utility belt. The positioning of the main menu items was based on the fact that most people use their right hand dominantly. With this in mind, menu items that would serve the primary action were placed closer to the right hand, as it would typically have better dexterity than the left hand. This design choice was later identified to be biased towards right-handed users during the pilot test which resulted in adding a different layout to accommodate left-handed users as well (further discussed in Section 4.6.1).

When a main menu item was selected, submenu items would appear around the user's hand and would stay in place until a refined selection was made, then it would disappear. Positioning the submenu items around the user's hand provided quick access for the selection. This positioning also followed the radial menu layout, which provided equally accessible options due to the layout's property of ensuring menu items to be equally distant from the hand (Komerska & Ware 2004; Ren & O'Neill 2013). The radial menu layout has also enabled eyes-off interaction with enough practice, according to a previous study (Chertoff, Byers & LaViola 2009).

Block selection for a specific shape was the primary selection required to complete the task, therefore the Addbox was placed in front of the user where it was clearly visible. Specifically, the Addbox was placed closer to the dominant hand, making it more convenient to use the dominant hand for selecting blocks. Most people were presumed to be dominantly right-handed, therefore the Addbox was placed closer to the right hand. The dominant hand, i.e., right hand, typically has more dexterity than the non-dominant hand and this also helped to place the blocks correctly with more precision to complete the task. This is another reason why the Addbox was placed closer to the dominant hand.

Based on the task, changing the colour was a supporting action to having the correct block. Since changing colours is a supporting action, it should be used by the hand that does supporting actions (typically the left hand). Therefore, the Paintbrush was positioned in front of the left hand so that it would be more convenient to select colours with that hand.

Positioning the Measure tape to the side was intentionally done so that it was outside the direct line of sight of the user when facing forward. This was to study two concerns: firstly, to test the limit to the range of motion and selection that was considered comfortable, and secondly to test if participants would eventually rely on eyes-off interaction instead of constantly looking back (Schramm, Gutwin & Cockburn 2016).

Placing the dustbin to the side provided a position that was readily available to the user for block disposal. Having the dustbin to the side also ensured it was out of the way to prevent accidental block disposals, since it only required the block to touch the dustbin for the block to be disposed of.

The Arrow adjuster was placed directly behind the user because it was assumed that this menu item would be seldomly used. It would only be used in the beginning of a session to find a comfortable height. Then it could be moved out of the way and be ignored.

4.4.4 Selection method

The selection process was done by reaching out and touching the virtual objects, similar to how objects are picked up in the physical environment. Using a method of movement and interaction that users are familiar with allows them to transfer known skills to a new context (Sharp, Preece & Rogers 2019:78). This selection process was informed by the fact that selection techniques need to be easy to understand and control (Argelaguet & Andujar 2013).

To interact with any of the Belt Menu options, the participant would need to:

1. Grab and hold the desired menu option (e.g. Addbox). While holding the virtual representation, the submenu options for the select menu option would appear around their hand, e.g., blocks selection (Figure 4-10).
2. Touch the desired submenu option, e.g. Z-shaped block segment, and release (Figure 4-11). The desired object, e.g., Z-shaped block, would then be attached to the controller that made the selection (Figure 4-11).

Should there be a need to cancel a selection, the trigger button could be released while no submenu options were being touched. The selection process for the initially-selected menu option would then be cancelled.

A selection typically requires a button to be pressed and released. This action of using a button can be split into two halves, the press sub-action and the release sub-action. The two interactions describe a selection process that makes use of two halves of a button press. Identifying sub-actions in a button press was informed by the decomposition of a selection technique as proposed by Argelaguet and Andujar (2013), which resulted in designing the selection process as follows:

- **Object indication**: touching a desired menu item.
- **Confirmation of selection**: pressing and holding down the trigger button to select the main menu item that was touched. The submenu items would then appear around the controller. By touching a submenu item, performing another object indication, and then releasing the trigger button, a submenu item would be selected. Thus, only one button press was used.
- **Feedback**: while touching a main menu item, the controllers had a constant soft vibration and would stop if the menu item was not being touched. When touching a submenu item, the controller had a stronger more abrupt vibration, similar to a nudge, upon contact of each menu item.

This allowed the selection process of two selections to be done in one button press, one to select a main menu item and another to select a submenu item. Doing so reduced the number of buttons pressed by half, which increased the efficiency and allowed rapid selection. This is one of the guidelines for selection techniques by Argelaguet and Andujar (2013). By reducing the number of button-presses and taking advantage of both halves of a button press, the selection process was also simplified and, although unconventional, simple to understand and learn.

As discussed in Section 4.3, direct manipulation, which is the primary interaction technique used with the VR technology for the current study, is not the most efficient method of interaction. However, this detail was justified by the fact that more natural movement is generally preferred in VR systems (McMahan et al. 2010). The use of both halves of a button press would not reduce the overall effort of the big arm movements but would result in minimal effort, thereby addressing the guideline by Argelaguet and Andujar (2013), which requires selection techniques to produce low levels of fatigue.

Another guideline for selection techniques by Argelaguet and Andujar (2013) is to ensure that selection must be accurate and error-proof. This was done by refining the selection in supporting the user to select the menu item that they intended to select, a process referred to as disambiguation. The specific disambiguation that was employed for refining selections in the Belt Menu was the "last intersected" method of heuristic disambiguation (Moore et al. 2019), which refers to selecting one virtual object amongst multiples objects that are being touched by choosing the last virtual object that was touched. "Last intersected" was chosen as the heuristic disambiguation technique because of the way the submenu items appeared around the user's hand in a radial menu layout. Depending on the position of the user's hand, as the submenu items appear by holding down the selection button, a submenu item may have already been touched unintentionally. However, if the user then touched a desired submenu item and released the selection button, that submenu item would be the last object touched. This ensured that the selection was more accurate to what the user indicated as the desired selection based on their touch.

The desire to customise a system, i.e., a menu system, is typically only seen in experienced users so that they can make changes that would optimise their performance, while novice users would rather focus on learning the system without any adjustments (Shneiderman et al. 2009:64). By including an element of customisation, participants were observed to determine when they would develop this desire as part of observing expected behaviours, as discussed in Section 3.4.2.3. Customisation was provided to participants in one simple way, namely, by allowing them to change the height of the Belt Menu according to their own preference. Height was accommodated because the height of participants may have affected their ability to reach menu items of the Belt Menu if this method of customisation was not available. Limited customisation was supported to prevent participants from spending too much time pondering possible changes instead of using the Belt Menu.

Any level of change or customisation should be in the control of the user so that they only need to adapt according to their own choices (Scarr et al. 2013). Consistency in the layout and positioning is important to make things easier to remember and to learn so that users can become familiar with the Belt Menu and become progressively more confident in their selections (Cockburn et al. 2014:11). With practice, participants should become familiar enough to show expert user behaviour by relying less on visual cues and more on spatial awareness and proprioception, potentially resulting in eyes-off interaction and multi-tasking (Cockburn et al. 2014).

4.5 The scenario and task

To test the Belt Menu in a way that yielded accurate and informative results on whether it allowed users to rely on proprioceptive senses for menu item selection, the Belt Menu needed to be used to complete a task in a given scenario. It is important that all factors of the test kept the focus on the usage of the Belt Menu. The general idea for the scenario was to place participants in a big open space in the IVE, since this would allow participants to feel less confined and be more comfortable. The scenario in the IVE was well-lit so that participants could clearly see everything that they needed to interact with. A comfortable and well-lit environment helped to ensure that data collected would not be affected by a poorly designed scenario.

The task that was used in the current study to test the use of the Belt Menu needed to allow data collection to be focused on the level of support that the Belt Menu provided to complete the task and not about the complexity of the task. The chosen task was made simple enough so that no specific skill was required to ensure that user performance recorded was not affected by a skill bias. The initial idea for the task was to require participants to build a small structure using blocks of different shapes, colours, and sizes. However, this idea was discarded because the task was overly complex as it was more focused on the ability to assemble a matching structure instead of using the Belt Menu.

Because of these reasons, another task was chosen to test the Belt Menu. The task chosen for the current study required participants to place blocks of different shape, colour, and size into boxes according to the labels of each box. This is similar to sorting objects into containers, an activity that is commonly practiced since childhood, therefore participants were not expected to have any trouble with this task. The usage of the Belt Menu was to generate blocks of different shapes and customise them by changing the colour and size using the Belt Menu before placing the blocks into the correct box.

The IVE where the task was done in had three boxes placed in front of the participant and each of them was labelled with a differently-shaped block (Figure 4-20). The different shapes of the blocks resembled L, T, and Z of the English alphabet (Figure 4-21). The participant was tasked to place a specific number of blocks into each box, where the placed blocks needed to match the label marked on the respective boxes. The task became more complex with each progressive session by requiring each block to be a specific colour (turquoise, pink, lime) and size (small, medium, large) (Figure 4-21).

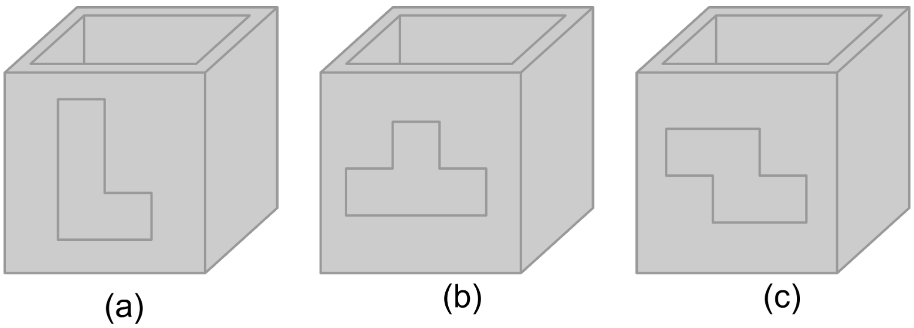


Figure 4-20: Boxes marked with differently-shaped blocks

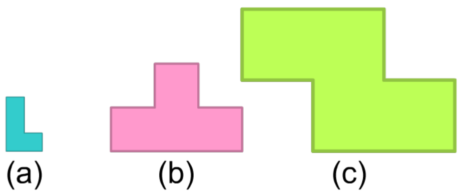


Figure 4-21: The colours and sizes of the blocks

4.5.1 Allowing for practice

One of the goals of the current study was to determine how the design of the Belt Menu supports users to easily become familiar with it, which requires exposure and usage. The more participants used the Belt Menu, the more familiar they would become with it for when they needed to use it to complete the task.

As mentioned in Section 3.4.2.3, it was expected that each participant's behaviour would change through a progression in their level of expertise as they became more familiar with the Belt Menu. This means that participants would need time to become familiar with the Belt Menu. To accommodate this practice, time was given in each session to allow participants to explore the Belt Menu and familiarise themselves with each menu item and submenu item.

Familiarity with the Belt Menu came with remembering the selection method, various menu items and submenu items, the functions of each of them, and where each of them is positioned. This helped to establish a sense of spatial awareness and proprioception (de Jesus Oliveira et al. 2017). Therefore, providing a time and space for participants to orientate themselves and practice interactions with the Belt Menu allowed them to reinforce what they had learnt about the Belt Menu and practice new actions, i.e., select and use menu items that were not required in previous sessions. It was expected that participants would be able to complete the task with progressively less focus on interacting with the Belt Menu by progressively relying more on proprioceptive senses and less on visual guidance 3.4.2.3.

Using three separate sessions provided the opportunity to investigate each participant's ability to retain their familiarity with the Belt Menu. Specifically, the focus was on observing their change in user behaviour, i.e., the level of focus on completing the task instead of using the Belt Menu and the level of reliance on proprioceptive senses, were used as indications for changes in their level of expertise. Investigating each participant's familiarity and changes in their user behaviour were used as indications of the Belt Menu's ability to support reliance on proprioceptive senses, which was crucial for the current study.

Each of these sessions provided different stages for the task that needed to be completed, with each stage being progressively more complex than the previous. The complexity required the participant to do more interactions with the Belt Menu, which reinforced their familiarity with the Belt Menu, not only while practicing but also while doing the task. Progressive complexity helped to determine whether participants could take advantage of their familiarity with the Belt Menu to handle a more complex task by using the Belt Menu more. It was important to study each participant's potential progression of familiarity with the Belt Menu, since a successful menu design should allow an expert user to multi-task by focusing on a more demanding task while effortlessly using the designed menu system (Cockburn et al. 2014:3).

Before each stage, the participant was allowed to interact with the IVE that they were placed in, including the Belt Menu. This encouraged exploration and exposure, which results in progressive familiarity (Cockburn et al. 2014:11). They could use this time to practice doing various interactions with the Belt Menu and to reorient themselves before starting the task. When the participant was ready to do the task, they could indicate it in the IVE by standing on a provided black pad, which together with a black sphere were collectively called the startpad (Figure 4-22). The participant would indicate that they were ready by standing on the black pad and grabbing the black sphere, thereby activating the startpad (Figure 4-23). Once the startpad was activated, interactions with the Belt Menu to complete the task would be recorded to inform user performance, including the time taken to complete the task. Until the participant activated the startpad, any interaction performed in the virtual environment by the participant would be considered practice. The positioning of standing on the startpad ensured that the participant was positioned correctly to do the task. Upon activating the startpad, a visible count down of three seconds would be indicated to the participant to prepare for the task. The startpad would disappear after the countdown reached zero (Figure 4-24).

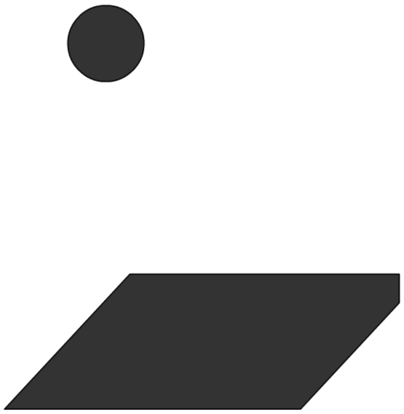


Figure 4-22: Startpad

4.5.2 Three different stages

To complete the task, a specific number of blocks needed to be correctly placed into each box. Specifically, there were three shapes that corresponded to three boxes. If the requirement to complete the task was to place 10 blocks correctly for each shape, then a total of 30 blocks needed to be placed correctly. This was indicated by a label nearby the corresponding box. If a block was placed correctly into a box, the label by that box increased the counter for “correct”. If incorrect, it would increase the counter for “incorrect” (Figure 4-23). There was no particular order required, so long as the blocks were placed correctly. When the task was first developed, the required number of blocks for each box was 10. However, informal testing indicated that fewer would achieve similar results and the task would be less tedious. Therefore, a goal of five blocks per box was eventually used. This was one of the details that was further examined in the pilot test discussed in Section 4.6.

As mentioned before, complexities were introduced by requiring specific colours and sizes for the blocks. The descriptions and figures below specify how the complexities were introduced with each progressive session.

Stage 1 (plain blocks): the participant was asked to place blocks into the correct boxes in accordance with the label marked on each box. All blocks were grey in colour in stage 1 (Figure 4-23 and Figure 4-24).

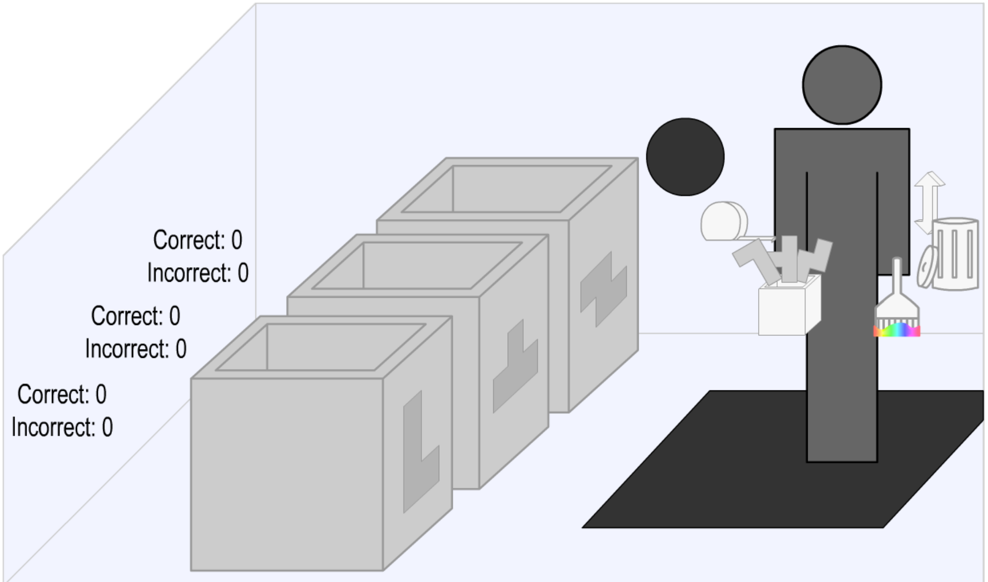


Figure 4-23: Stage 1 layout

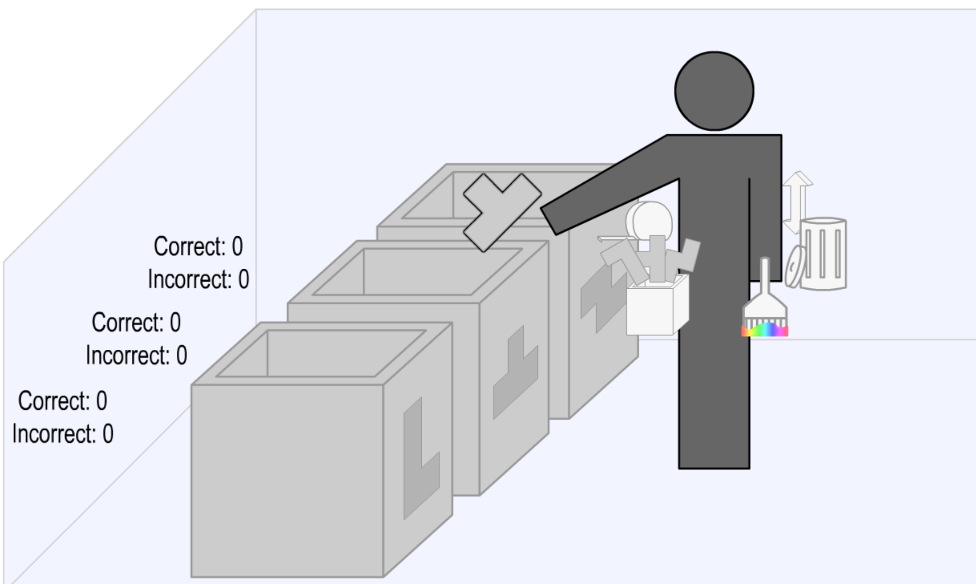


Figure 4-24: Stage 1 started

Stage 2 (coloured blocks): the participant was asked to do the same as stage 1 but additionally had to match the colour of the label marked on each box (Figure 4-25 and Figure 4-26).

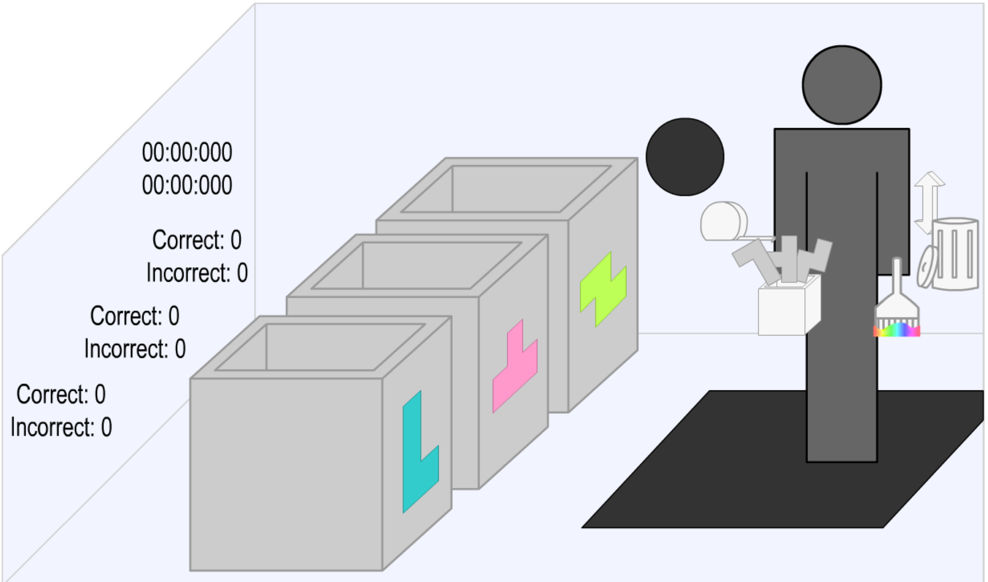


Figure 4-25: Stage 2 layout

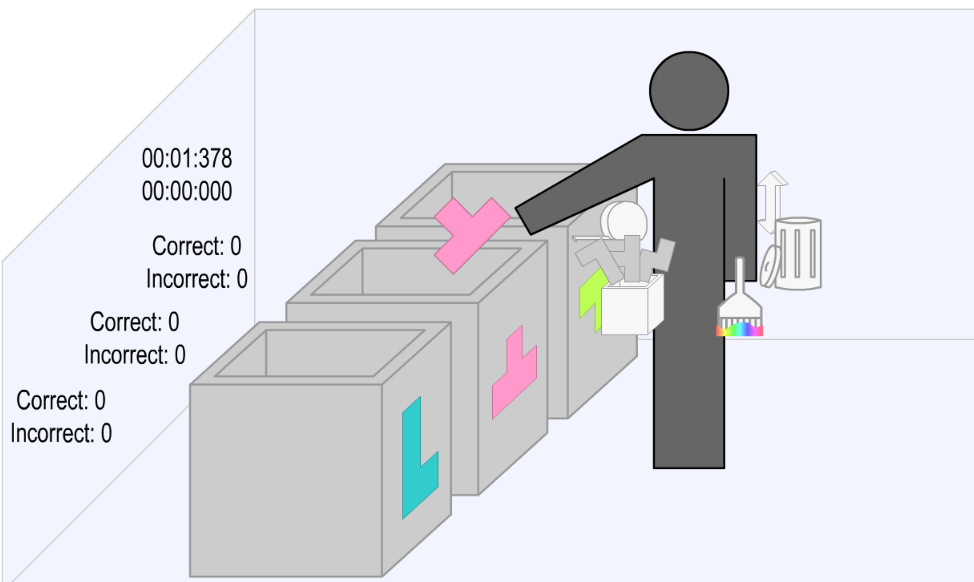


Figure 4-26: Stage 2 started

<u>Stage 3 (coloured and resized blocks):</u> the participant was asked to do the same as stage 2 but additionally had to match the size of the label marked on each box (Figure 4-27 and Figure 4-28). The sizes were marked as S for small, M for medium, and L for large on each box and the shape on the box also changed in size to match.

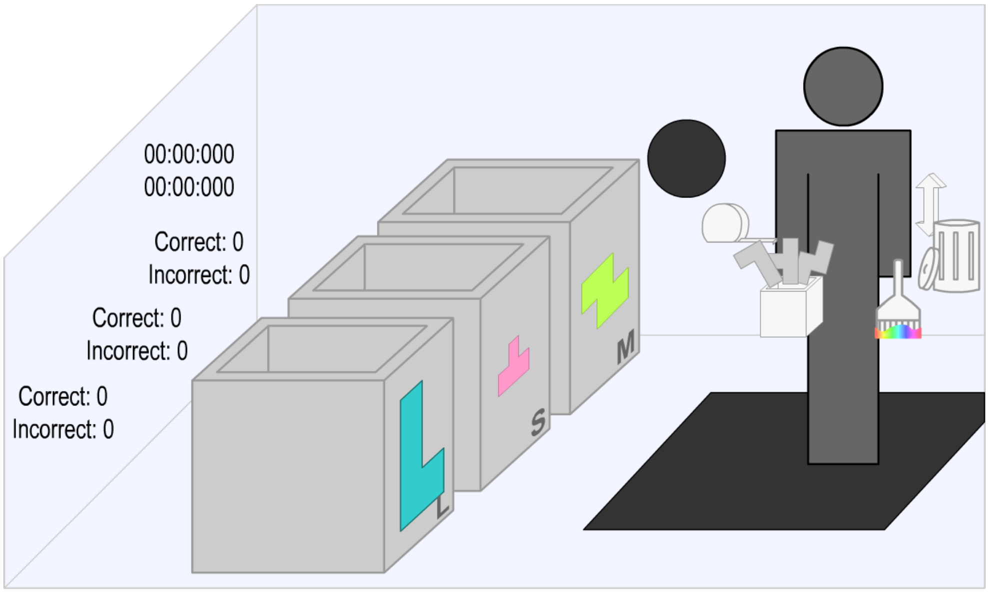


Figure 4-27: Stage 3 layout

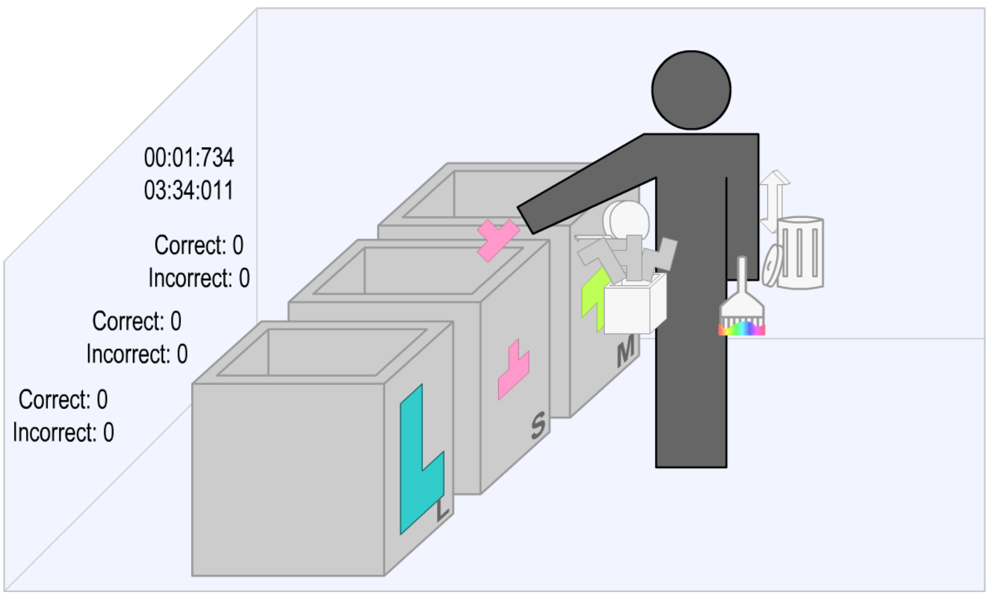


Figure 4-28: Stage 3 started

4.6 Pilot Testing

A pilot test, consisting of five participants, was used to test for various usability details and to find and correct bugs in the programming in terms of all aspects contained in the IVE, such as the Belt Menu, the scenario, and the task. Another use of the pilot test was to refine the questions that would be used for the interviews with the participants, as discussed in Section 3.4.3. User-friendly details were checked to determine if:

- participants were able to recognise the function of each menu option correctly,
- the layout of the menu was sensible to people other than the researcher,
- the method of selection was simple enough to understand.

To complete the task, participants were required to place a specified number of correct blocks into each box, according to the shapes. During informal testing, while the task was being built into the system, the initial number required to complete the task was to place 10 correct blocks into each box. However, upon multiple attempts done by the researcher, it was deemed as excessive, because placing a total of 30 blocks made the task tedious to complete and led to a significant amount of repetition of performed actions. The number of correct blocks to place for each box was thus reduced to five correct blocks to complete the task. During the pilot testing, it was confirmed that placing a total of 15 blocks (five of each shape) would be sufficient to study participants using the Belt Menu. This amount resulted in participants interacting with the Belt Menu enough to make reliable observations about user behaviours in comparison to expected behaviours (as discussed in Section 4.5.1).

4.6.1 Changes

Based on the outcome of the pilot test, various changes and fixes were implemented. The details for the changes are as follows:

- The dustbin was removed as users could just drop blocks if they no longer wanted them.
- The layout was rearranged so that all items would be within view of the user without the need to look behind them (Figure 4-29).
- The arrow-adjustor (most-right menu item in Figure 4-29) was moved to the dominant side of the user. This tool would typically only be used at the start of a session when the user would adjust the Belt Menu to a comfortable height. Therefore, it could be placed to the side of the user where their dominant hand would be preoccupied with interacting with the blocks.
- The Measure tape (most left menu item in Figure 4-29) was moved to the side of the non-dominant hand as this hand would typically be used to interact with the tools while the dominant hand would be preoccupied with interacting with the blocks.
- Since the layout in the original design (Figure 4-14) was predominantly designed for right-hand dominance in mind, a left-hand dominant layout was added to eliminate right-handed biased interactions. This was done by horizontally swapping the positions of each menu item so that the positions were mirrored.

Figure 4-29: revised Belt Menu layout (top view)

Submenu items were revisited to increase visibility and to make selections and interactions easier. Previously only the colour submenu used wheel segments (Figure 4-16). The blocks submenu laid out the three shapes in a triangular position (Figure 4-17) and the Measure tape submenu was laid out as two measure tapes side by side (Figure 4-18).

After pilot testing it was determined that wheel segments for all submenus would create more visual consistency and bigger targets, making it easier to select submenu options (Figure 4-32). Counters for each box were placed right above each box so that it was clearer what these numbers represented (Figure 4-30). These also served as a backboard to make it easier for blocks to fall into the boxes. They were initially placed on a wall behind the boxes further away (see Figure 4-23). The size labels on each box were also moved from the bottom right of the box to the top right of the box (Figure 4-30), which made the label more visible so that users would see more clearly what size the blocks needed to be when throwing blocks into each box.

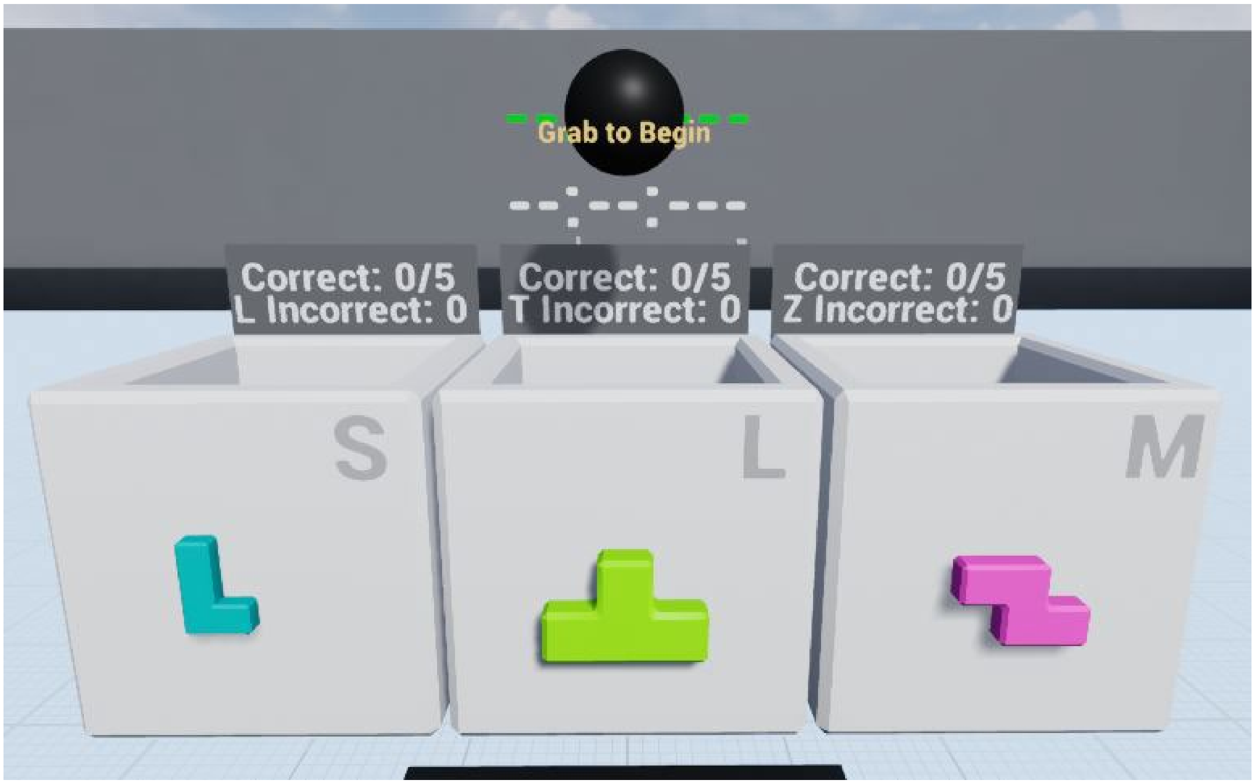
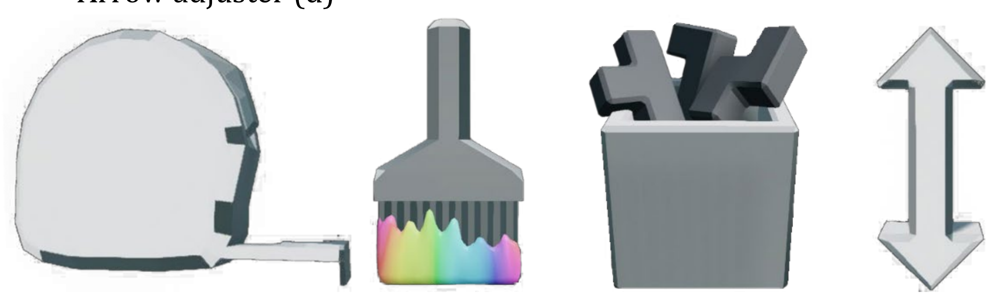


Figure 4-30: Finalised boxes for the task in stage 3

The final designs for each of the menu items are as follows:

- Main menu (Figure 4-31)
  - Measure tape (a)
  - Paintbrush (b)
  - Addbox (c)
  - Arrow adjuster (d)



(a) (b) (c) (d)

Figure 4-31: Main menu items (final design)

- Submenu (Figure 4-32)
  - Resize wheel (a)
  - Colour wheel (b)

- Blocks wheel (c)

(a) (b) (c)

Figure 4-32: Submenu wheels (final design)

As a result of the pilot testing, changes and fixes were applied so that the task can be done with minimal hinderances caused by design flaws and technical issues. The final implementation of the scenario in the IVE was produced and used for data collection in usability tests with participants as shown in Figure 4-7 and Figure 4-8.

4.7 Built-in data recording

Having user performance checks built into the testing system allowed for more accurate and granular detail to be captured. This also allowed the researcher to focus their attention on observing user behaviour during the usability test.

Basic data analytics logic was built into the Belt Menu to track the following details:

- **Hit/miss selection attempts:** this was used to determine the success rate of selection attempts.
  - Hit: this refers to the fact that an item was selected and attached to the participant's hand. This is regardless of whether the selected item was the item that the participant wanted to select.
  - Miss: this refers to the fact that a participant reached out in the direction of a menu item to select an item from the menu but nothing was selected.
- **Left- or right-hand selection:** this was to check if the participant used their dominant or non-dominant hand for selecting certain menu options. Prior to doing the usability test, participants were asked if they usually use their left or right hand dominantly. These data would also reveal how often they used each hand.
- **Overall time to complete a stage:** this was tracked to determine if participants could perform the task faster with practice. This is related to familiarity with the Belt Menu and success rates of selection attempts.
- **Timer:** time was recorded to measure how long a participant took to complete a task for each attempt. The timer started after a three second countdown from when a

participant grabbed the black sphere and ended when that participant completes the task, as discussed in Section 4.5.1.

To keep track of missed selections, menu items were developed with "miss areas", which was the small space (Figure 4-33, Figure 4-34) surrounding each menu item, invisible to the participants. Any attempts to make a selection in this area without actually touching the menu item itself would be recorded as a miss.

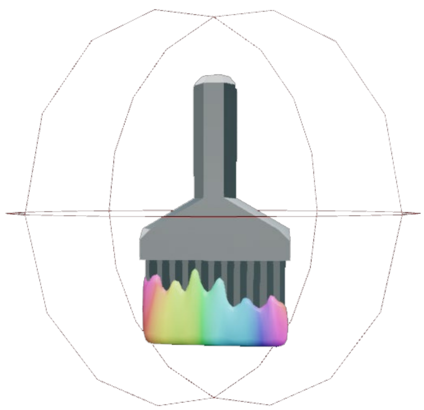


Figure 4-33: Hit and miss areas of the Paintbrush

Figure 4-34: Hit and miss areas of the colour wheel segments

By keeping record of these values, the following data could be calculated:

- Comparing the total amount of selections with the time it took for a participant to complete a task could be used to calculate how many selections a participant made per time unit. For example: If a participant made a total of 47 selections in session 1 and took 45 seconds to complete the task, the participant would have made 1.04 selections per second (s/s) in session 1. This could be used as a measurement to see if their selections per second (s/s) would have increased or decreased for each consecutive session.

- Keeping track of the amount of hit and missed selections provided measurements that could be used as supporting evidence for how accurate participants were able to make selections.
- Investigating number of times each main menu item and submenu item were selected alongside the accuracy of selections could help determine whether participants struggled to select any particular menu items. Any discovery made with this metric indicated a need to pursue reasons behind the struggle.

Analysing the results of these calculations provided ways to verify the findings extracted from the account of the participant's experience. The analysis of these results and findings are discussed fully in Section 5.3.

4.8 Summary

This chapter covered the design decisions made for testing how the identified criteria in Section 2.10 can be used to inform menu system design that relies on proprioception for menu item selection. The menu system that was designed according to the identified criteria was called the Belt Menu, which was developed in an IVE. The Belt Menu was specifically designed to ensure that reliance on proprioception can be supported by making design decisions regarding the representation, layout, and accessibility of various menu items. The selection method used to interact with the Belt Menu was also carefully designed to simplify the selection process and to ensure that it was a low effort interaction that could support rapid selection. Details about how the IVE was designed were also discussed, which included the details for various hardware and software used to create the IVE, as well as the scenario and the task used to test the Belt Menu.

The next chapter discusses the process of interpreting each participant's experience with the Belt Menu, which was done by analysing captured data from the use of the Belt Menu to complete tasks. This also includes the discussions regarding the interpretations of each participant's own experience through data gathered from observation, interviews, and focus groups. Investigating each participant's experience helped to understand how the identified criteria, discussed in Section 2.10, can support reliance on proprioception for menu item selection.

5. Data Analysis

The previous chapter presented details regarding the design decisions and the process of implementation for the IVE that encompassed the task and Belt Menu. This chapter discusses the details about how the collected data were processed and analysed. Both user performance data and data about the participants' experiences were collected. Therefore, the processing and analysing of both quantitative and qualitative data are addressed. Based on the analysis, results were extracted to understand participants' behaviours from subjective participant reports and researcher observations in the form of qualitative data. User performance (quantitative) data were collected to objectively verify the findings from the subject reports and observations.

Out of the 17 participants, 16 participants had at least one week (seven days) between each session. One participant had a four-day gap between Session 1 and Session 2 due to scheduling challenges.

5.1 Processing the data

Background experience of each participant's exposure to IVEs and VR technology that uses an HMD was collected to provide a better understanding of each participant's context. This provided the basis for which they would compare their own experience with the Belt Menu. This was done via an online questionnaire using Google Forms, which can be exported as raw data into a Google Spreadsheet and produce graphical representations that provide an overview understanding of each participant's exposure to IVEs.

User performance data were captured automatically by the system (Section 4.7) and then processed into a spreadsheet so that calculations such as averages, minimums, and maximums were calculated for each of the three stages, which enabled the resulting values to be compared for analysis. Finally, these values were visualised into graphs that helped to provide an overview of various aspects of performance with the Belt Menu. These visualisations were used to triangulate findings from the participants' experiences so that a more holistic understanding could be achieved.

Data captured about the participants' experiences with the Belt Menu were processed by taking the transcriptions and observation notes made by the researcher and performing multiple rounds of coding through Atlas.ti, which resulted in emergent themes. These themes were then analysed to determine the relationships that the themes had with each other, which informed the understanding of the participants' experiences in terms of developing the ability to rely on proprioception for menu item selection.

The sections below provide discussions in the following order: firstly, the discussion regarding the background experience of participants was analysed to obtain context for understanding any prior experience with IVEs; this discussion is followed by the analysis and findings of the user performance, which helps to have an initial understanding of the inferences from user performance; finally, all this provides a foundation to understand the results of the participants' experiences with the Belt Menu.

5.2 Background experience with IVEs

As a criteria for the target population for the current study, participants needed to have some experience with IVEs, such as video games, so that they would not be too distracted by the various elements of the IVE and would instead focus on the given task. Before each session with a participant, background information regarding exposure to IVEs and VR technology was collected with an online questionnaire.

The purpose of this background information was twofold:

- If it was the participant's first time with VR technology, the equipment would be carefully explained and they would be given some time to familiarise themselves with the VR technology and the IVE before being asked to do the task.
- Keeping track of their background experience provided insight on how to understand the participant's behaviours, e.g., if it was their first time using VR technology then it could be expected that they might be disorientated at first.

Below are the results that represent the background experience of the 17 participants for the current study.

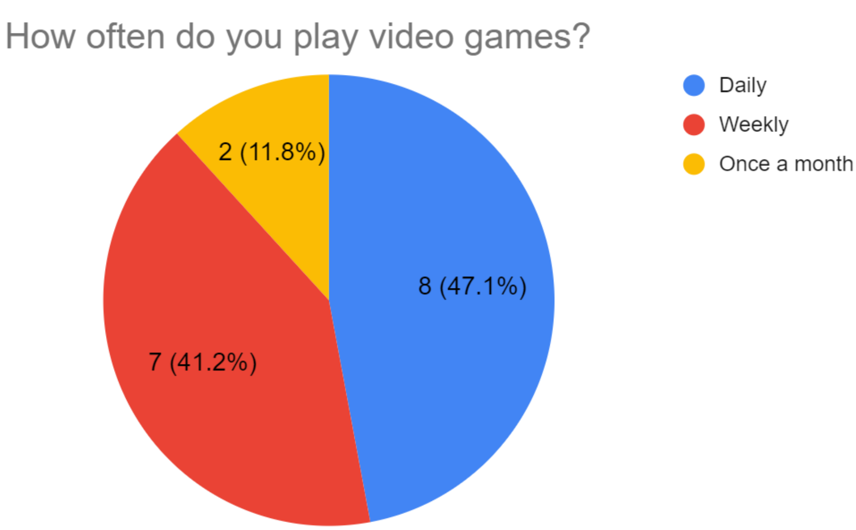


Figure 5-1: Frequency of playing video games

All participants noted that they enjoy playing video games and, as can be seen from Figure 5-1, play them frequently.

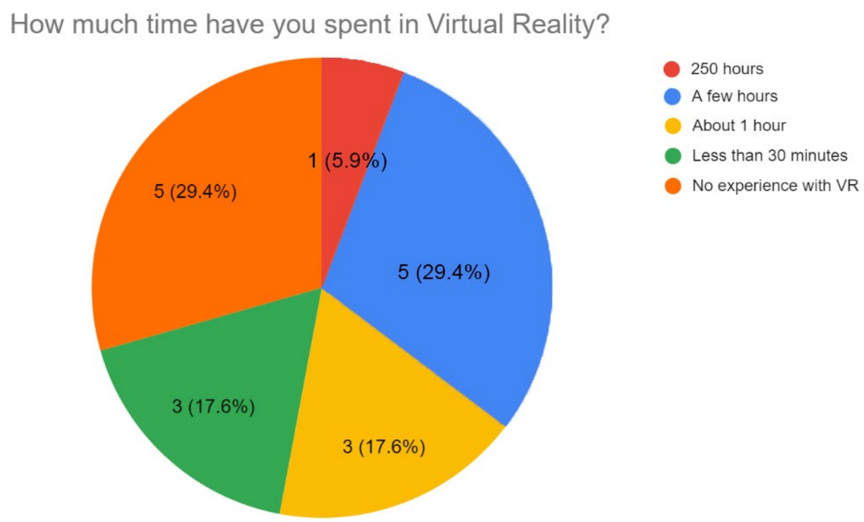


Figure 5-2: Exposure to VR technology (using an HMD)

As specified in the questionnaire (Appendix B – Questionnaire), time spent with VR technology specifically refers to any VR technology that uses an HMD. Figure 5-2 indicates that five participants have never used VR technology before, everyone else has had some time using VR technology in varying degrees.

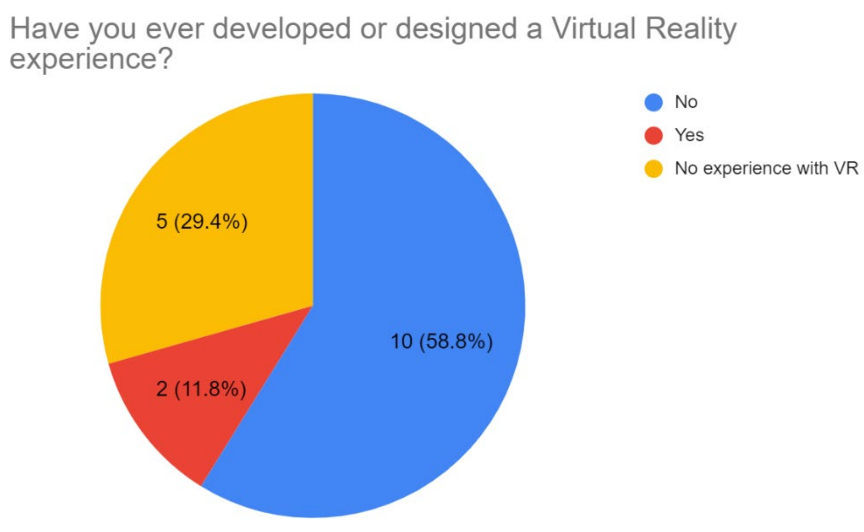


Figure 5-3: Experience in developing VR experiences

The values shown in Figure 5-3 visually represented any work experience that participants may have had in the past with VR technologies, whether it was in the capacity of development or design. This past work experience with VR technologies provided an indication of potential expert knowledge that participants may have. Out of the 17 participants, only two of them have worked on VR technologies in the past. Such past experience in working with VR technologies suggested that these two participants had potential expert knowledge regarding VR technologies. The participant that reported 250 hours spent using VR technology in Figure 5-2 is one of the two participants who have developed or designed for VR experiences before (shown in Figure 5-3). All other participants (indicated by the yellow and blue segments in Figure 5-3) either have no experience with VR technology at all or have only interacted with VR experiences for entertainment purposes. Based on these facts regarding past experiences, two participants were identified to have potential expert knowledge with regards to VR technologies which may have influenced the feedback that these they provided for this study.

5.3 User performance

Quantitative performance checks were captured by the system and produced raw data in the form of a CSV file. This was then converted to a spreadsheet where calculations were done for each participant regarding their three sessions. A full explanation of what kinds of performance checks were done has been discussed previously in Section 3.4.4. Below is a brief explanation for the various performance checks recorded. The discussion also includes how the data were used to make deductions linked to the participants' experiences in using the Belt Menu.

Data were collected for each participant over three sessions. Collecting data over multiple sessions allowed for an investigation of whether participants can become familiar with the Belt Menu over time, as discussed in Section 3.3.1. During each session, participants were encouraged to do the task over multiple attempts. Each attempt resulted in the following metrics of data:

- Time taken to complete the task.
- Number of selections made from the Belt Menu, including:
    - Accuracy of selections.
    - Comparing hit/miss ratio to minimum required selection.
    - Total number of selections made with each menu item.
    - Total number of selections made with each hand.
    - Total missed selections with each hand.
    - Speed of selections.

Each of these metrics is discussed along with their importance in the sections below.

5.3.1 Time taken to complete the task

Capturing the recorded time taken to complete a task provided a measurement that can inform the efficiency of participants using the Belt Menu in completing the task. The purpose of timing the participants was to keep track of each participant's individual time differences to observe progress in their efficiency compared to their own performance in their previous attempts and sessions. Any comparison between participants was used to investigate the difference in behaviour that may have contributed to their efficiency.

During each of these attempts, a timer was started when they indicated that they were ready and stopped when they had completed the task, as discussed in Table 3-1. The times were recorded as MM:SS:mmm, where "M" refers to two digits for minutes, "S" indicates two digits for seconds, and "m" indicates three digits for milliseconds. This format for time is also used consistently throughout this chapter. The system tracked the timing to the millisecond because it was important to see if there was even a minor time difference. This can be seen in sessions where a participant had very similar time differences between each attempt. For example, participants #01 (00:31.753), #13 (00:31.562), and #16 (00:31.829) all completed the task in Session 1 in 31 seconds, but their times differ in the milliseconds, which could be used to make comparisons for speed if necessary.

Each attempt by a participant was timed to see how long they took to complete the task of that session. The fastest time identified for all attempts of each participant for each session was used as a comparison for the time to complete the task. The median of all participants' fastest times for each session was as follows:

- Session 1 - 00:33.362
- Session 2 - 00:54.031
- Session 3 - 01:37.744

Median was used for comparison because it displays a more accurate mid-range indication of the dataset since it is not skewed by outlying times recorded.

Out of the 17 participants, 15 of them took longer to complete the task for Session 2 when compared to Session 1, which had a median of 00:33.362. It was expected that the median time would increase between Session 1 and Session 2 because the task for Session 2 required the participants to use both hands instead of just their dominant hand. Session 2 required the participants to use their non-dominant hand to acquire an extra tool and apply it to the block that was selected and held in the dominant hand (Section 4.5.2).

Every participant took longer to complete the task for Session 3 (median of 01:37.744) when compared to Session 2 (median of 00:54.031). This was also expected because the non-dominant hand would have to constantly switch between the Paintbrush and the Measure tape and apply it to the block that was selected and held in the dominant hand (Section 4.5.2). This occurrence is discussed in detail in Section 5.4.4.2a.

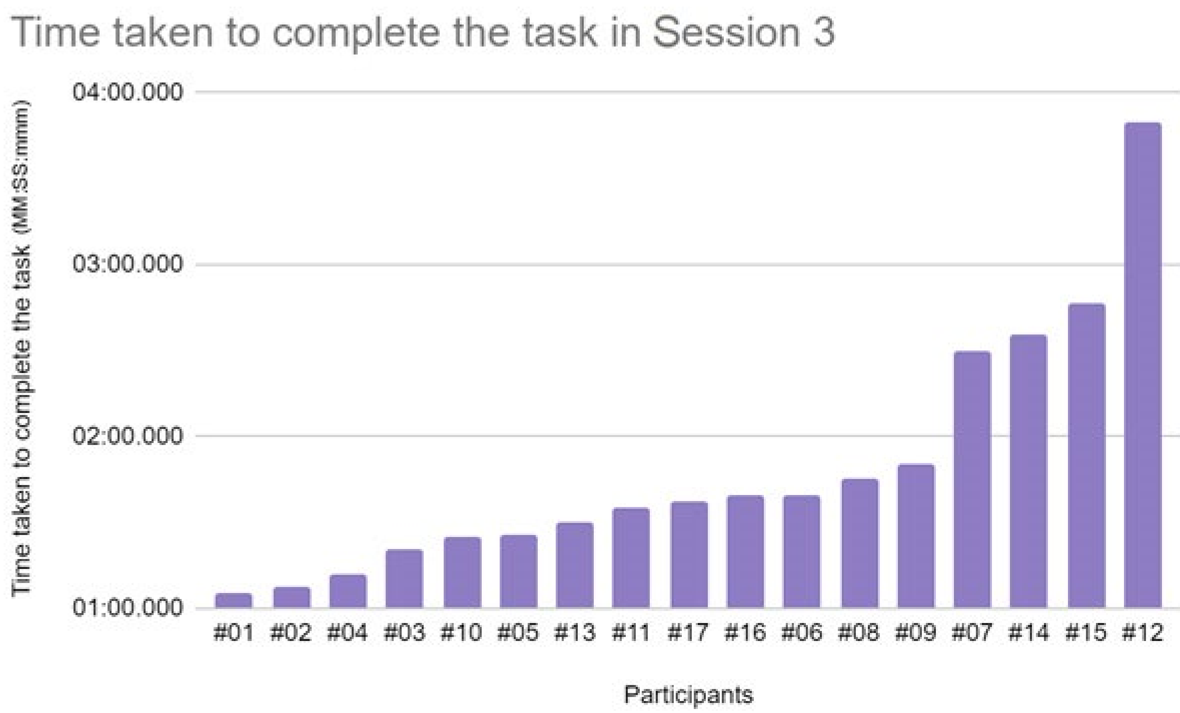


Figure 5-4: Time taken to complete the task in Session 3

Figure 5-4 visualises the time taken to complete the task in Session 3, sorted from the quickest completion time on the left to the slowest completion time on the right. The completion time for the task in Session 3 was used to measure the participant's efficiency for two reasons:

- The participants have all had equal exposure to the Belt Menu, thus their experiences are more standardised when being used for comparison compared to previous sessions.
- This session required the participants to fully utilise all menu items of the Belt Menu.

The following three participants were the fastest to complete the task in Session 3:

- Participant #01 - 01:05.672
- Participant #02 - 01:07.880
- Participant #04 - 01:12.276

Based on background experience with IVEs and VR technologies, it can be expected that participants who have had more exposure would be quicker in completing the task. This proved to be somewhat true where participant #01 not only has experience with VR technology but has also developed software for VR technology while participants #02 and #04 have had a few hours of experience with VR technology but no development experience. However, this expectation is only somewhat true because participant #03 has about 250 hours of experience with VR technology and has development skills for VR technology as well. Even though participant #03 has a background of having the most experience with VR technology, they were still outperformed in terms of completion time by two other participants with less experience. That being said, participant #03 was still amongst the participants who have the fastest completion time. These results indicate that there is a correlation between background experience and efficiency to complete the given tasks, but experience is not the ultimate determining factor.

5.3.2 Number of selections made from the Belt Menu

Keeping track of the number of selections helped to identify various problem areas that could be further investigated to understand user behaviour, e.g., high number of selections per second could identify where participants were either very efficient in doing their task or that they were frantically selecting items out of feeling overwhelmed. A user's performance can affect their ability to feel confident in their selections. These performance checks provided evidence that verified findings from the participants' experiences discussed in Section 5.4. The discussions below focus on providing an explanation for understanding what the number of selections made with the Belt Menu mean and the inferences that were made from these numbers.

5.3.2.1 Minimum number of selections required to complete the task

To provide context for what the number of selections meant, it was important to establish a standard that could be used to measure accuracy and efficiency. For a participant to complete the task, they would need to make a minimum number of selections on the Belt Menu. Determining this number was important because it provided a measurement that could be used as the standard of optimal efficiency, i.e., minimum selections would require minimum effort from the participant. The minimum number of selections for each stage of the task was determined by counting the minimum number of selections required to select a tool with the Belt Menu, e.g., a coloured brush, and multiplying that number of selections by the number of times this action was needed to complete the task.

Each box required blocks with specific properties, i.e., colour and size. Each of the three boxes required a specific shape with a randomised property to be added to the block. The discussion below provides details for minimum number of selections to occur. Before looking at the data collected from participants, it was important to determine what the minimum number of selections was to complete the task in each session. The next few paragraphs explain how this was determined.

To interact with the Belt Menu, participants would need to select something from it. The Belt menu consisted of four main menu items along with submenu items. The Addbox provided access to either the L, T, or Z segment that resulted in respectively shaped blocks when selected. Similarly, the Paintbrush provided access to a recolouring tool of either turquoise, lime, or pink segments. The same layout was used for the Measure tape that provided access to either a plus or a minus tool for enlarging or shrinking a block, respectively.

Each interaction with the Belt Menu that resulted in a tool being selected required two selections; one from the main menu items, and another from the corresponding submenu items. The explanation for each menu item selection is discussed in more detail below.

The following representations are used in the calculation formulas:

- Sessions 1, 2, and 3 are respectively denoted as S1, S2, and S3.
- To select the L block, a selection must be done on the Addbox and then selecting either the L, T, or Z segment, which was two selections. This is represented as a shaped (L|T|Z) block. The same process would be followed to select a T block or a Z block.
- The colour that was required was randomised between turquoise, lime, and pink, which was two selections. Therefore, it is represented as colour selection (T|L|P), where T is turquoise, L is lime and P is pink.
- The size that was required was randomised between small, medium, large, which was potentially two selections from the Belt Menu (see explanation for Session 3 below). Therefore, it is represented as Resize selection (Plus|Minus), where Plus is the enlarge tool and Minus is the shrink tool.

In Session 1, a participant was required to place five blocks of each shape (L, T, Z) into their respective boxes. Since there are three different shapes, a participant needed to select a total of 15 blocks from the Belt Menu. However, to select one of the shapes from the Belt Menu, the participant needed to select two menu items (the Addbox and the specific shape's segment). The Addbox (main menu item) needed to be selected to bring up the submenu wheel that provided the option of selecting a wheel segment that gave the participant a block of the shape that they had selected 4.4.1.2. The participant needed to do this five times for each shape (L, T, Z). Two selections (main menu selection of the Addbox item + a selection of one shape segment) per shape (L, T, Z) repeated five times results in 30 selections. Following this logic, the formulas below show a breakdown for the minimum number of selections required to complete the task for each session.

Session 1 (30):

$$Min\ selections\ for\ S1\ (30) = [Addbox + L\ block] \times 5 + [Addbox + T\ block] \times 5 + [Addbox + Z\ block] \times 5$$

Session 2 required the participant to do the same as Session 1 with one added complexity, namely, the boxes required a specific colour for each shaped block. These required colours on each box were randomised and changed after each block was placed correctly in the respective boxes according to shape and colour. There was a small chance that all 15 blocks required from the participant were the same colour. However, due to the randomisation of colours required for each box, it was more likely that different colours would be required for each block and would therefore be another 30 selections from the Paintbrush. Therefore, the minimum was 60 selections, assuming the participants needed to change colours for each block.

Session 2 (60):

$$\begin{aligned} Min\ selections\ for\ S2\ (60) &= ([Addbox + L\ block] + [Paintbrush + Colour\ (T|L|P)]) \times 5 \\ &+ ([Addbox + T\ block] + [Paintbrush + Colour\ (T|L|P)]) \times 5 \\ &+ ([Addbox + Z\ block] + [Paintbrush + Colour\ (T|L|P)]) \times 5 \end{aligned}$$

Session 3 required the participant to do the same as Session 2 with an addition of needing to resize the shaped blocks. Because the required colour and size of the blocks were completely randomised, it was possible that all 15 blocks required were medium sized and were only one colour. However, this was unlikely and so the calculation shown below is done according to all 15 blocks requiring a colour and size change.

Session 3 (90):

$$\begin{aligned} Min\ selections\ for\ S3\ (90) &= ([Addbox + L\ block] + Colour\ (T|L|P) + Resize\ (Plus|Minus)) \times 5 \\ &+ ([Addbox + T\ block] + Colour\ (T|L|P) + Resize\ (Plus|Minus)) \times 5 \\ &+ ([Addbox + Z\ block] + Colour\ (T|L|P) + Resize\ (Plus|Minus)) \times 5 \end{aligned}$$

By identifying the minimum number of selections required to complete each session, it can be used as a benchmark to measure the efficiency of participants. Therefore, any selections made beyond the minimum number of selections required can be considered as unnecessary selections. The more selections that were made beyond the minimum required selections, the less efficient participants were in completing the task.

The system recorded selections as hit and miss selections. The details of how this was done was discussed in Section 4.7. In addition, an unnecessary selection was a hit selection that was made beyond the minimum number of selections required to complete the task. More details discussing the causes of unnecessary selections are provided in Section 5.4.3.2c.

5.3.2.2 Accuracy of selections

Investigating the accuracy of a selection contributes to understanding participants in their experience to become familiar with the Belt Menu and build confidence in their selections.

When a participant wants to use the Belt Menu, they need to select a menu item from the Belt Menu. Selections can be identified with two different levels of accuracy which were recorded by the system (Section 4.7): either a hit or a miss.

A hit recorded by the system constituted that a menu item was selected but the system did not distinguish whether or not the selection was a desired item by the participant making the selection. The recorded selections simply kept count of what the participant selected. A distinction between a selection that results in a menu item needed to complete the task and a selection that the participant did not need to complete the task was important because it provided a more correct understanding of the selection accuracy. This distinction was made through a process of elimination by considering the minimum required number of selections to complete the task, along with the participants' verbal reports and direct observations by the researcher, which is elaborated on in Section 5.3.2.3. As a result, a selection can be distinguished as follows:

- Hit: the participant successfully selected an item from the Belt Menu, regardless of whether the item was needed to complete the task. This kind of selection was recorded by the system, as discussed in Section 4.7.
    - <u>Necessary</u>: the participant hit the menu item to select from the Belt Menu that is needed to complete the task.
    - <u>Unnecessary</u>: the participant hit a menu item from the Belt Menu, but it was not a menu item needed to complete the task. An unnecessary selection results in participants needing to redo their selection by making another selection.
- Miss: the participant moved their hand to select by reaching towards the area of a menu item but failed to touch and select a menu item from the Belt Menu, i.e., their hand was not in contact with the menu item when they pressed the button for selection. This kind of selection was recorded by the system, as discussed in Section 4.7.

The discussion in this section focuses on establishing a basic-level analysis for accuracy by simply looking at hit and miss selections, based on data recorded by the system. This provides a starting point for understanding how accuracy was investigated. Any other selections were not recorded by the system and are therefore only discussed in detail later in Section 5.3.2.3.

Each selection with the Belt Menu made by all 17 participants was counted and recorded by the system, as discussed in Section 4.7. The resulting cumulative number of selections, i.e., hits and misses, recorded for all participants was 3,104 in Session 1, 7,858 in Session 2, and 9,307 in Session 3. Figure 5-5 provides a visualisation for the total number of hit and missed selections for all 17 participants across all three sessions. Sessions are colour-coded for hit selections and miss selections as Session 1 (blue), Session 2 (purple), and Session 3 (green). The three bars on the left are the total number of hit selections in each session while the three bars on the right are the total number of missed selections in each session. The progressive increase in the number of selections over the three sessions is a confirmation that the task became significantly more complex with each session.

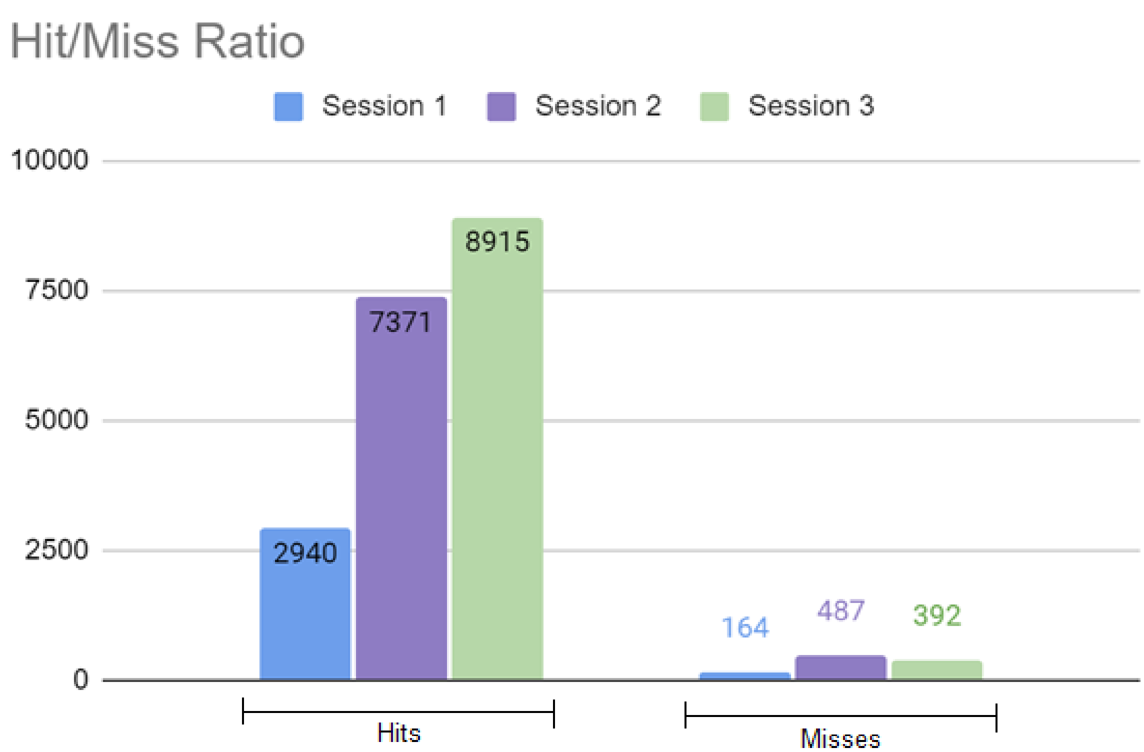


Figure 5-5: Total count of hits and misses for each session

The total hit selections for each session are calculated as the following averages for each session:

- Session 1: 94.72% (2940/3104)
- Session 2: 93.80% (7371/7858)
- Session 3: 95.79% (8915/9307)

Based on the hit miss ratio visualised in Figure 5-5, it can be seen that all 17 participants already had high average accuracy (94.72% hit rate) from Session 1. The high hit rate suggests that there was little difficulty for the participants to select objects and tools from the Belt Menu.

These values indicate that the hit rate decreased from an average of 94.72% to 93.80% in Session 2 but increased again to 95.79% in Session 3. This occurred even though the number of total selections drastically increased with each session. The differences for the total number of selections between each session are more apparent when looking at the visualisation shown in Figure 5-5. Figure 5-5 also shows more clearly the vast differences between the hit and missed selections for all three sessions.

It should be emphasised that with each session a new tool from the menu needed to be used, which made each session progressively more complex than the previous. Therefore, the increased misses between Session 1 and 2 can be expected. A drastic increase of unnecessary selections between Session 1 and Session 2 can also be expected due to a new tool that was required to be used. However, a decrease in missed selections in Session 3 when the task got even more complex indicates that participants were struggling less to select from the Belt Menu.

Interestingly, the rate of hit selections at 95.79% (8915/9307) in Session 3 increased to a higher percentage compared to the rate of hit selections at 94.72% (2940/3104) in Session 1. This increase in accuracy is worth noting because the task for Session 3 was more complex than the task in Session 2 and significantly more complex than Session 1, as is visible by the difference in the total number of selections made for Session 1 and Session 3.

5.3.2.3 Comparing hit/miss ratio to minimum required selection

Section 5.3.2.2 discusses the hit/miss ratio of successfully selecting a block or tool from the Belt Menu. However, this does not necessarily indicate whether the selected block or tool is the one that the participant needed for the task, as discussed in Section 5.3.2.2 above. Comparing the total selections per session to the minimum number of selections required will result in a more accurate indication to determine the accuracy and efficiency of participants' selections from the Belt Menu.

As discussed in Section 5.3.2.1, there is a fixed minimum number of selections required to complete the task in each session (Session 1 – 30, Session 2 – 60, Session 3 – 90). The statistics in Figure 5-5 only show the hit/miss ratio, which does not take into consideration whether the selected menu item was the menu item that the participant needed for the task.

Any other selections more than the realistic minimum can be considered unnecessary selections, i.e., selections that resulted in a menu item that was not needed to complete the task. Causes for unnecessary selections are discussed further in Section 5.4.3.2c. By distinguishing between an unnecessary selection and a missed selection, it provided an understanding that the accuracy ratio visualised in Figure 5-5 only indicates accuracy in terms of whether or not items were selected and does not reflect whether the selection was necessary for the participant to complete the task.

Therefore, investigating the minimum of required selection (MRS) compared to the total number of selections (TNS) yields a more informative efficiency and accuracy rating. To accurately represent the TNS of each session, the total number of attempts was identified, which was recorded by the system. For each session, each participant was asked to do a minimum of two attempts to complete the task. As a result, some participants were only willing to do two attempts while other participants voluntarily did up to five attempts. The total number of attempts for all 17 participants in Session 1 was 45 attempts, as indicated in Table 5-2.

Table 5-2: Number of attempts over three sessions

	Attempts		
Participant	S1	S2	S3
#01	2	3	4
#02	2	2	3
#03	2	3	3
#04	2	5	5
#05	3	4	3
#06	3	3	3
#07	4	2	2
#08	2	3	3
#09	4	2	2
#10	2	3	3
#11	3	3	3
#12	3	3	3
#13	2	3	3
#14	3	4	3
#15	2	3	2
#16	3	2	2
#17	3	4	3
Total	45	52	50

Min	2	2	2
Max	4	5	5

In Session 1, the MRS to complete the task is 30 selections. As indicated in Table 5-2, a total of 45 attempts were used in Session 1 while completing the task across all participants, therefore, the total MRS to complete the task would be 1350 (30 $MRS \times$ 45 attempts). However, the TNS across 45 attempts resulted in 3104 selections. Therefore, the percent of unnecessary selections in Session 1 is calculated as follows:

$$56.51\% \text{ unnecessary selections} = \frac{3104 \text{ TNS} - (30 \text{ MRS} \times 45 \text{ attempts})}{3104 \text{ TNS}}$$

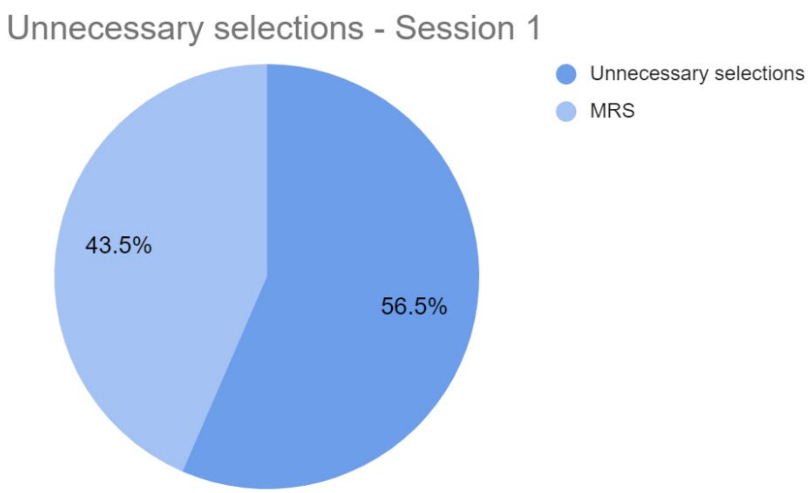


Figure 5-6: True accuracy – Session 1

For session 2, the MRS to complete the task was 60 selections. Similar to Session 1, participants were required make a minimum of two attempts for session 2. In total, the number of attempts for all 17 participants was 52 attempts to complete the task, as indicated in Table 5-2. As a result, the total MRS would be 3120 (60 MRS × 52 attempts). Comparing to a TNS across 52 sessions of 7858 hit selections, only 3120 selections were actually required to complete the task. This means that the percent of unnecessary selections in Session 2 is calculated as follows:

$$60.30\% \text{ unnecessary selections} = \frac{7858 \text{ TNS} - (60 \text{ MRS} \times 52 \text{ attempts})}{7858 \text{ TNS}}$$

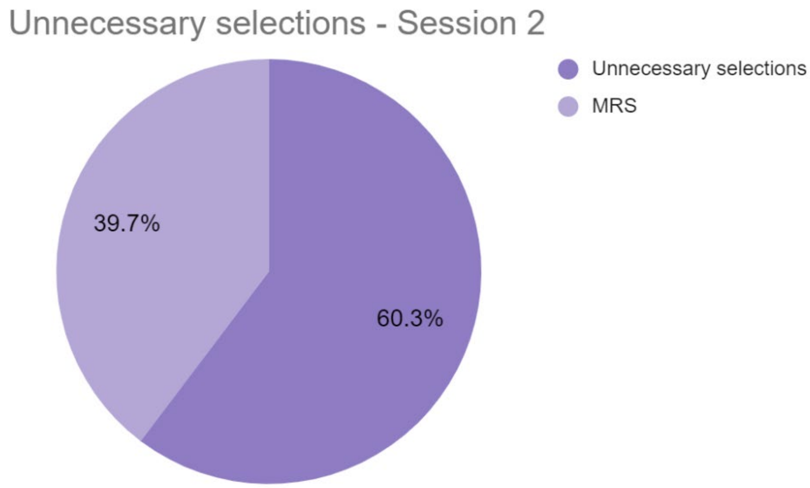


Figure 5-7: True accuracy – Session 2

The MRS to complete the task in Session 3 was 90 selections. With a total of 50 attempts across all participants, as indicated in Table 5-2, cumulatively the MRS would be 4500 (90 MRS × 50 attempts). The TNS across all 50 sessions was 9307 selections. Therefore, the percentage of unnecessary selections in Session 3 would be calculated as follows:

$$51.65\% \text{ unnecessary selections} = \frac{9307 \text{ TNS} - (90 \text{ MRS} \times 50 \text{ attempts})}{9307 \text{ TNS}}$$

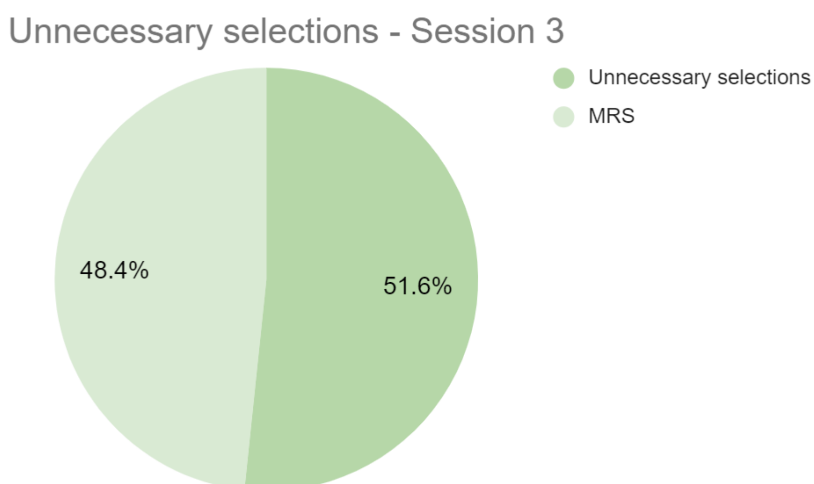


Figure 5-8: True accuracy – Session 3

The above percentages of unnecessary selections from Session 1 (56.51%) to Session 2 (60.30%) shows in increase in the percentage of unnecessary selections, which indicates that the selection accuracy had decreased. However, in Session 3 the unnecessary selections decreased to 51.65%, which is less than Session 1 (by 4.86%) and Session 2 (by 8.95%). A decrease in unnecessary selections also indicates an increase in selection accuracy. This follows the trend described in the discussion under Figure 5-5, where the hit/miss ratio worsened in Session 2 but improved in Session 3 beyond the hit/miss ratio in Session 1. This improvement is despite the task in Session 3 being the most complex of the three sessions. This consistency is worth noting because the hit/miss ratio discussed in Section 5.3.2.2 does not consider that hit selections might also be unnecessary selections, as discussed at the end of Section 5.3.2.1, i.e., the participant successfully selected a menu item but it was not needed for the task. Since the results in Section 5.3.2.2 correlate to the accuracy calculated in this section, the trend described above proves to be reliable.

5.3.2.4 Total number of selections made with each menu item

Investigating the selection count of menu items provides a different perspective of understanding the hit/miss ratio that clarifies which menu items participants struggled the most to select. Menu items with higher rates of missed selections would be identified as menu items that are difficult to select due to positioning.

Each menu item has a specific positioning in relation to the participant, e.g., the Addbox and the Paintbrush are always in front of each hand, as shown in Figure 5-9. The positioning of each menu item also affected how accessible these menu items were to the participant. Menu items that were in front of the user (e.g., the Addbox and the Paintbrush) were more clearly visible and, therefore, would be easier to access. Menu items that were to the sides of the user (e.g., the Measure tape and the Arrow adjuster) were outside the direct line of sight when facing forward. To access the menu items on the side, participants would have to move their arms more to reach these menu items, meaning that these menu items would be more difficult to access. The numbers in the table below represent the total number of selections done on each menu item and is cumulative across all 17 participants for sessions 1, 2 and 3.

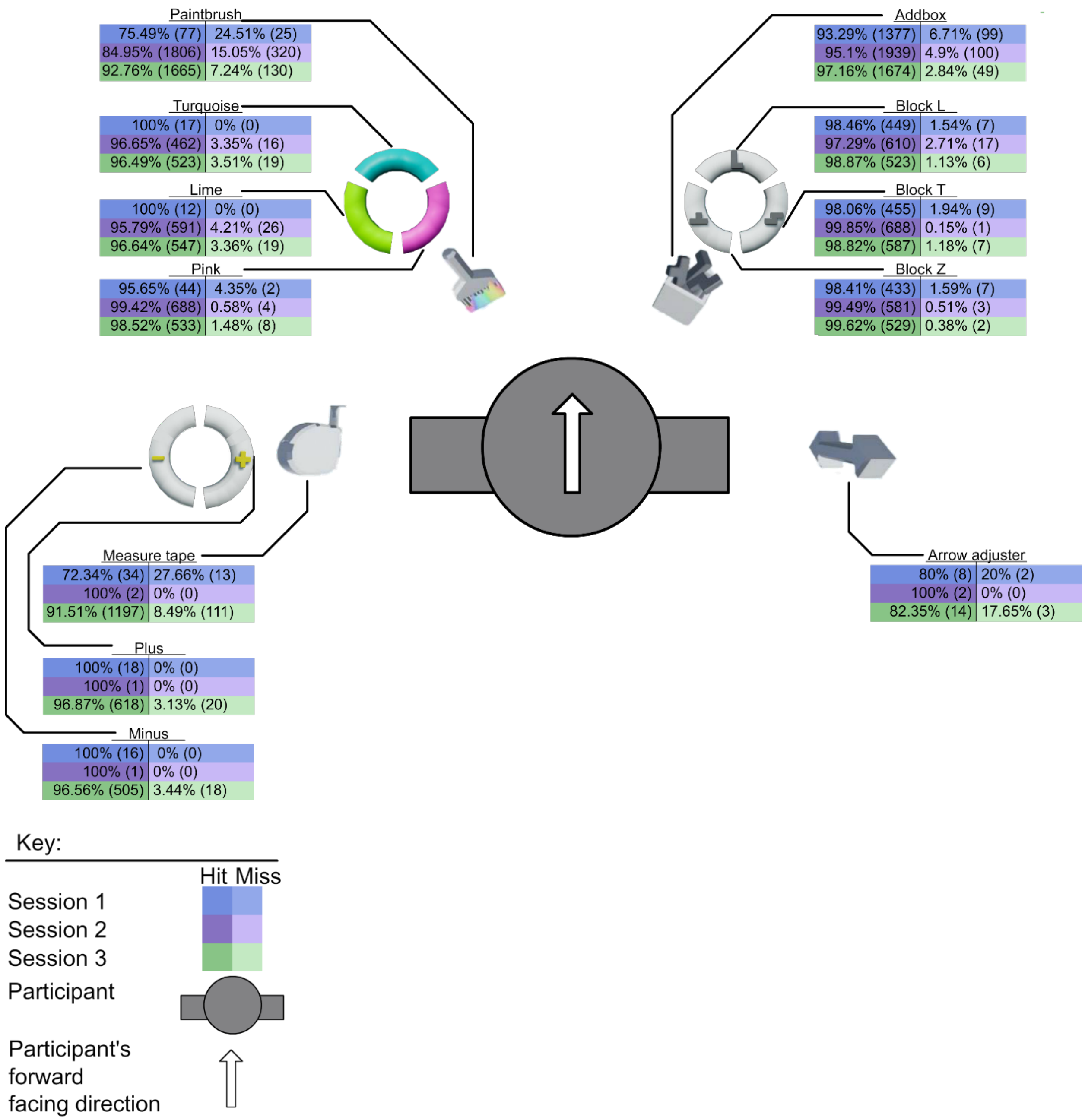


Figure 5-9: Selection count of each menu item

Figure 5-10, Figure 5-11, and Figure 5-12 indicate the ratio of missed selections, i.e., the participant moved their hand and made a motion to select the menu item, but did not select it. The range of colour segments in the pie charts in Figure 5-10, Figure 5-11, and Figure 5-12 represent the following menu items:

- Blue segments represent the Addbox, which was used to get different shaped blocks (L, T, Z). The submenu items for the Addbox are represented as lighter shades of blue.

- Green segments represent the Paintbrush, which was used to give the blocks a specific colour (turquoise, lime, pink). The submenu items for the Paintbrush are represented as lighter shades of green.
- Orange segments represent the Measure tape, which was used to change the size of the blocks (plus tool, minus tool). The submenu items for the Measure tape are represented as lighter shades of orange.
- The grey segment represents the Arrow adjuster, which was used to change the height of the Belt Menu. There are no submenu items for this menu item.

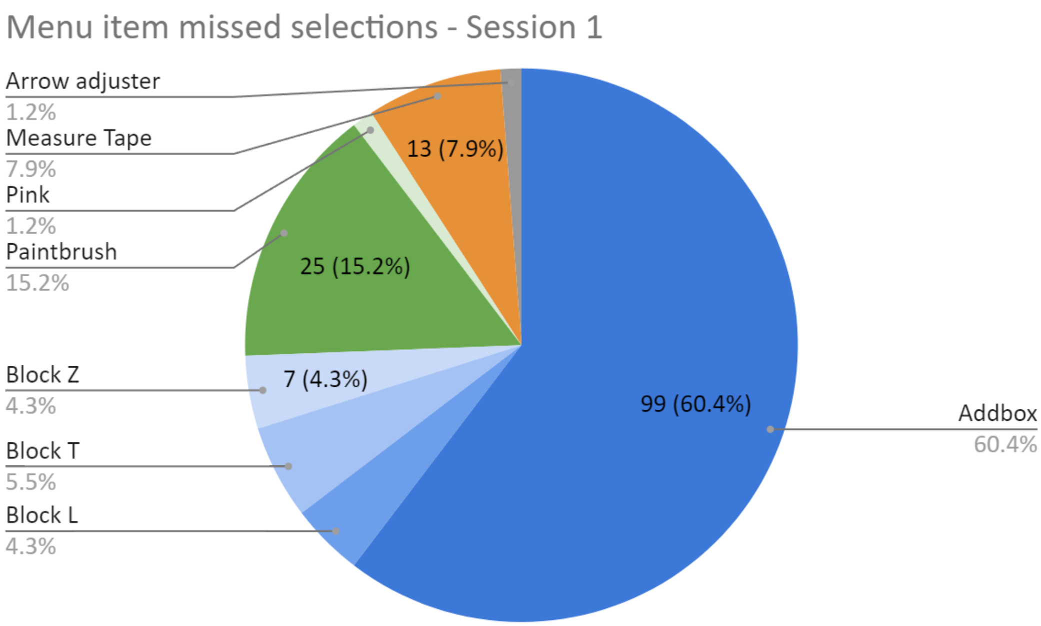


Figure 5-10: Missed selection on specific menu items - Session 1

In Session 1, the majority of the missed selections were contributed by blocks selection, i.e., selecting the Addbox main menu item and the submenu items for obtaining blocks of different shapes (L, T, Z), as shown in the blue range in Figure 5-10. This can be expected because the task only required using blocks selection and more selections provided more chances to miss selections. This expectation can be observed for possible changes in the next two sessions.

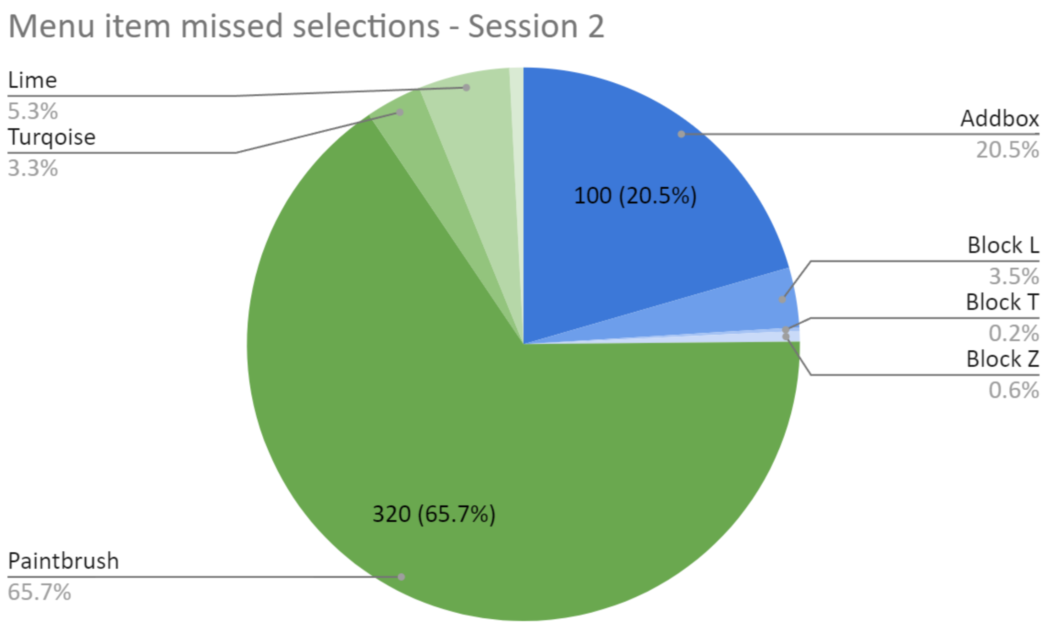


Figure 5-11: Missed selection on specific menu items - Session 2

In Session 2, selections for blocks were no longer the major contributor of missed selections. Instead, selections for the colouring tools caused the most missed selections, as shown with the green range in Figure 5-11. This follows the expectation, and a possible trend, that participants struggled more with newly introduced menu items. In addition, because the focus for Session 2 was on a more complex task, it is possible that participants deferred from using unnecessary menu items, i.e., the Measure tape and the Arrow adjuster.

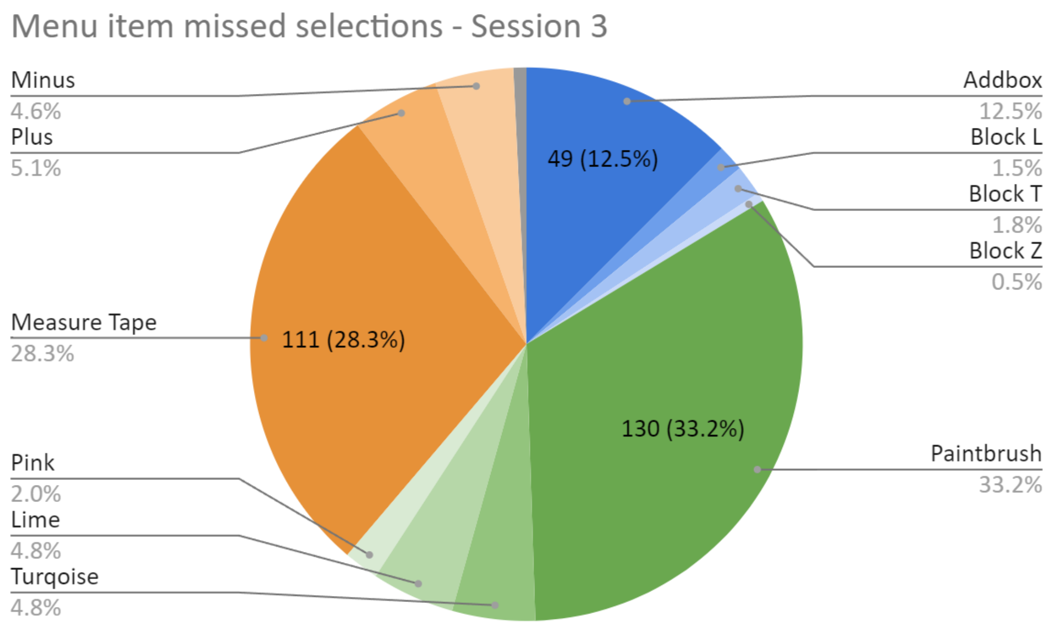


Figure 5-12: Missed selection on specific menu items - Session 3

Missed selections in Session 3 were distributed more evenly between the Paintbrush (33.2%) and the Measure tape (28.3%), with exactly an eighth of the errors contributed by the selections for the Addbox (12.5%). Interestingly, even though the selection for the Paintbrush was more practiced in Session 3 due to prior usage from Session 2, it remained the menu item that was missed the most. There are several possible explanations for these higher missed selection rates of the Paintbrush and Measure tape. One possible reason is the fact that one hand was preoccupied with holding a block, which requires subconscious attention, while the other hand is making selections for either the Paintbrush or the Measure tape. Another possible reason for this is the fact that the hand used for selecting the Paintbrush and Measure tape needs to constantly switch between tools, making the interaction more prone to errors. Use of the dominant and non-dominant hands for selecting the various menu items may have contributed to the difference in missed selections as well, and is discussed further in Section 5.3.2.6.

All three visualisations (Figure 5-10, Figure 5-11, Figure 5-12) for the three sessions indicate that the majority of the selections that were missed were contributed by the main menu items (the darkest segment of each colour range) – the submenu items all have a lower miss rate across all three sessions. A possible reason for this is that main menu items serve as a point of orientation before selecting something from the submenu options. The submenu wheel segments always appear around the grabbed menu item, which is in the centre of the participant's hand, as shown in Figure 4-16, Figure 4-17, Figure 4-18, and Figure 4-32. For example, if a participant wants to select a Z-shaped block then they would grab the Addbox and the three segments for each shape would appear around the participant's hand. From there they can move to select the wheel segment for the Z-shaped block.

The Arrow adjuster has been excluded from this observation because it is only used to adjust the height of the Belt Menu and was rarely used (only 29 times in total). This was typically done at the beginning of the session, so that participants could find a comfortable height to work with. The only exception was participant #16 during Session 3, where they regularly adjusted the height in Session 3 because the menu items were obscuring their view of the size labels on the boxes.

5.3.2.5 Total number of selections made with each hand

The investigation of hand usage was important because menu items were designed with hand dominance in mind, i.e., frequently used menu items were placed close to the dominant hand, while supporting menu items were placed near the non-dominant hand, as discussed in Section 4.4.3 and 4.6.1. Recording selections according to hand usage yielded data that helped to provide insight into whether the position of menu items, relative to each hand, contributed to the efficiency of completing a task.

Out of the 17 participants, three participants were left-handed. Although the study of handedness was beyond the scope of the current study, the use of both hands was required to complete the tasks and, therefore, it was important to keep note of handedness. As discussed in Section 4.6.1, a different layout was provided for left-handed participants to accommodate for preferred hand usage.

The pie charts below are visualisations of the hand usage ratios for each session, displaying the progressive increased usage of the non-dominant hand over the three sessions.

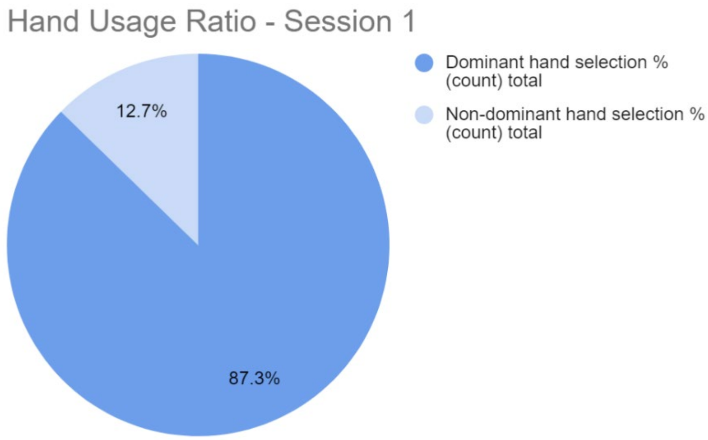


Figure 5-13: Hand usage ratio - Session 1

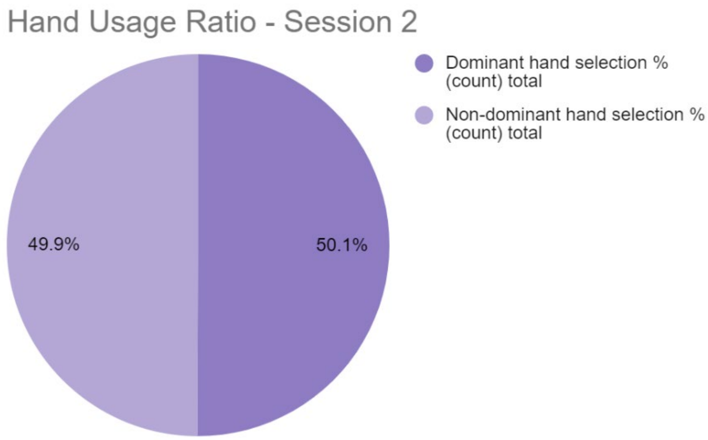


Figure 5-14: Hand usage ratio - Session 2

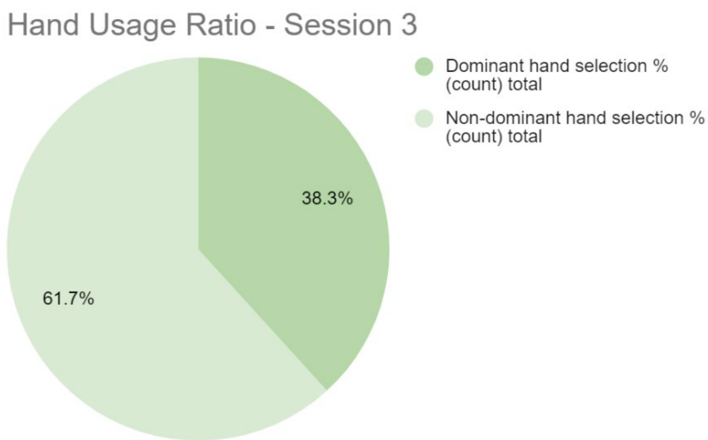


Figure 5-15: Hand usage ratio - Session 3

Although all 17 participants used their dominant hand less with each progressive session, this is not an indication that they preferred to do so. Rather, it is because the tasks in Session 2 and Session 3 required participants to hold one shaped block with the dominant hand while selecting multiple menu items with the non-dominant hand.

5.3.2.6 Total missed selections with each hand

By analysing the accuracy of selections for each hand, context can be provided to understand possible discomfort when selecting certain menu items. Menu items were intentionally placed to be closer to certain hands for easier access. The results for measuring the accuracy for each hand provided evidence that can be used to support discussions regarding the designed layout.

The task in Session 1 is the only task that does not require participants to use both hands to complete the task. Because the use of the dominant hand was the only requirement in Session 1, hand usage and its accuracy was not investigated in detail.

In Session 2, all participants had cumulatively missed more selections, i.e., there were more unsuccessful attempts to select a menu item, with a total of 6.20% (487/7858) compared to Session 1 with a total of 5.28% (164/3104). This could be because the task for Session 2 was more complex when compared to Session 1. The task for Session 2 required the participants to make selections with both of their hands, thus needing to make double the number of selections, as discussed in Section 5.3.2 above. Out of the total of 487 missed selections for all participants in Session 2, the dominant hand contributed 24.85% (121/487) of the missed selections while the non-dominant hand contributed 75.15% (366/487) of the missed selections. These results make sense because the usage of the dominant hand is typically more proficient and accurate than the non-dominant hand.

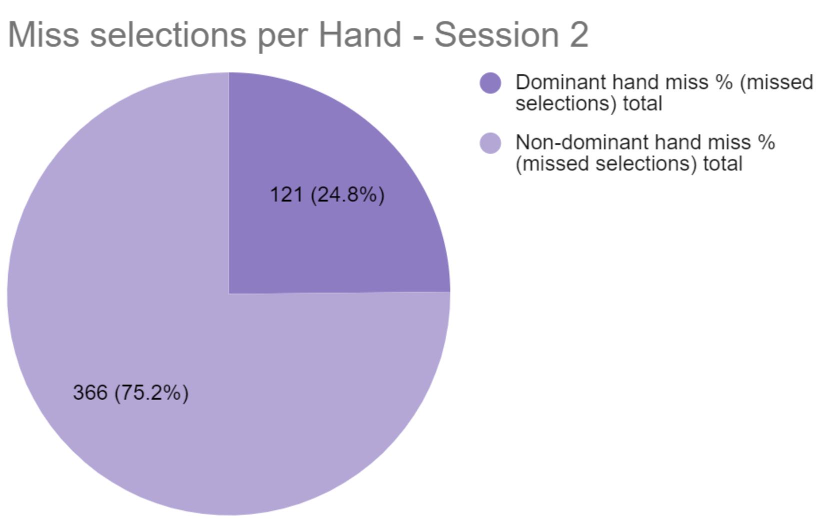


Figure 5-16: Ratio of missed selections according to each hand - Session 2

As mentioned before in Section 5.3.2.2, participants overall had more missed selections in Session 3 than in Session 1, but fewer missed selections than in Session 2. Out of the total of 392 missed selections in Session 3, 18.88% (74/392) of them were made with the dominant hand while 81.12% (318/392) were made with the non-dominant hand.

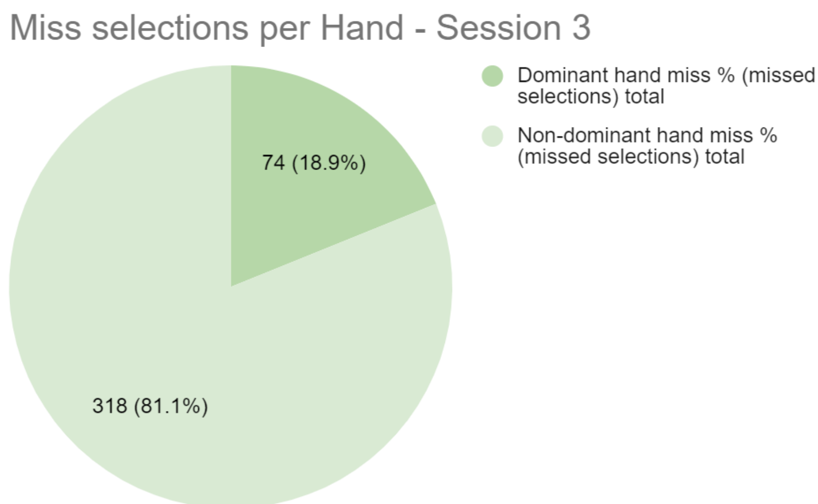


Figure 5-17: Ratio of missed selections according to each hand - Session 3

It can be expected that the dominant hand would make fewer missed selections because it is usually more proficient and accurate than the non-dominant hand. But also, the task in Session 3 required the non-dominant hand to do more selections, as shown in Figure 5-15, leading to more chances for missed selections.

Specifically, the task in Session 3 required participants to use the Measure tape in addition to the Paintbrush, with both tools being located closer to the non-dominant hand, leading to increased selections required by the non-dominant hand. For every block, there was a chance that menu items required the same colour as the previous block, and so the participant would not need to reselect a different colour. However, this was nullified when the Measure tape was introduced because they would need to constantly switch between the Paintbrush and the Measure tape to ensure the correct colour and shape of each block. This meant that the number of selections required by the non-dominant hand doubled. The strain on the non-dominant hand was visible in an increased missed selection percentage, as shown in Figure 5-17.

Despite increased selections that put more strain on the non-dominant hand, a hand that is usually uncomfortable to use frequently, the overall number of missed selections decreased in Session 3 (392/9307) compared to Session 2 (487/7858), as shown in Figure 5-5. The current study was not intended to contribute to menu system design for hand dominance, but these results align with Habibi and Chattopadhyay's (2021) findings with regards to hand usage, in which their study indicated that there is less of a performance difference between hands when using touchless input instead of a computer mouse or stylus.

5.3.2.7 Speed of selections

Pursuing an investigation regarding the speed of selections for each participant over three sessions provided some evidence of the participants' behaviours when using the Belt Menu. Having evidence of such behaviours provides a method of triangulating the findings that result from trying to understand the participants' experiences, e.g., having high efficiency in selections or frantically making selections from feeling overwhelmed. Both behaviours can be supported by the speed of selections made.

Details about the time used to complete tasks were discussed in Section 5.3.1 and the total number of selections for each session for all participants was recorded. Using these two metrics together produced a unit that was used to measure the rate of selection to complete a task, which can be used as a metric to inform efficiency.

All participants' total selections were divided by the time to complete the task, in seconds, which resulted in the selections per second (s/s) for each attempt of each session.

$$s/s = \frac{total\ selections}{time\ to\ complete\ the\ task\ of\ a\ session\ (in\ seconds)}$$

Then the average of all attempts of each session from a single participant was calculated as follows:

$$s/s_{(average)} = \frac{\sum(s/s\ for\ all\ attempts)}{number\ of\ attempts}$$

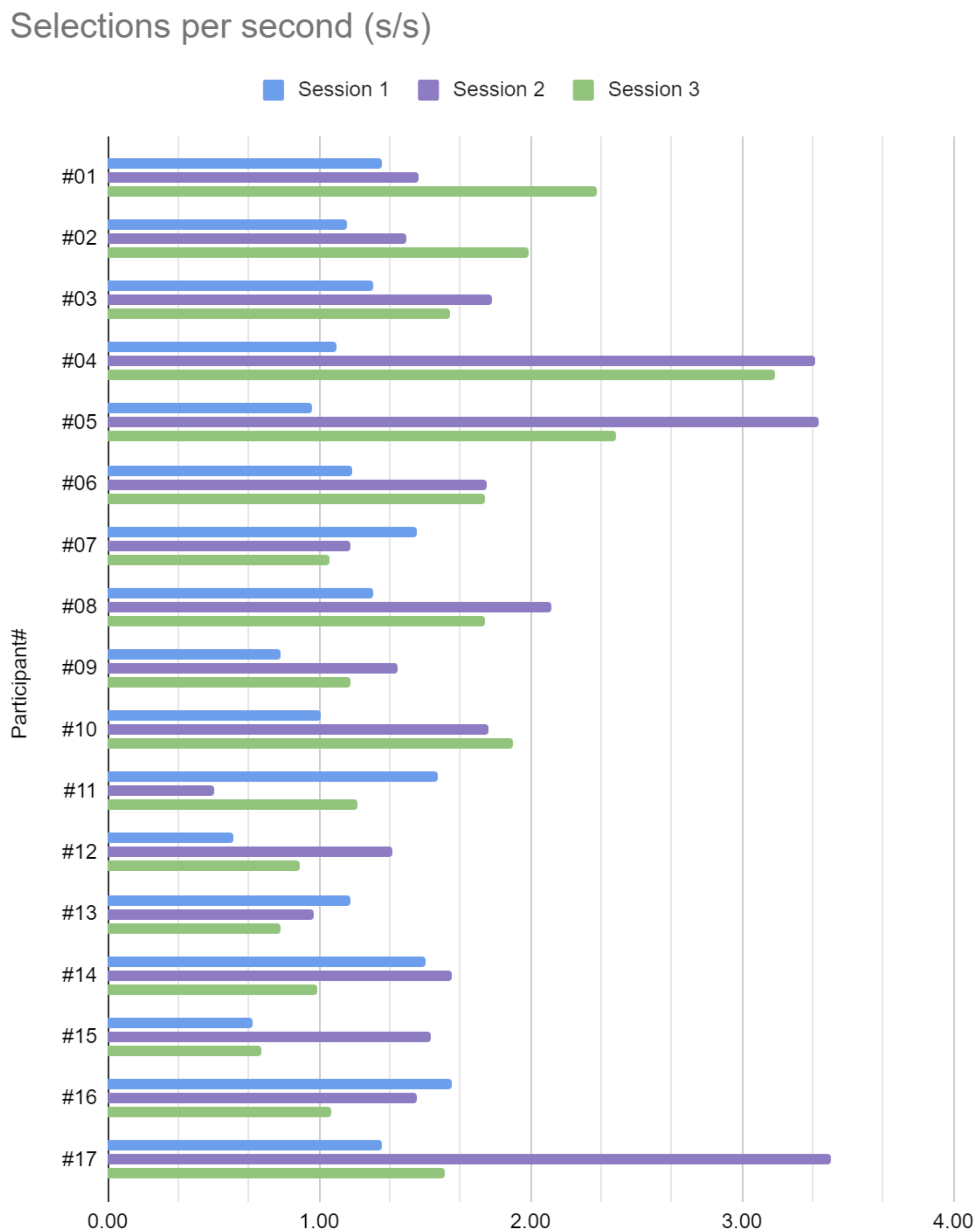


Figure 5-18: Selections per second over three sessions

In Session 1 the task only required participants to make selections with the dominant hand, which resulted in a median of 1.16 s/s, as shown in Figure 5-19. In Session 2 the task became more complex, where both their dominant hand and their non-dominant hand had to be used. Each hand was used to select one menu item. This would be one explanation as to why the median number of actions increased to 1.53 s/s. In Session 3 the task became even more complex, as their non-dominant hand had to select an extra menu item in addition to what they did for the task in Session 2. The extra selection required in Session 3 resulted in needing to switch between tools by constantly doing an extra selection with the non-dominant hand, which was confirmed by all 17 participants during their interviews when prompted. As a result, the median s/s in Session 3 increased to 1.60 s/s.

Participant #01 had a selection rate of 2.64 s/s while participant #02 had a selection rate of 2.19 s/s. Both participants (#01, #02) had a s/s that was above the median of 1.60 s/s, but did not have the highest s/s. Participant #04, had a selection rate of 3.15 s/s in Session 3 but did not complete the task the fastest, indicating that s/s does not necessarily correlate to higher efficiency.

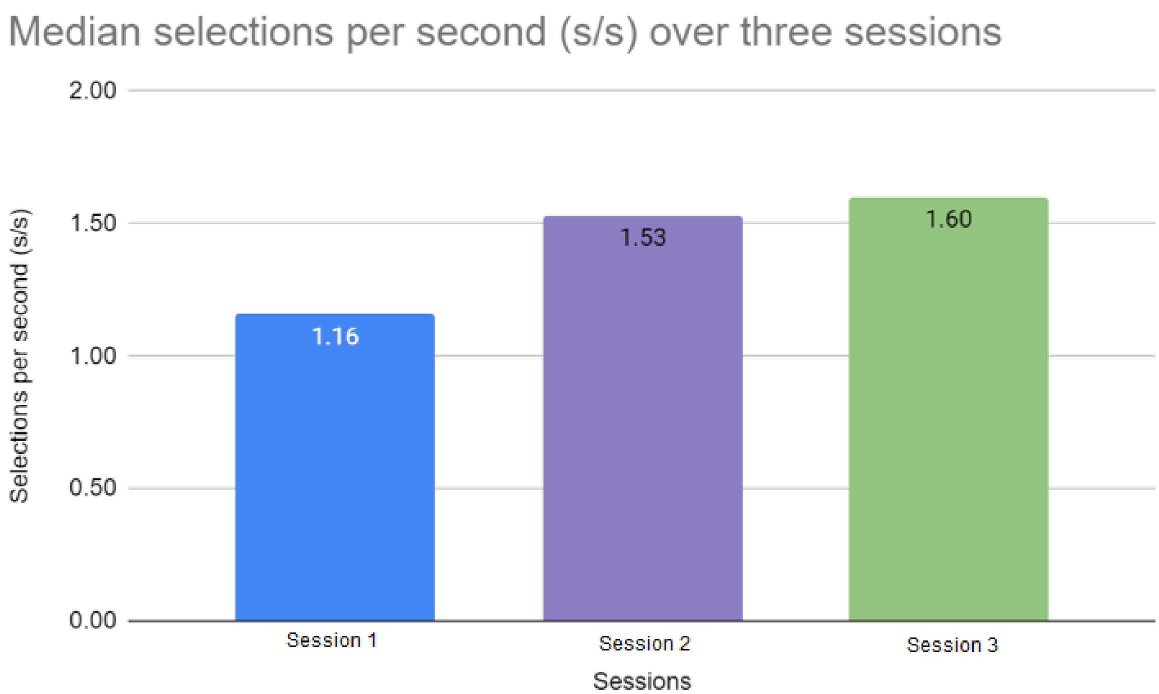


Figure 5-19: Median selections per second (s/s) over three sessions

According to Figure 5-18, the s/s for nine of the 17 participants (#03, #04, #05, #08, #09, #12, #14, #15, #17) showed an increase in Session 2 (purple lines) and then decreased again in Session 3 (green lines), even though Session 3 required more selections to complete the task. This decrease in s/s in Session 3 for these nine participants, despite requiring more selections to complete the task, is worth noting because it contradicts the trend that the s/s would increase if there are more selections to be done to complete the task, as shown in Figure 4-19.

5.3.3 Inferences from the user performance data

Having background experience in IVEs and VR technology contributes towards efficiency but does not directly correlate because the participant with the most experience with VR technology did not clearly outperform other participants in terms of performance metrics, e.g., performance time and accuracy. Participants had a median of less than 50% of the selections to be necessary to complete the task for all three sessions (Session 1 – 43.5%, Session 2 – 39.7%, Session 3 – 48.4%). This can also be understood as the percentage of accurate selections. There was an expected accuracy dip between Session 1 and 2 but in Session 3 accuracy was the highest of all three sessions, despite having the most complex task. This suggests that participants had become familiar with the menu system.

Most missed selections occurred with main menu items, possibly because main menu items also serve as a point of orientation before selecting something from the submenu options, therefore aiding the accuracy of selections with submenu items. Participants also missed the most selections with the colouring options, i.e., the Paintbrush and the three colours. Hand usage for the non-dominant hand increased progressively based on the layout of the menu system. Many of the missed selections were caused by the non-dominant hand, however, this is also due to the non-dominant hand needing to make more selections than the dominant hand.

The speed of selection increased progressively over the three sessions, most likely due to the complexity of the task increasing, which resulted in more selections that needed to be made. Out of 17 participants, nine of them in Session 3 had a lower selection speed compared to Session 2, despite the more complex task. The speed of selection contributed towards efficiency but the two are not directly dependant. Participant #01, who had the quickest completion time in Session 3 as shown in Figure 5-4, did not have the highest selections per second, as shown in Figure 5-19.

The next section will investigate the experience of using the Belt Menu in reference to the qualitative data collected.

5.4 Experience with the Belt Menu

As detailed in Section 3.2.1, the feasibility of the Belt Menu, and thus the identified criteria in Section 2.10 as well, is informed by user experience. Specifically, should participants experience an ease of learning to use the Belt Menu and find it easy to become familiar to interact with, it was expected that they would be able to develop expert user behaviour that resulted in eyes-off interactions and multitasking.

Investigating participants' experiences with the Belt Menu was done through constant comparative analysis (Taylor, Bogdan & DeVault 2016:164; Pickard 2019:267, 271), which involved the process of coding, resulting in themes being identified from the various sources of data. These themes were distilled into specific areas of interest by considering how each theme contributed to addressing the research questions. Some of the identified themes were not directly relevant to addressing the research questions but still provided insight to help understand the participants' experiences with the Belt Menu. The process of identifying each theme and the relevant relationships are discussed under their respective subsections below.

5.4.1 Coding and themes identification

Transcriptions from the interviews and focus groups were imported into Atlas.ti for analysis. All these data were coded by the researcher as the sole coder, and emergent themes were identified by highlighting words and phrases that were tagged with an identified theme, i.e., a constant comparative analysis was applied (Taylor, Bogdan & DeVault 2016:164; Pickard 2019:267, 271). As each transcription was processed, some of the themes were refined and re-evaluated, resulting in editing the themes, e.g., adding, editing, splitting, renaming. Themes regarding various user behaviours were identified and are discussed in their own subsections below. The coding process resulted in 121 codes, which were further analysed to understand how user behaviours were related to one another. These were then grouped together. As discussed in 3.5.2, the participants' behaviours were investigated for changes in behaviour that indicate progression in their level of expertise. As a result, codes that inform the level of expertise were categorised, as indicated in Table 5-3. The level of expertise was determined by participants' descriptions of when the behaviours occurred, as well as from the observation data that indicated a progressive increase in familiarity and confidence in their selections over time. Literature discussed by Shneiderman et al. (2009:66–69) identified three stages of expertise, however, the results of the current study found that there are user behaviours that are experienced in multiple stages and not necessarily exclusive to one stage. Table 5-3 presents a simplified understanding that conforms to the three stages identified by Shneiderman et al. (2009:66–69). A more accurate understanding would be to identify these user behaviours according to a spectrum of expertise, where novice and expert behaviours would be on opposite ends rather than three clearly defined stages, with some user behaviours also being experienced in all stages of expertise.

Table 5-3: Codes categorised according to the level of expertise

Expertise	Codes
Novice	Accidentally apply tool
Novice	Button awareness
Novice	Clumsy
Novice	Confusing at first

Expertise	**Codes**
Novice	Direct looking
Novice	Easy to remember
Novice	Easy to understand
Novice	Forgetting
Novice	Function unsure
Novice	Looked at main menu
Novice	Mental strain
Novice	Synchronous interaction
Experienced	Asynchronous interaction
Experienced	Consistency
Experienced	Customisation
Experienced	Dead zone
Experienced	Default selection
Experienced	Deselect
Experienced	Easy to become familiar
Experienced	Easy to fix
Experienced	Enjoyable
Experienced	Error recovery
Experienced	Focus on submenu
Experienced	Focused on the task
Experienced	Outline
Experienced	Prefers layout as designed
Experienced	Previous session
Experienced	Relying on shadows
Experienced	Resize menu objects
Experienced	Smooth selection
Experienced	Spatial awareness
Experienced	Time pressure
Experienced	Undo action
Experienced	Wave selection
Expert	Autopilot
Expert	Easier than existing methods

Expertise	**Codes**
Expert	Error prevention
Expert	Eyes-off interaction
Expert	Go fast
Expert	Less fatigue than existing methods
All	Awkward positioning
All	Bimanual interaction
All	Double checking
All	Glance
All	Haptic
All	Non-dominant hand doing more
All	Peripheral vision
All	Recognition over recall
All	Throwing

Additionally, groups were identified with regards to user behaviours that shared similarities. The codes that were grouped together are presented in Table 5-4 and are arbitrarily colour-coded to distinguish between the groups.

Table 5-4: Codes that are grouped

Codes	**Groups**
Approach	Dropping
	Per block
	Per colour
	Throwing
Awareness	Button awareness
	Controller overlapping
	Easy to remember
	Haptic
	Menu pop up
	Outline
Hand Usage	Asynchronous interaction

Codes	**Groups**
	Bimanual interaction
	Criss-cross hands
	Dominant hand
	Non-dominant hand
	Non-dominant hand doing more
	Synchronous interaction
Unexpected	Default selection
	Relying on shadows
Visibility	Direct looking
	Eyes-off interaction
	Glance
	Peripheral vision

By identifying user behaviours according to level of expertise and the abovementioned groups, user behaviours were found to be related to properties of the menu system in such a way that supported participants to use the Belt Menu to complete the tasks in the three sessions. Interpreting the participants' experiences with the Belt Menu resulted in the codes discussed above to be identified, along with any discovery of relationships that these codes had with each other, depicted in Figure 5-5-20.

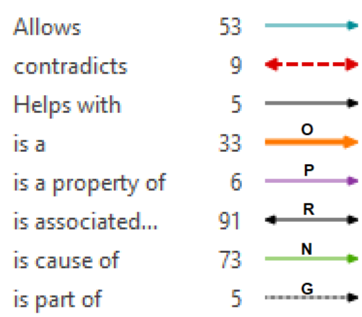


Figure 5-5-20: Key for the different relationships in the graph

The key for the relationships in the graphs is shown in Figure 5-5-20, which indicates the type of relationships between codes. The numbers indicate the total number of occurrences for each type of relationship, whereas the arbitrary letters above the various lines are used to distinguish between different relationships.

The various types of relationships between codes can be understood as follows:

- **Allows**: a participant behaving in a certain way allowed them to interact with the Belt Menu in certain ways, e.g., using the dominant hand allowed for less errors to be made.
- **Contradicts**: certain user behaviours are considered opposites, e.g., directly looking at menu items when selecting them compared to eyes-off interaction.
- **Helps with**: suggestions on improving the Belt Menu could have a positive effect on the overall user experience, e.g., suggesting more options for adjusting the positioning and layout of menu items could help make selections easier.
- **Is a**: could be considered as a type of a larger concept, e.g., selecting the wrong menu item needed for the task is a type of user error.
- **Is a property of**: participants could consider some aspects of the Belt Menu to have a positive or negative impact on the experience, such as the selection process being attributed to be easy to understand and use.
- **Is associated with**: user behaviours could sometimes be related to one another but not have any other particular relationship identified, e.g., eyes-off interaction and peripheral vision were associated with the menu being attached to the user.
- **Is a cause of**: some user behaviours could cause a possible chain of actions, e.g., wanting to double-check that a selection was made successfully caused participants to take a quick glance at menu items just after the selection was made.
- **Is part of**: user behaviours would be done with one another, which forms part of an umbrella concept for user behaviours. This relationship differs from the "is a" relationship in that all parts of a user behaviour were needed to make up the whole interaction, e.g., bimanual interaction required the use of both the dominant hand and the non-dominant hand.

Based on these relationships, networks of codes were identified, which enabled further investigation into how these user behaviours could provide insight for understanding the participants' experiences with Belt Menu. These networks resulted in graphs, as shown in Figure 5-21, Figure 5-22, and Figure 5-23, which are visualisations of how the codes, represented as nodes, were related to one another according to a specific focus on a theme, e.g., user behaviours relating to hand usage was visualised in Figure 5-23 by focusing on bimanual interaction. These graphs were then used to provide a broader perspective of how various user behaviours influence each other by focusing on specific themes. The analysis of identifying codes and relationships between these codes regarding user behaviours provided an understanding of how the various menu properties supported participants to establish awareness and develop familiarity with the menu system.

5.4.1.1 Thematic visualisations

The graphs (Figure 5-21, Figure 5-22, Figure 5-23) below provide a visualisation of how various codes were related to one another according to a specific focus, which resulted in themes being identified. These visualisations reflect relationships between codes within the identified themes, based on the insights from the observations and interviews.

Figure 5-21 illustrates (from the top right) that wave selection is a method that was easy to remember and understand how to use, i.e., memorability and learnability. "Wave selection" and "wave gesture" were the names given to this selection method by some participants but from this point on is referred to as "gesture selection" for the current study because the hand motion is more commonly referred to as a "gesture" in literature (Sharp, Preece & Rogers 2019:229–230). Gesture selection is the selection method designed for the Belt Menu, where half a button press, i.e., button pressed down, is used to select a main menu item, while the other half of a button press, i.e., button released, is used to select a submenu item from the wheel segments. This selection method was perceived to be an efficient way to perform selections with the Belt Menu and helped easily fix erroneous selections. Being able to easily fix erroneous selections allowed participants to safely interact with the Belt Menu with increasing confidence, comfort, and familiarity. A discussion focused on gesture selection is provided in Section 5.4.4.1.

The properties of learnability and memorability contributed to participants finding the Belt Menu to be easy to become familiar with. As familiarity increased with experience over each session, so did the accuracy of selections, as discussed in Section 5.3.2.3. As a result, there was a reduced rate of erroneous selections. With practice, the interaction of selection became habitual and required less mental capacity, resulting in selections being performed with "autopilot", as indicated in Figure 5-21 near the bottom right. This suggested that participants had also gained a level of spatial awareness with the Belt Menu.

Near the top-left of Figure 5-21, a link of relationships shows how double-checking interactions did cause participants to "look directly" at their hands to perform selections. This is because participants would gain confidence and rely less on visual guidance, i.e., by relying on glancing, peripheral vision, or eyes-off interaction. If their confidence is based on a flawed memory of menu item positions, they would select a menu item that they were not intending to. This would result in a dip in performance confidence and lead to needing to recommit the correct position to memory through practice. In this case, that specific participant would need to retrain their transition from novice user to expert user for selecting that menu item.

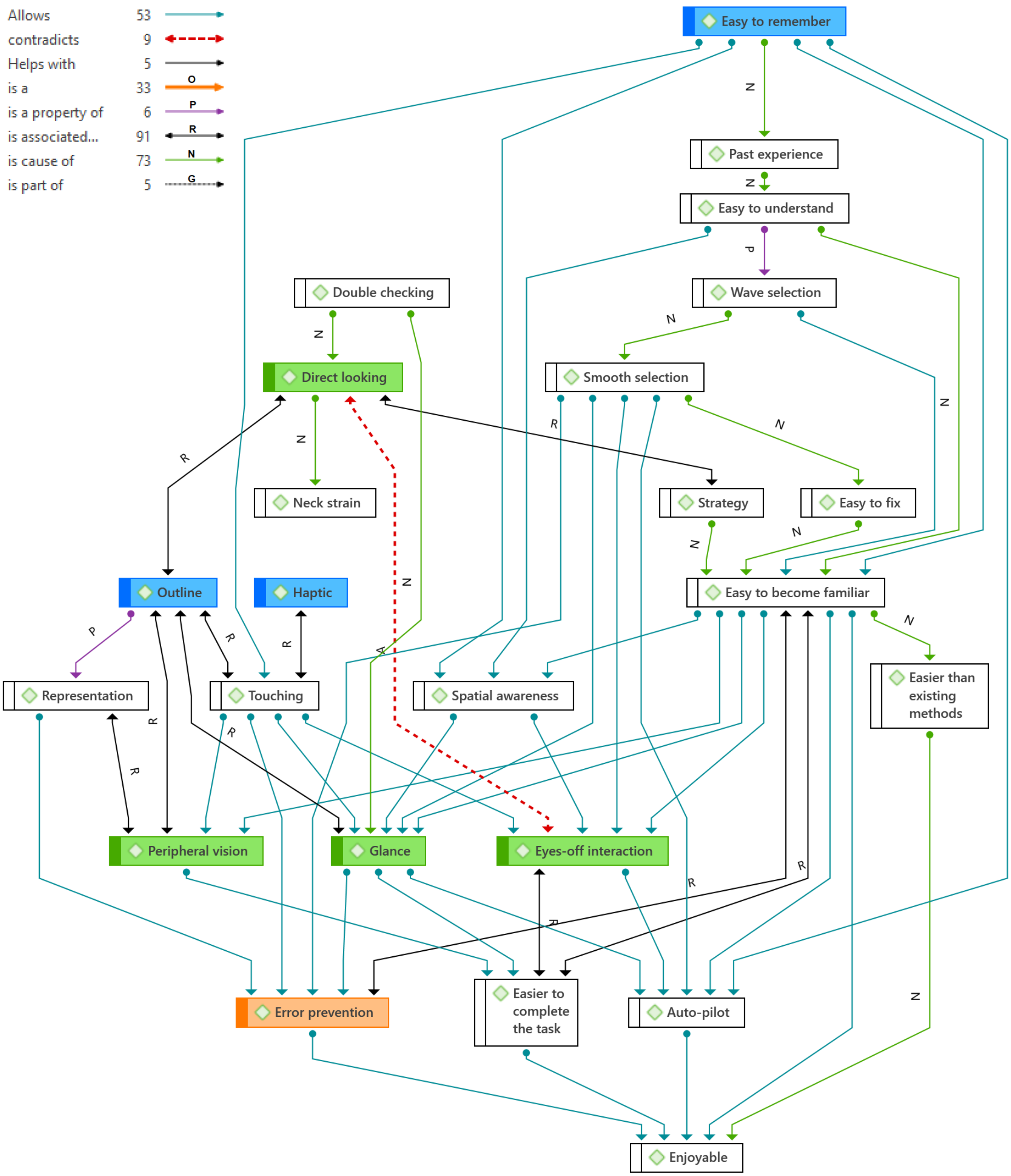


Figure 5-21: Relationships linked to various levels of reliance on visibility

In Figure 5-22, the "wave selection" node is in the middle near the top. Immediately above that it shows that "button awareness" and "easy to understand" are attributed as properties of "wave selection". One of the causes to find "wave selection" to be "easy to become familiar" is because it caused a “smooth selection”, which in turn allows developing “spatial awareness” and less reliance on visual guidance such as “glance” and “eyes-off interaction”.

“Smooth selection” was also associated with error prevention, so that selections were made more accurately due to the fact that selections could be corrected by “overriding previous selections” and “reselecting” menu items. When unnecessary selections were made, these selections were “easy to fix” because of a smooth selection method. With experience, it was found that selections felt like “autopilot”, which meant that not much attention was given to the selection process.

Regarding Figure 5-23 below, all purple nodes are related to hand usage, orange nodes are related to errors, and white nodes have no particular affiliation. The centre of the graph indicates that the use of the “dominant hand” and the “non-dominant hand” are part of “bimanual interaction”. Immediately, it can be seen that using the dominant hand allows for error prevention, which makes sense since this hand is usually more accurate and agile. In contrast, the non-dominant hand is a cause of feeling “clumsy”, which ultimately was a cause of “user error”. The non-dominant hand was also required to do more, which was a cause for the non-dominant hand to feel “clumsy”. More use of the non-dominant hand than the dominant hand resulted in trying to criss-cross hands, but this method was also associated back to feeling “clumsy”.

The use of the non-dominant hand was the cause of feeling clumsy, which led to various causes of user errors, such as “accidently applying tools”, “struggled to switch tools”, and “pressed trigger [selection button] excessively”, as visualised on the bottom-left half of Figure 5-23. The use of bimanual interactions to interact with the Belt Menu led to using the closest hand to alleviate clumsiness. In short, this graph provides evidence that some participants felt awkward using their non-dominant hand more, which contributed to erroneous actions, while their dominant hand helped to prevent erroneous actions.

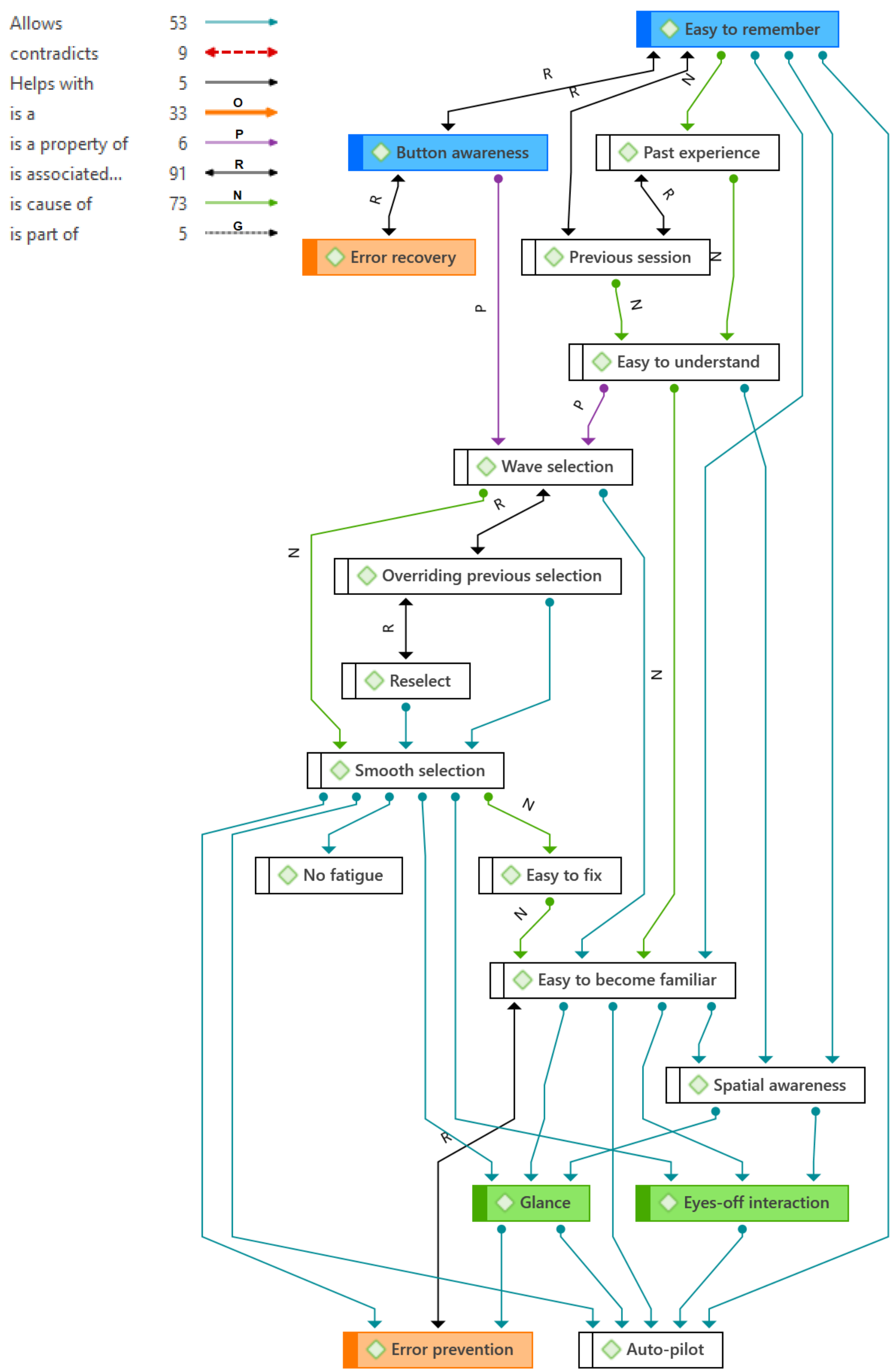


Figure 5-22: Relationships between gesture selection (wave selection) and other user behaviours

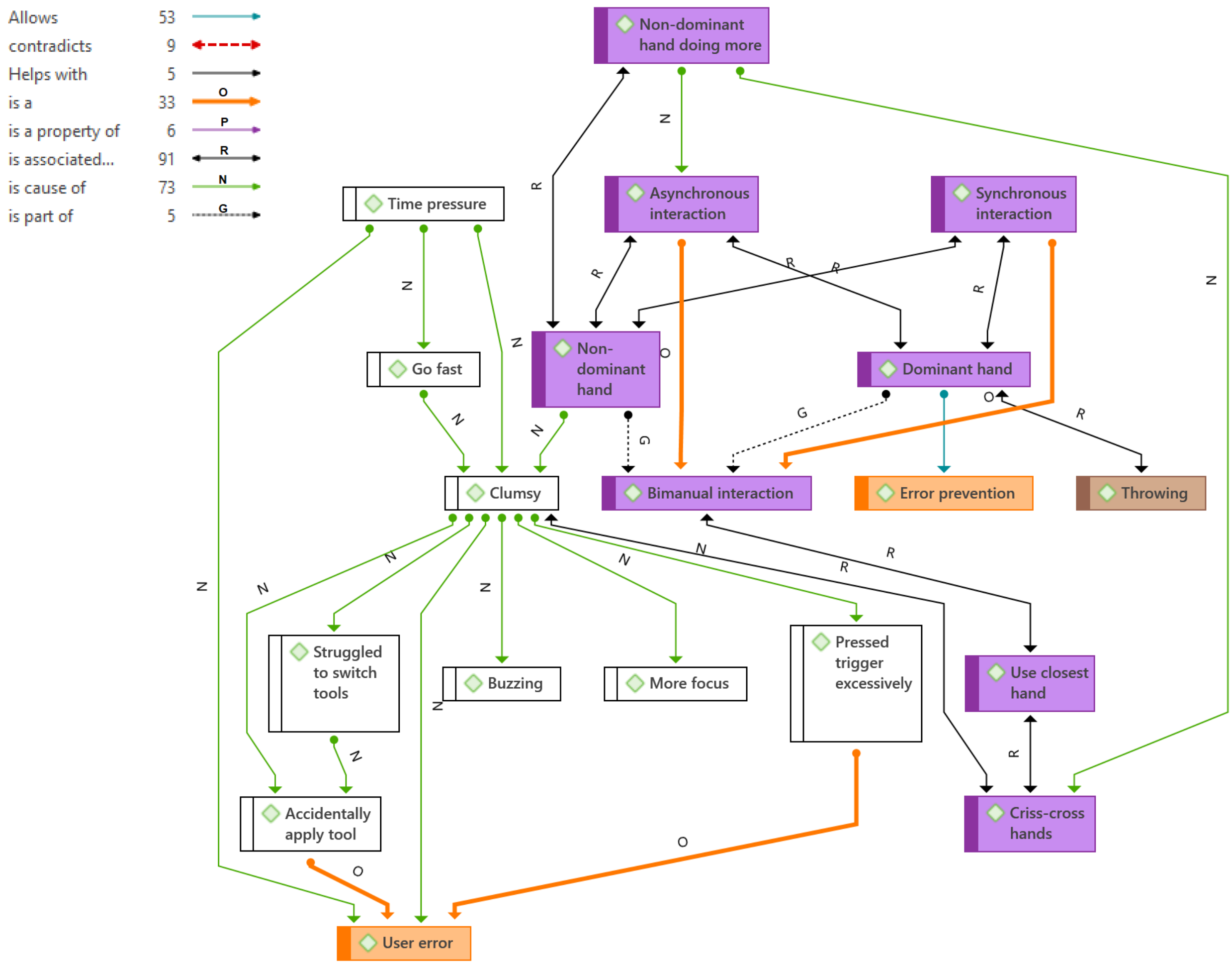


Figure 5-23: Relationships linked to bimanual interaction

5.4.1.2 Structure for the remainder of the chapter

Within each section below, the discussion begins by introducing the concepts that are attributes of the Belt Menu which were used as inspiration to identify themes from the user behaviours. After the introduction, examples from participants' behaviours are highlighted, followed by inferences that can be made from these examples.

The subsections below are structured to clearly identify three main concepts: unexpected experiences, support for establishing awareness, and support for developing familiarity with the Belt Menu. The subsections are ordered by firstly distinguishing user behaviours that were unexpected, and therefore interesting, before providing in-depth discussions that address the research questions identified in Section 1.5. Doing so allows anomalies to first be extracted and understood in isolation, before trying to understand how they are relevant to the topic of the current study.

5.4.2 Unexpected experiences

As with any study that involves human experience, there is value in identifying anomalies that can provide new perspectives that help to understand experience. The subsections below discuss how various unexpected behaviours contributed to the participants' performance when completing the task, thereby also affecting their experience with the Belt Menu.

5.4.2.1 Strategy and standing position

While observing participants, it was noticed that participants had various strategies and standing positions on how they would approach the task. Investigating these approaches helped to understand reasons behind different experiences. Although these approaches were not designed as part of the Belt Menu, this observation provided clarity on behaviours that influenced the participants' experience with the Belt Menu in a positive or negative way. The variations can be simplified to five approaches.

There were two strategies in terms of how the blocks would be placed into the boxes:

- **Strategy #1**: placing a specific block shape in a specific box until completion and then moving to another box for the next shape, i.e., place five L blocks into the correct box for the L blocks, then place five T blocks correctly into the box for T blocks, and then correctly place five Z blocks into the box for Z blocks.
- **Strategy #2**: Constantly placing blocks into different boxes, i.e., standing roughly but closely in front of all three boxes and placing the various L, T, and Z blocks into their respective boxes correctly in no particular order.

In addition to the strategies, participants also had three different preferences for where they would stand in relevance to the boxes:

- **Position #1**: Standing in front of the box that the participant would want to place a specific block.
- **Position #2**: Standing in the middle of the tracked space and throwing.
- **Position #3**: Standing in the middle of the tracked space and taking a big step forward to drop the block into boxes each time and then stepping back to the middle of the tracked space.

Various strategies and positioning would affect the overall time taken to complete the task in various ways.

Strategy #1 was also observed as a more methodological approach as each box was addressed by placing five blocks correctly until completion before moving on to do the same with the next box. This strategy allowed the participant to focus on one box at a time which is expected to require less mental strain as they only need to switch their attention for the correct box three times. Strategy #2 was observed as a more random approach, placing the blocks correctly in no particular order or pattern. This approach was expected to cause more mental strain compared to strategy #1 due to the need to constantly switch attention between each box.

The use of strategy #2 was speculated as one of the contributing factors for participant #14 taking longer (above the median completion time) to complete the task even though they perceived themselves to be making selections quickly. As shown in Figure 5-4, participant #14 is one of the four participants who has a drastically longer completion time compared to the rest of the participants. Although other participants (#03, #08, #10, #12, #16) also made use of strategy #2 in sessions 1 and 2, it was only used by participant #14 in Session 3. A possible reason for this is that participants deferred from strategy #2 as the task became more complex and adopted strategy #1 to build a more methodological approach to help complete the task. It is also possible that participants initially used strategy #2 and felt that they could do the task without much focus when there was no perceived pressure in Session 1, i.e., when there was no visible timer.

Position #1 would require the least effort and skill as participants could simply drop the block into the correct box once they were happy with the block's shape, colour, and size. There were seven participants (#01, #02, #03, #04, #13, #16, #17) who made use of this position.

Position #2 would require the participant to throw more accurately, which is a skill that was not required to complete the task. The throwing motion would also require more physical effort and skill than dropping the block. If the block was not thrown into the correct box, it would require some form of correctional action by either: reaching for the block and picking it up and throwing it again, or selecting a new block (and possibly colouring and resizing it) to throw it again. Six participants (#06, #07, #08, #09, #10, #12) made use of position #2.

Position #3 would require the participant to constantly move forward and backwards, which takes time. The participant would also become tired more easily over time. This extra movement also required some level of mental strain to constantly become re-centred in the room. Four participants (#05, #11, #14, #15) adopted position #3.

Despite the risk of potentially needing extra effort, participant #06 stated that "It was fun to throw the blocks in [the boxes] because I tried to get better with [*sic*] it." This serves as evidence that they enjoyed doing the task by using position #02 because they liked challenging themselves to improve in throwing more accurately. This behaviour was also confirmed in the video recordings for Session 2. The rest of the participants had either assumed one of the three positions subconsciously or did not express any comments about this.

Participant #05 mentioned during Session 2 that "First session was very easy and made me excited for the next session. But for this session I just felt overwhelmed", in which they were referring to the fact of having to constantly switch between tools by selecting different menu items. Observations from the video recordings and screen recordings indicate that participant #05 made use of strategy #1 and positioning #3. It is possible that they felt overwhelmed due to the extra mental strain of needing to re-centre themselves after placing each block in a box.

During Session 3, participant #11 tried to do the task spawning all 15 blocks (five of each shape) beforehand and placed them in front of each box. This strategy proved less efficient than using the Belt Menu as intended. Observing this approach of participant #11 and seeing the results provided evidence that the design considerations (Section 2.10) used to inform the Belt Menu optimises the user for efficiency.

As visible in Figure 5-18, participants #4, #5, and #17 had significantly higher selection rates than the other participants in Session 2. These selection rates can be considered outliers compared to the selection rates of the other 14 participants. They were among the upper half (3rd, 6th, and 9th out of 17, as shown in Figure 5-4) of the fastest to complete the task in Session 3 which suggests that they may have similar approaches to complete the tasks. Both participants #04 and #17 made use of position #1 which was observed to be the approach that required the least amount of effort while participant #05 used position #3, an approach that was observed to be the least efficient. However, given that there is a significant gap in placement (six placements difference) for completion time between the two participants (#04 and #17) who the most efficient position and the fact that participant #05 used the least efficient position but was still faster than participant #17, the correlation between positioning and efficiency is not evidently strong. Other participants who also made use of these positionings did not share the same high selection rates either. As such, it is unlikely that positioning played a significant role in causing these high selection rates. Further discussions regarding these significantly higher selection rates are discussed in the next section.

Although participants had varying approaches to completing the task, they all had access to all the menu items that they needed. This attests to the intentional design of having menu items consistently around the user's body, which allows the menu items to always be available to the user.

5.4.2.2 Significantly high selection rates

Since the standing position was refuted as a cause for significantly high selections rates, as discussed above, it is worth discussing other potential causes that were evident in the results. A discussion of participant #05 feeling overwhelmed in Session 2 was already discussed in the previous section. They were also observed to frantically make selections as a result of feeling overwhelmed, resulting in having a high selection rate which is visible in Figure 5-18. Participant #17 mentioned that the haptic feedback in the controllers were distracting and annoying which made them feel overwhelmed which was a sentiment shared by participant #05 and is discussed further in Section 5.4.3.4. Despite this, participant #5 was among the upper half (6th out of 17, as shown in Figure 5-4) of the group to complete the task in Session 3, suggesting that they may have managed to overcome their sense of feeling overwhelmed in the last session. They also had a lower selection rate in Session 3 despite needing to complete a more complex task, as shown in Figure 5-18, providing further evidence to support this observation. They still had a high selection rate compared to other participants in Session 3, indicating that they still made a lot of mistaken selections while being able to complete the task quickly. There is the possibility that participant #05 works well under pressure and in chaos. i.e., make a lot of mistakes, however there is no other evidence to support this speculation.

The performance of participant #17 is slightly different being that they placed 9th for fastest completion time in Session 3, i.e., the median amongst the 17 participants, meaning that they were not particularly fast nor slow. However, their selection rate was more normalised in Session 3 compared to the rest of the participants which shows a significant dip in their selection rate. It is possible that they may have also managed to overcome the feeling of being overwhelmed. That being said, this did not seem to help them to be more efficient in completing the task itself. It is possible that participant #17 prefers to approach the task with more care so as to feel less overwhelmed and was able to do so in Session 3 because they felt more familiar with the Belt Menu.

For participant #04, they made use of five attempts each in Session 2 and Session 3 which provides a possible reason for a significantly higher number of total selections, however the calculation that defines the selection rate is based on the average of all attempts in each session. Therefore, this cannot be identified as a significant cause for high selection rate of participant #4. There is also no evidence to suggest that participant #4 felt overwhelmed. Another possibility can be that they were intentionally experimental in trying to understand the Belt Menu through exploration which was done via repeated selections. This desire to experiment with the Belt Menu may explain why they made five attempts, where most participants made use of 3 attempts in Session 2 and Session 3 (as indicated in Table 5-2), since these sessions both involved a task that made use of more menu items of the Belt Menu. Participant #4 discussed that the selection method used for the Belt Menu felt simple enough that erroneous selections can easily be corrected with another selection. The full discussion regarding the participants' opinion about the selection method is provided in Section 5.4.4.1. This sentiment may also explain why they had such a high selection rate.

5.4.2.3 Relying on shadows

Due to lighting effects in the IVE, menu items cast shadows on the ground near the user. Lighting and shadows were included in the IVE to provide a more convincing impression that it was similar to the physical environment. While shadows were not intentionally included with the purpose of them being used by participants, some participants interestingly used them through peripheral vision to locate menu items.

Participant #10 discussed that they noticed the shadows cast from the menu items and the controllers and that they would overlap when they had touched a submenu item. When asked about whether they noticed the state of the menu items changing from main menu items to submenu wheel segments, they said that “This time [Session 2], I tried doing that and I noticed that I can also rely on the shadow. Especially the measuring tape.” They used this as an additional way to determine if they had touched a menu item when they did not look directly at the menu items.

Participant #08 made use of the change in shadows to determine if the submenu wheel had opened when selecting the Measure tape, which was not directly within eyesight while looking forward. They stated that “Having the shadows really helped understand where everything is without looking directly at the menu items.”

Participant #05 did not make use of the shadows to interact with the menu items, however, they stated that “The shadows were the only way I saw that there were two other tools. I looked down and I was like: ‘There are four shadows but only two tools. What?’ [sic]”. Participant #05 was referring to the fact that they only saw the Addbox and Paintbrush in front of them and only became aware of the Measure tape and Arrow adjuster after seeing the shadows of these two menu items that were not in front of them. These menu items were situated outside of direct eyesight when looking forward, which was intentionally done to test the participants’ limitations of their awareness. Since participant #05 was one of those who indicated to have no prior experience with VR technology discussed in Section 5.2, it is possible that they were not yet familiar with interacting with an IVE in a way that may have allowed them to notice these menu items in Session 1.

For future studies, the use of shadows can be intentionally considered as a design guideline for menu systems to support awareness of the existence and interaction of menu items when used in an IVE. This can be used as an implicit cue that is less visually intrusive compared to other designs such as highlighting menu items until it is seen.

5.4.2.4 Design flaws and suggestions

Specific issues for improvement were identified as participants were exposed to the Belt Menu to complete the tasks. With each session, where the task became progressively more complex, participants developed preferences and desires for features that they would anticipate benefitting their ability to complete the task. These features, or lack thereof, are discussed in each subsection below. Suggestions and preferences related to layout are discussed in Subsection 5.4.3.2.

a. Obscured vision

The labels for the required size of the blocks were sometimes obscured by the Belt Menu. When the size label was obscured, participants would stand in a different spot or adjust the belt menu higher or lower.

Seven participants expressed that the size labels on the boxes being obscured was not an issue with the menu system but rather poor positioning of the size labels in the IVE. It is possible that this occurred because the Belt Menu was adjustable to be at different heights to accommodate participants of varying height.

The implication of this design flaw is that menu systems should consider how the various ways of customising layout and positioning could obscure vision with different perspectives. This consideration is relevant because the desire for customised layout was mentioned by participants, which is further discussed in section 5.4.4.3.

b. Belt Menu rotation

The Belt Menu did not rotate with the user's body, which was a design flaw as the position of the Belt Menu was tracked according to the HMD. This meant that the Belt Menu followed the movement of the user's head and not their body because no specific sensors were used to track the Belt Menu according to the user's body movement. This was a known design flaw of the Belt Menu that was intentionally left unaddressed for two reasons:

- Following the rotation of the HMD was disabled, since basing the position on head rotation would fix items that are offset to the side of the user's peripheral vision. Since the task only required the participant to face one direction, i.e., only towards the three boxes that participants would need to place blocks in, participants were not anticipated to rotate their body to face a different direction and it was therefore deemed unnecessary to find a solution to have the Belt Menu rotate with the participant's body without using additional sensors. Time and effort could then be focused on other aspects of the current study.
- The approach of designing the Belt Menu was specifically chosen so that it can be used by most commercially-available VR technology. The HTC Vive Pro has the ability to add additional sensors that are commercially-available but need to be purchased separately, which can be attached to the user's body for the Belt Menu to be linked to, but this would then require additional equipment that is not available for other VR technologies like the Oculus Quest. Using such additional technology would have thus limited the generalisability of the design considerations used to inform the Belt Menu.

A few participants (#07, #11, #17) noticed the lack of rotation and attributed discomfort to this design flaw when trying to reach for menu items on the sides (Measure tape, Arrow adjuster). As mentioned in Section 5.4.3.2a, these two menu items were intentionally placed outside of comfortable reach so it can be expected that the participants would have experienced discomfort.

Should future research make use of the identified criteria (Section 2.10) to design menu systems that rely on proprioception for menu item selection, they can consider finding a solution for this rotation issue. Since only three participants struggled with this issue, the rotation issue does not seem to cause a noticeable negative impact on the design of the Belt Menu. However, ways of addressing this problem would positively contribute to the design of proprioceptive menus.

c. Undo action

An undo action typically provides a user with the ability to reverse an action that they did not intend to do, e.g., pressing the button combinations of "CTRL+Z" in a word processor could allow the user to undo the deletion of a word in a document. Providing this action allows users to have more control over a system by allowing them to quickly rectify any erroneous actions, making the system easier to use.

All 17 participants, when prompted, stated that it was easy to switch between tools when they had erroneously selected the wrong tool or applied the wrong colour/size to fix their error. When asked about fixing selections that were incorrect, participant #01 stated that "It was very easy. [I] can just reselect colour or size and drop a block to select a new one". However, participants #05, #10, #12, and #15 wanted an undo tool. This would be used to retrieve a block or to prevent a block from falling into the wrong box. The four participants speculated that this kind of tool could reduce erroneous actions.

d. Deleting blocks

"Deleting" is an action that is typically used to remove unwanted items in a user interface (UI), whether it is to reduce clutter, prevent erroneous selections, or to make searching for something easier.

Participants #05 and #14 wanted some way to delete blocks rather than leaving them lying around in the virtual environment outside of the boxes. They preferred it if their virtual space was not cluttered by blocks that they had erroneously selected. This feature was in the original design but was removed based on feedback from the pilot study (which involved three people) because the environment was considered to be sufficiently large that clutter would not be a problem and searching for a specific block on the ground of the IVE was unnecessary, as discussed in Section 4.6.1.

The lack of ability to delete blocks did not hinder participants from completing the task but it made the experience of completing the task slightly less pleasant for two participants. The addition for deletion is a logical suggestion but would require careful consideration in terms of layout. It would need to be positioned somewhere that is easily accessible, but also out of the way so that items are not accidently deleted. An undo action for deleting blocks would also need to be considered.

e. Confirmation action

A confirmation of an action communicates to the user that the action was received in the form of some feedback, e.g., a sound or a visual change. Selections with the Belt Menu resulted in a tool being held in the user's hand when a selection was successful. The gesture selection, discussed in Section 5.4.4.1, resulted in a fluid selection process that made the selection easy. However, some participants found this process to be lacking feedback when they finalised a selection.

Out of the 17 participants, eight (#02, #04, #05, #06, #08, #09, #10, #16) wanted an extra button to press when selecting a menu item. Their reasoning for this is to get a more explicit confirmation that the action of selection was done. Another concern was that the current design made accidental application of tools too easy because it was applied by just touching the block with the tool to apply it. Having an extra button press when applying the tool would prevent accidental changes to the blocks. It was particularly interesting to have #05 agree with adding a confirmation action because they mentioned that in Session 2 they felt overwhelmed with the task and started pressing buttons excessively. Having an extra button press for each selection in such a state could instead aggravate this situation.

However, participants #02, #04, #08, and #10 also mentioned that this was a minor issue because it was easy enough to switch to a different tool and change the block back. This comment suggests that error recovery was easy enough to be negligible. Participants #01 and #14 expressed concerns that adding an extra button press would make the selection more complex and more confusing when overwhelmed with the task.

Whether a confirmation action is desirable is unclear as eight participants expressed a desire for this, two participants preferred the selection process as it was given, and the rest of the participants did not express concerns in this regard. However, what can be understood from the desire of wanting a confirmation action is that some method of preventing accidental selections is required. Designing the selection for a menu system should include consideration of how this can be done where a confirmation action is one potential solution.

f. Dipping

Dipping was a selection method suggested by the researcher during focus groups as an alternative method for changing size and colour instead of using tools. This selection method entails changing the block's colour without the need of applying a tool held by the other hand.

Instead, the blocks would be used to directly touch the different colour options, like dipping them in a paint bucket. This suggestion was used to stimulate participants to consider preferences for the current method (using a tool of a specific kind).

Some participants (#09, #16, #17) said they imagined it would be better because then they could free up the one hand to do something else or even not use their non-dominant hand at all. Participant #08 was concerned that dipping would take up more space, which would clutter their view and further obscure the view in front of them. Participant #03 expressed dipping for colours would result in an inconsistency since all other menu items are selected from the wheel layout and applied using a tool attached to the controller.

The intention of posing this question during focus groups was to probe participants to consider other designs and get feedback in comparison to the one chosen for the Belt Menu. The implications from this discussion suggests that the current design can be improved but most participants, except for participants #09, #16, and #17, were happy with the current design.

g. Default selection

A default selection in the context of the Belt Menu refers specifically to a selection from the submenu wheels. Without moving to touch and select any particular wheel segment, the menu should result in a selection, thereby producing a default selection.

Participants #04 and #15 discussed a default selection where leaving the controller in the centre of the submenu wheel would always result in selecting the option closest to the centre of the user's body. For example, with a right-handed user had the colour wheel on their left and so the pink colour is on the right which is closer to the centre of their body, as shown in Figure 4-32. Although this proved true, it was not intentionally part of the design. There were no defaults explicitly programmed to the centre of the submenu wheels.

Participant #15 mentioned that the default selection would be confusing if a user was not aware of this. But if a user became aware of this default selection, then they could use it to their advantage. One participant (#15) realised this and they took advantage of this when needing to select the T block.

Participant #04 discussed that they would rather prefer a "dead zone" in the centre of the submenu wheels. This means that if the controller was placed at the centre of the wheel then it would not be selecting anything when the trigger is let go of. This allows users to cancel their selection in a more convenient hand position rather than having to move their hand away from the wheel entirely.

Both of these suggestions, i.e., specifying a default selection as part of the design or providing a "dead zone", should be carefully considered when designing the selection method for a menu system. Making a decision regarding default selection can provide the user with more control over the selection method, which influences their accuracy in selections.

5.4.3 Supporting awareness of available menu items

The awareness of menu items is a crucial aspect of a menu system because without this, the user will not know that the items exist or are accessible because they are not aware that these menu items can be used. The sections below discuss various aspects of the Belt Menu that provided support in this regard.

5.4.3.1 Visual representation

The visual representation of the menu items contributed towards supporting users to learn and familiarise themselves with the Belt Menu in terms of the function for each menu item. This factor is the first property of the Belt Menu that the participants were expected to notice, which gave them a first impression of how they expected the Belt Menu to work.

a. Icons for menu items

The icons of menu items provide the first clue for the function of a specific menu item. If this representation matches the expectation of a user then they will understand how to use the function. Out of 17 participants, nine commented that the Measure tape was misrepresented. They assumed that it was used for measuring the length of something rather than a resizing tool. This did not appear to be a problem in the pilot study. These participants said the representation only made sense after using the tool (applying it to a block to make it bigger or smaller).

Participant #02 suggested that the "Measuring tape (ruler) is more to measure length than size." and that they "Would've preferred a block with arrows going up and down. There could be a more elegant solution. [It] Can be better thought out.". Participant #10 said that the function for the Measure tape was obvious but was not sure how to use it. In contrast, participant #09 said that they often work with a Measure tape in a workshop so the representation of a Measure tape for size made sense. However, they proposed to not have a tool for resizing but to rather have the options of the different size on the block selection. Participant #08 and #17 mentioned that the function of the Measure tape was made obvious after seeing the submenu items (Plus and Minus).

Participant #07 also mentioned that the Plus and Minus symbols on the tools were not obvious. They pointed out that they would have liked to have some text label or representation on the enlarge or shrink tools. It was then pointed out to participant #07 that a plus and minus symbol were on those tools respectively. This was an acceptable representation by participant #07 once it was noticed. Participant #13 was unsure what the plus and minus symbols meant. They assumed it was used for adding and subtracting something.

Regarding the Addbox (used to spawn blocks), participant #08 mentioned that they did not see what the Addbox was until their third and final session. Up until that point, they were less concerned about what the Addbox looked like and more focused on the function (getting blocks from it).

Participants #02 and #17 mentioned that the Arrow Adjustor item was not clear until it was interacted with. Participant #05 was confused when they first interacted with the Arrow adjuster because they expected it to also have submenu items like all the other menu items. That being said, they would not want to change the representation because it made sense.

Participant #12 initially thought the tools (Paintbrush and Measure tape) were used to apply to the menu items. This assumption was based on the fact the Arrow adjuster was used to make changes to the menu. They tried to paint the menu a different colour or to make the menu bigger or smaller. This assumption was especially strong with the Measure tape because the positioning was relative and directly opposite to the Arrow adjuster, as shown in Figure 4-29.

According to participants #14 and #16, it was clear that the Paintbrush was used to change the colour of something but was not sure what to paint. Participant #14 tried to paint various things, e.g., other menu items or the three boxes, by brushing the Paintbrush across the surface during the practice attempt in their first session. Eventually, they tried to apply the Paintbrush to the block and were surprised that the whole block changed colour immediately by just touching the tool. They initially expected to have to brush every surface of the block. Although this was a mismatched expectation initially, they did not have a problem with the fact that the Paintbrush instantaneously changed the colour.

Misunderstandings of visual representations were caused due to expectations based on real-world counterparts, e.g., Measure tapes are usually used to identify the dimensions of objects and not to change the dimensions or sizes of the object. Another cause for misunderstanding was because participants were unsure of what the tools can be applied to, e.g., a Paintbrush in the real world can be used to colour anything it touches and requires the colour to be brushed on all surfaces of the object. Based on these misunderstandings, representations can be considered more carefully depending on different use cases, e.g., functions for a virtual car mechanic context can have more literal representations because there are literal tools that can be used as inspiration.

Although there was an initial misunderstanding of the visual representations and their corresponding functions, all 17 participants expressed that the visual representations made sense once they had used the functions of each menu item. These misunderstandings caused an initial confusion but were quickly overlooked, which indicates that the misunderstanding was not a significant hinderance for them to become familiar with the Belt Menu. This willingness to overlook the initial misunderstanding also suggests that users who are learning a system are willing to learn and adopt new concepts as long as the understanding can be applied moving forward.

b. Transparency

Section 4.4.2 discussed a design decision where main menu items would become transparent while selected. This design choice was to ensure that attention is reduced from a menu item that was already selected so that more focus can be given to the new available options. However, participants #04 and #05 wanted to extended this to submenu items that were already selected and speculated that this would further decrease visual clutter, e.g., if the turquoise colour is already selected then the turquoise wheel segment in the submenu should be transparent and disabled as well.

Participant #04 suggested that menu items should decrease in opacity based on two conditions: if the user was already holding something from a menu item and the controllers were not close to the menu item. That way, menu items that are not needed would not visually be in the way. This suggestion appealed to participant #05 as well who complained about the menu being “too claustrophobic”, which is discussed in more detail in Section 5.4.3.2a.

Other participants did not comment on menu items becoming transparent, possibly because they either did not notice that this happened with main menu items or that they were indifferent of the menu items behaving in this way. The two participants who mentioned this property have the sentiment that this menu item behaviour is welcomed to the point that they would want to see it in other menu items as well.

c. Size representation of Blocks

The size (small, medium, large) of blocks was represented to participants only in the actual size of the block and had no clear labelling. The only labelling for the size of blocks required by the boxes in front of participants was indicated as S (small), M (medium), and L (large).

Participants in focus group 3 mentioned that the size of blocks could have been made clearer. Although the sizes of the blocks changed, it was not clear what size the block was without comparison. For example, the block could have been covered in the letter ‘L’ if it was a large block, as suggested by participants #15 and #16.

Although this was not a comment on the Belt Menu itself, this provides insight into the visual representation of items that come from making selections with the Belt Menu.

5.4.3.2 Layout and positioning

The layout and positioning of the menu items also contributed towards supporting users to learn and familiarise themselves with the Belt Menu in terms of the accessibility for each menu item. Participants needed to establish spatial awareness with regards to the layout and positioning and commit them to memory in order to become familiar with the Belt Menu.

a. Positioning

Menu items were specifically placed within arm's reach of the user with two of the menu items, one on each side of the user roughly on the 3 o'clock and 9 o'clock positions on the face of a clock with the user in the centre, specifically placed to test the limits of comfortable reach. Each menu item was floating around the participant's body at about at a forearm's distance away from the user. From an arm's resting position, i.e., straight and down, each menu item was accessible by lifting the forearm in the direction of the menu item.

Participants #03, #05, and #06 reported that the menu items were too close and caused them to feel a bit "claustrophobic". They would have preferred the menu items to be further away from their body. During the focus group, participant #03 expressed that they preferred to think of the menu system more like a workstation than a belt. Besides these three participants, no one raised issues with the placement of the menu items being readily available within arm's reach.

Awkward positioning was a complaint from participants #08 and #17. They stated that the Measure tape and the Arrow adjuster were placed in a such a way that was just outside the comfortable range of motion for them. This was particularly emphasized with regards to the Measure tape because it was frequently used in Session 3, whereas the Arrow adjuster was only used a handful of times to find a comfortable height for the Belt Menu.

Participant #08 discussed that their forearm was too long so they would have to tuck their elbow behind their back to select the Measure tape. Participants #08, #15, and #17 mentioned that they turned their body to reach the Measure tape, so it was not awkward. This was confirmed using the video recordings. Participant #14 reported that they had no issues with reaching the Measure tape and did not need to turn. However, in the video recordings, participant #14 did twist their body slightly. Although these are contrasting observations, it is an indication that the need for participant #14 to twist their body was not a notable discomfort.

Participants #16 and #17 reported that they intentionally moved the menu to a position that would be out of the way so that the controllers would not constantly vibrate, which is discussed in more detail in Section 5.4.3.4. Video recordings of participant #16 also show that they moved the menu items as low as possible, around knee height, but still within reach of their arm's length.

Between the Measure tape (Hit: 91.51% | Miss: 8.49%), Plus tool (Hit: 96.87% | Miss: 3.13%), and Minus tool (Hit: 96.56% | Miss: 3.44%), a total of 2469 out of 9307 selections were done cumulatively from all 17 participants, as shown in Figure 5-9, in Session 3. This accounts for

23.53% of selections done in Session 3, and these were considered uncomfortable interactions. These complaints confirm that menu items placed that far to the side is an inconvenience, specifically if it is an item that is used frequently. This awkward position may also have contributed to having a lower accuracy for selecting these menu items, which is indicated in Figure 5-12 where these menu items had the second-most missed selections. The awkward position was not due to menu items being out of reach, but instead requiring the arm to bend at an awkward angle. As mentioned in the beginning of this section, menu items were placed a forearm's distance away from the user's body, however, since the length of a forearm varies this may not be the best metric to measure menu items away from the user's body. Instead, menu items could be placed even closer to the body resembling more closely a belt, which would result in selections reaching inwards towards the user's body. This would be an easier angle to reach and control. This would also be less in the way of the user visually.

Possible positions for the side menu items that could lead to less discomfort could be:

- Placing the menu items closer to the front, i.e., 10 o'clock and 2 o'clock positions.
- Placing the menu items to be even closer to the participant's body so that the user would reach inwards towards their body, with their elbow pointing away from their body, similar to grabbing keys from a belt.
- Considering the height of the user and using this measurement to determine the distance that menu items should be away from their body. An individual who is tall will have longer arms compared to a shorter person. That way menu items can be further away from the user if they are taller, making menu items more accessible.

All three of these positions would allow the elbow and arm to be angled in a way that is more natural to the human body.

b. Submenu for Resizing

The resize tool, known as the Measure tape, provided options to change the size of blocks by having either a plus tool (enlarge) or minus tool (shrink), which when applied to a block either upscaled or downscaled the block, respectively.

One of the focus groups discussed an inconsistency with the design of the resizing submenu wheel segments, where there were only two options (plus tool and minus tool), as shown in Figure 4-32, but three sizes (small, medium, large), as shown in Figure 4-21. This was also inconsistent with other submenus, where other submenu wheels, e.g., colour wheel segments, had three options for three colours (turquoise, lime, pink) as shown in Figure 4-32. With the Measure tape, the options were either to upscale or downscale, which sometimes required applying the resize multiple times until the block was the correct size. This was a complaint expressed by participants #14, #15, #16, and #17.

These participants (#14, #15, #16, #17) preferred three submenu items for resizing (small, medium, large) while others (participants #08 and #13) liked the original design with just two options. Having three menu items would make it more consistent with other submenus and one can immediately select which size it is, instead of having to upscale or downscale, e.g., it would be easier to make a small block large if there was a "large" tool instead of applying Plus to a small block twice. Participant #08 contrasted this opinion by stating "Just because I didn't look at it [resize submenu items] or I tried to not look at it when I chose it and trying to remember small, medium, and large where each [of them] are… whereas, you know, if I turn right I get plus, if I turn left I get minus.", meaning that having two menu items required less to remember because they only had to remember two directions, i.e., left is plus and right is minus.

However, if there were to be more than three sizes, e.g., extra-small, small, medium, large, and extra-large, then participant #08 admitted that it would be quicker to have a tool for every specific size instead of reapplying the shrink or enlarge tool multiple times. Participant #16 also conceded that if there were more than three sizes, having specific selections for each size could add too many options which could clutter the menu items and require selections to be more precise.

What can be learnt from this is that consistency is important to users and if there are any deviations then the reason should be obvious and logical to the user. As discussed by participant #08, more menu items require more accurate selections and more items to remember, especially when this is performed without paying visual attention.

c. Unnecessary selections

As pointed out in the discussion under Section 5.3.2.3, a hit selection can result in a necessary selection or an unnecessary selection. Based on the data from observations and discussions during the interviews, various causes for unnecessary selections were identified. As a result, the causes of unnecessary selections were as follows:

- Selecting an item as an error (not the item that the participant wanted to select) by:
    - selecting a tool that the participant intended to (but it is the wrong tool) and applying it to the block, and then needing to rectify the error by reselecting the correct tool,
    - selecting a tool that they did not intend to (the wrong tool) and reselecting the correct tool.
- Correctly selecting an item (retrieved) but the participant:
    - dropped the block on the ground and decided it was easier to redo the selections to get the correct block again instead of bending down to pick up the block that was dropped,

- threw the block outside of reach, so they must redo the selections to get the correct block again,
- placed the block in the wrong box, so they must redo the selections to get the correct block again,
- pressed the deselect button, which dismisses a tool, so they have to reselect the correct tool again.

- Needing to switch between tools even though the colour and/or size required from the box is the same.
- Needing to switch colours because they moved onto working on a different shaped block, even though the initial block required was the same colour and/or shape.

Identifying these causes for unnecessary selections helps to provide context that leads to a clearer understanding of user performance. From the perspective of participants, this also helps to understand how they perceived their own accuracy and performance. This perception may have influenced their confidence in their selections from the Belt Menu, leading to a positive or negative impact on their ability to improve on their level of expertise.

5.4.3.3 Visual guidance

As discussed by Schramm et al. (2016), visual guidance is relied on by users for interaction but they progressively defer from this reliance by relying on other senses to increase efficiency. The desire towards adjusting their approach for interaction to increase efficiency is more prominent with experienced users (Cockburn et al. 2014:4–5; Ericsson & Harwell 2019). Therefore, reliance on visual guidance was investigated with particular interest. The ability to perform eyes-off interaction is also an indication that participants have established enough spatial awareness to rely on their proprioceptive senses for menu selection, a crucial factor for the current study.

While observing participants, specific behaviours were identified regarding their reliance on vision to help with selection. During the interviews, participants were asked if they relied on visual guidance for their selections. Discussions around visual guidance resulted in participants communicating the extent of this reliance. The reason for these various levels of reliance stemmed from their confidence in their selections. The identified behaviours were as follows:

- Directly looking
- Glancing to double-check
- Peripheral vision
- Eyes-off interaction
- Relying on shadows

Each of these behaviours are discussed in detail below for how certain participants reported doing selections by relying on these behaviours.

a. Directly looking

"Directly looking" refers to instances where the participant is looking, with focus, at what their hands are selecting from the Belt Menu and when placing the block in the box. This behaviour was interpreted as a novice behaviour because participants did this when they were still learning the system.

Participant #02 discussed that for the given task during the sessions, they intentionally looked at every selection to prevent selecting the wrong menu item. Participants #14 and #15 shared a similar sentiment except that for participants #14 and #15, this approach is not exclusive to the task given to them in the current study or even for interacting with IVEs with VR technologies. These participants stated that this approach is just how they do things in general, to look and make sure that they are doing things correctly. This user behaviour is possibly linked to "the paradox of the active user", where users resist adopting a new method, or in this case a new behaviour, to avoid the risk of experiencing a performance dip, even though it is temporary (Carroll & Rosson 1987).

Participant #05 stated that it was satisfying to watch the instantaneous effect that the tools had on the block, so they generally looked directly at the block to watch it happen. This is potentially caused by the novelty of experiencing a new system, i.e., the Belt Menu. However, this novelty may fade away as a user uses the system more regularly, e.g., used in a daily task. This sentiment was also specifically about applying the tools and not about directly looking at selections made from the Belt Menu. The current study focuses the reliance on visual guidance for menu item selection, which excludes the actions performed with the menu items afterwards. As mentioned by Norman (2003), the pursuit of providing optimised performance is to allow for a positive experience. If the novelty of the interaction itself allows for a satisfying experience, then it still ultimately achieves the goal.

b. Glancing

"Glancing" refers to reaching out to select a menu item, initially without looking, and then quickly looking at their hand as they finalise their selection. This is done only to confirm that their hand is in the right place before selecting a menu item. Glancing was interpreted as a behaviour from someone who is more experienced as this was done once participants had established a basic idea of where all the menu items were positioned. They were able to reach in the general direction without paying much attention until they wanted to press the trigger button for selecting a menu item, then they would glance just to confirm that the selection was successfully made.

Participants #02, #05, #07, #08, #10, #11, #12, #13, #14, and #17 discussed that they did not do the selections blindly (without relying on vision). Selections were often done by taking a quick glance to double-check that the selection was done correctly and then looking elsewhere, even before the selection was complete.

c. Peripheral vision

Relying on peripheral vision means that the participant was not paying visual attention, with their visual sense, on menu items when making a selection, but the menu item was still visible. This behaviour was also observed as experienced user behaviour because it displays familiarity with the Belt Menu to the point where they are not actively looking for visual confirmation.

Participants #16 and #17 mentioned that it was easy enough to "mash [*sic*]" things together that were attached to the controllers without looking. It was not to say that they were doing it completely blind (eyes closed) or looking away, but it was done without paying much attention. Participant #10 looked at the menu items out of the corner of their eye to see selections while focusing on other things (e.g., throwing the block).

It was discussed in the focus groups by participants #04, #05, #07, #15, and #17 that they only struggled to select things without looking when engaging with submenu items, i.e., wheels segments. It was easy to select the four main menu items (Addbox, Paintbrush, Measure tape, Arrow adjuster) without paying much attention. This indicates that there are different levels of expertise when it comes to the main menu items and the submenu items. Participants were not really concerned with the main menu items, except for the first session when they were still learning how the system works. The main menu items were just a means to get a specific submenu open.

While the participants perceived to struggle less with selecting main menu items, the recorded performance discussed in Section 5.3.2.4 reports lower accuracy for selecting main menu items except for the Addbox.

There are various possible contributing factors to this contradiction:

- The Addbox was always selected with the dominant hand, which is usually more accurate and efficient for general use (determined by observations and recordings). This design decision was based on the fact that the Addbox was considered the major interaction, which should be reserved for the dominant hand, as suggested by Bowman and Wingrave (2001:5). All other main menu items were selected with the non-dominant hand, which is typically less accurate compared to the dominant hand.
- The Addbox was not selected as often as the Paintbrush and Measure tape, as discussed in Section 5.3.2.4, which means there is a smaller chance for missed selections to occur.

- Section 5.3.2.4 also discussed that submenu items had a lower percentage of missed selections because main menu items may have served as a point of orientation for the selections.
- The discrepancy between measured accuracy and subjective experience can also be caused by the fact that main menu items were selected without focus while submenu items were selected with focus due to the perceived lack of accuracy, therefore leading to more careful selections by looking at the menu items during selection.

The implications from these contradictions could also mean that, despite having missed selections with the main menu items, the participants did not perceive them as a hindering factor from completing the task. Instead they were more focused on correctly finalising their selections from the submenu wheel segments.

d. Eyes-off interaction

Eyes-off interaction is described as performing an action while looking elsewhere, i.e., the hands are operating outside the user's visibility. This kind of user behaviour indicates that the user is confident enough with selecting from the Belt Menu that they would focus their attention elsewhere and it is described as an indication of expert user behaviour (Bowman & Wingrave 2001).

Participants #02, #14, and #15 selected menu items by intentionally looking at their hands when making selections. All other participants confirmed that they were not paying much visual attention to the selections that their hands were performing. This does not necessarily mean that these participants performed eyes-off interaction, however, this does indicate that they were confident enough with their selections to focus on the task.

Participants #02 and #11 mentioned that they had occasionally applied the tools to the block absentmindedly without looking at it but that it was not something that they actively tried to do. During the interview after Session 2 with participant #08, they stated that it was easier to perform selections from the Belt Menu while looking but faster to do without looking. Participants #16 and #17 specifically said that they tried to select without looking but deferred away from it because the main menu items were awkwardly positioned.

Gesture selection, discussed in Section 5.4.4.1, was also mentioned by participant #03 as a contributing factor for being able to perform eyes-off interaction. Participant #04 perceived this method of selection to be low effort by "just waving the hand in the [correct] direction", with seven participants (#04, #06, #07, #08, #09, #11) sharing a similar sentiment. In particular, participant #06 compared this method of selection to shifting gears when driving a manual car, where the driver would typically be paying visual attention to the road instead of looking at the hand that is shifting gears.

Participant #01 reported that as the task became more complex, they would focus less on looking at the menu items and try to do more multi-tasking and use more quick glances. However, they admitted to making more errors with this approach. This can be confirmed by the recorded accuracy of participant #01 who made more unnecessary selections (Session 1 – 90.63% | Session 2 – 81.94% | Session 3 – 93.39%) across all three session than the calculated median of the 17 participants for all three sessions (Session 1 – 94.7% | Session 2 – 93.8% | Session 3 – 95.8%). Even though participant #01 made more unnecessary selections than the calculated median, they had the fastest completion time with the most complex task in Session 3.

Participant #02 mentioned that in their first session, when the task was easy and straightforward, they would select the various block shapes without looking. But in the second and third sessions they did not want to lose time by making unnecessary selections when selecting submenu items and so they intentionally looked and focused on every selection. This is evident in the hit percentage of participant #02, which was never below 96% across all three sessions (Session 1 - 100% | Session 2 - 96.98% | Session 3 - 98.8%). The attitude of not wanting to lose time with frantic selections can also be observed in their selections per second (s/s). Selections made by participant #02 in Session 1 (1.25) and Session 2 (1.56) were slower than the median of the rest of the participants (Session 1 - 1.16 | Session 2 - 1.53).

Comparing the contrasting approaches for eyes-off interaction of participants #01 and #02, it is interesting to find that in the last session they were both the fastest to complete the task. Participant #02 was careful not to make selections frantically and unnecessarily to avoid wasting time. Participant #01 was more careless, making unnecessary selections and trying to do things as quickly as possible. Both sentiments are reflected in the performance for selections per second (s/s), which was discussed in Section 5.3.2.7. Having these contrasting approaches while still producing similar efficiency serves as an example that eyes-off interaction is possible with practice but is not necessarily a preferred skill to rely on for increasing performance. Participants #16 and #17 mentioned that they performed eyes-off interaction with the Addbox and the Paintbrush but avoided eyes-off interaction with the side menu items due the awkward positioning. Participants #08, #10, and #11 actively tried to perform eyes-off interactions but were not always accurate in their selections, with participant #10 relying on shadows to do so. Participants #04, #06, #07, #08, #09, and #11 shared that they performed eyes-off interaction but were not consistently doing so with every selection, nor were they always consciously doing so.

With the varying reports of visual guidance, it can be understood that there were also varying sentiments towards pursuing the ability to perform eyes-off interaction. There were varying levels of reliance on visual guidance that participants were comfortable with to optimise their performance. To find satisfaction with a menu system, users may require the menu system to enhance their ability to complete a task. However, some users may find the interactions with the menu items to be satisfying within itself.

e. Reliance on shadows

Section 5.4.2.2 provided a discussion regarding the reliance on shadows for menu interaction. Although the reliance on shadows was an unexpected user behaviour, it provided insight into possible methods of using background elements in the IVE to support the user's ability to increase awareness with the Belt Menu.

As participants relied on shadows for menu interaction, the shadow was not the subject of their focus. Instead, the shadows provided a visual aid for establishing awareness in the following ways:

- Using them as an alternative visual indicator to directly looking, when the menu items themselves were out of sight.
- Noticing the visual changes in the shadows through peripheral vision as confirmation for selections.
- Becoming aware of more menu items than what was visible directly in front of them.

These methods of observing the shadows provided visual aid that was used through the various levels of visual guidance.

f. Factors that contribute to visual guidance

Based on the analysis of participants using visual guidance, various levels of reliance were identified, as discussed above, along with other user behaviours that related to visual guidance. The various levels of reliance were identified to be dependent on the level of familiarity with the Belt Menu.

Familiarity is a key component to good design. There are various components that were identified in the experiences by participants that led to a level of familiarity that allowed low-effort interactions with the Belt Menu. As users become more familiar, they make the transition from novice users to expert users. This transition involves progressively less reliance on visual guidance to increase in performance (Shneiderman et al. 2009:66–69; Schramm, Gutwin & Cockburn 2016). These behaviours were evident from 14 out of 17 participants as each of them progressed through sessions 1 to 3. The exceptions to this were participants #02, #14, #15, who preferred to look at what they did either because that is how they do actions outside of IVEs to make sure that that actions are done properly, or that they found it satisfying to observe the changes when tools were applied to the blocks. This familiarity was based on the positioning, layout of menu items relevant to their own body, and awareness of menu items. Existing literature and the results of this study suggest that there is a relationship between familiarity and visibility.

Various sources of literature were used as a basis to understand user behaviour that linked familiarity to visual guidance. Shneiderman et al. (2009:66–69) identified the relationship between familiarity and visibility in user behaviour, which was further studied by Schramm, Gutwin and Cockburn (2016) to explore how elements in a UI can be used to support development of expertise. Bowman and Wingrave (2001) discovered the user behaviour known as "eyes-off interaction", which is more prominent in users who are more familiar with a system. The results of the current study identified three levels of visual guidance that participants experienced before performing eyes-off interaction, namely: directly looking, glancing, and the use of peripheral vision. Understanding based on the aforementioned literature along with the results of the current study were combined to recognise how the four levels of visual guidance relate to familiarity. The relationship between familiarity and visibility can be illustrated as a spectrum of direct correlation between reliance on visual guidance and familiarity, as visualised in Figure 5-24.

Figure 5-24: Relationship between reliance of visibility and familiarity, as described by Shneiderman et al. (2009:66–69) and revisited by Schramm, Gutwin and Cockburn (2016)

When the Belt Menu was unfamiliar, users tended to rely on visibility to locate menu items so that they could be selected. As familiarity increased, their reliance on the visibility of menu items became less. Interacting with the Belt Menu required less visual focus as the Belt Menu became more familiar. Glancing was used to double check that the menu item was interacted with, instead of looking with intent. Peripheral vision was then used to establish spatial awareness and locate menu items, with less focus required than glancing. Eventually it became possible that menu items were selected without focus and done out of habit, sometimes resulting in selections performed with eyes-off interaction.

The exceptions to desiring less reliance on visual guidance are that users either:

- Intentionally chose to rely on visual guidance so that they do not risk a performance dip. This was also discussed as "the paradox of the active user", where users may defer from adopting a new method, or in this case a new behaviour, because they do not want to risk experiencing, albeit temporarily, a performance dip (Carroll & Rosson 1987).
- Find the visual aspects of the interaction to be appealing due to the novelty. In this case, the user was not focused on performance but rather on enjoying using the system.

It should be pointed out that, based on these findings, a clearer understanding was established regarding the relationship between the ability to use proprioception for menu item selection and the reliance on eyes-off interaction. This understanding is that the ability to use proprioceptive senses is not exclusive to eyes-off interaction, but instead using proprioception to guide selection is possible across the spectrum illustrated in Figure 5-24. As long as the user has established an accurate awareness of the menu items, they can rely on proprioception for their selections. It should also be made clear that an expert user can develop the ability to perform eyes-off interaction but will possibly not only rely on this method.

5.4.3.4 Vibrations

Haptic feedback was used to inform the user when they had touched menu items, as discussed in Section 4.4. There were different vibration patterns for main menu items and submenu items.

Fourteen participants liked that the vibrations in the controllers indicated that they had touched a menu item. Participant #14 stated that the vibration "gives a good feeling that you [have] really touched it. It gives an idea that you already reached there. Not a very hard vibration. [The vibration] Makes it more real."

Other participants (#05, #16, #17) complained that it just kept "buzzing" and was annoying. They interpreted the vibrations to be an indication that something was wrong. When prompted, each of them agreed that there is a possibility that this was due to past experiences in playing videogames with a controller. Haptic feedback in videogames is often used to indicate that something was wrong (e.g., taking damage, crashing into a wall). Although participant #11 had initially also made this negative association, they said that they were able to mentally change their perspective and did not have any concerns once the mental shift was made.

The suggestion mentioned in Section 5.4.3.2a, where menu items are placed closer to the user's body, may also resolve the "buzzing" issue because it is not as close to the user's hands when they are holding up their hands.

5.4.3.5 Developing awareness

What can be learnt from the above sections regarding visual representation, layout and positioning, visual guidance, and vibrations is that participants relied on these properties of the Belt Menu to establish spatial awareness and memory, even though there were varying preferences in doing so.

The various aspects of visual representation were discussed to help participants establish an accurate understanding so that they can be used appropriately. In addition, the data suggest that visual representations should be designed in a way that does not obscure, distract, or otherwise hinder, the user from completing the task.

Layout and positioning were discussed with regards to making menu items more accessible in a comfortable way and follow some level of consistency to guide users' expectations. Any exceptions to the consistency should have an obvious and logical reason to the user. Practice and exposure often provide a healthy space for learning. Erroneous and unnecessary selections with a menu system are inevitable and are naturally part of the process for improving the skills necessary to use the menu system. Identifying aspects of the menu system that caused erroneous selections provided direction for how the menu system can be improved.

Visual guidance was relied on in varying levels and, although there is a tendency for experienced and expert users to have specific levels of reliance, people have individual preferences regarding how much reliance they want to have to optimise their own performance.

Vibrations, i.e., haptic feedback, can help to create awareness of touching menu items in a way that is not visual. However, it can cause an annoyance if users perceive the vibrations to be a negative feedback, e.g., in video games where vibrations in handheld controllers usually indicate an error or taking damage.

5.4.4 Supporting users to become familiar

Once participants had developed a basic understanding and awareness with the Belt Menu, they could rely on these understandings to optimise their interactions with the Belt Menu. These understandings were supported by carefully designed aspects of the Belt Menu that helped with learnability and memorability (Bowman & Wingrave 2001; Sharp, Preece & Rogers 2019:20–22). As they became more familiar, it also reinforced their awareness of the menu items, which in turn also helped them to become more familiar with the Belt Menu. This cyclic dependency could contribute to the participants building their confidence in their selections with the Belt Menu and led to progression in expertise.

5.4.4.1 Gesture selection

The selection method designed and described in Section 4.4.4, where both halves of a button press are used as separate sub-actions, resulted in a more fluid selection process. This selection method is done by grabbing a main menu item and releasing when touching the desired menu item from the submenu wheel. This method of interaction and selection was intentionally designed to reduce the amount of button presses per action, which was discussed in full detail in 4.3.1. Fewer button presses were expected to result in less effort and less confusion for the user. This also allows for more efficiency due to less effort.

Participants #01, #02, and #03 enjoyed using this method for selection and mentioned that the selection was significantly more "intuitive" than other VR interactions because of this method. Particularly, participant #01 mentioned that, "…with the sessions a week apart I would start forgetting the placements but I remembered them without too much effort and naturally just waved my hand into the option that I wanted.". Participant #03 also expressed, "I liked that, irrespective of each tool, it was that you wave your hand in the direction of whatever you want on the wheel to select it. It is quite intuitive and nice". Of the 17 participants, ten positively discussed gesture selection during the focus groups. Specifically, participants #03, #07, #11, #09, and #16 stated that it was helpful to just wave their hand in the direction of the menu item to select it, i.e., it provided a smooth method of selection. As discussed in Section e, eight participants expressed a preference to rather have an extra button press to confirm the selection. However, this is still worth noting, especially coming from participant #03 who develops software that uses VR technologies, as mentioned in Section 5.2, and is therefore well-versed with methods of interactions and selections for IVEs.

Four participants (#02, #04, #08, #10) expressed that the gesture selection was simple enough to quickly perform reselections when correcting any erroneous selections they had previously made. Participant #04 discussed that the use of gesture selection along with strategy #01, i.e., placing all five blocks of one shape correctly into the box before moving onto the next shape and box, made completing the task easier because this motion was committed to memory. As discussed alongside Figure 5-21, gesture selection was attributed as supporting awareness, learnability, and familiarity, which in turn enabled less reliance on visual guidance.

Although the discussion in this section contradicts the desire for a confirmation action in Section 5.4.2.4e, what is important to note is that participants want a selection method that is smooth and easy to remember while also causing fewer accidental selections.

5.4.4.2 Hand usage

The menu layout was preassigned based on which hand each user considered their dominant hand, as discussed in Section 4.6.1.

All 17 participants noted that, in Session 1, it was easy to do the task by having the box blocks menu item closest to their dominant hand as all they had to do was get a block and place/throw it in the correct box.

a. Non-dominant hand doing more than the dominant hand

The task in Session 3 required a constant switch between the Paintbrush and the Measure tape. Because of the layout of the menu items, this was done by the non-dominant hand while the dominant hand would make one selection for the correctly shaped block and keep holding it while the non-dominant hand switched between tools. As discussed in Section 5.3.2.5, this resulted in participants progressively using their non-dominant more than their dominant hand over each session.

In sessions 2 and 3, some participants (#08, #14, #16) expressed that they would have preferred if the tools (Paintbrush and Measure tape) were placed by their dominant hand, instead of the non-dominant hand. They would then use their non-dominant hand to place the blocks into the correct boxes. Participant #08 used the analogy of using a hammer and nail. The non-dominant hand would hold the nail while the dominant hand uses the hammer. The preference of using the dominant hand for the tools became more prominent when participants were required to use two tools in Session 3. Participants mentioned that holding the block was a simple task that required no skill. It was awkward to perform more selections with their non-dominant hand than their dominant hand. In contrast, seven out of 17 participants (#01, #02, #04, #06, #07, #10, #13) discussed that they preferred the Addbox to stay on the side of their dominant hand because they felt that the dominant hand played the crucial role of placing the blocks in the correct box, which they were more comfortable to do with their dominant hand as it was much more proficient in throwing the blocks.

Because of the constant switching between the Paintbrush and the Measure tape being done with the non-dominant hand during Session 3, participants used their non-dominant hand for more actions than their dominant hand, as discussed in 5.3.2.6. The non-dominant hand had to select the paint colour and apply the colour to the block, followed by selecting the enlarge/shrink Measure tape, and apply it to the block as well. The dominant hand would only be used to select a block shape and hold it while colour and size were applied, and then place/throw them into the correct bin. This kind of distribution for hand usage is another possible contribution for the increased time taken for participants to complete the task for Session 3. Participant #02 suggested that the layout should not be based on hand dominance but rather on personal preference. This is a good suggestion because people still have different preferences for hand usage even though they may share a common dominance, i.e., a right-handed person may still prefer to hold the blocks with their left hand or vice versa. Taking that into consideration, users should be given control on the layout so that it can be according to their own preference.

Participants #01, #12, #13, and #15 stated that they were not sure if swapping the functions would have made a difference because they were accustomed to the functions from Session 1, and at that point it made more sense to select the blocks with their dominant hand. This sentiment, along with the findings in Section 5.3.2.6, further aligns with Habibi and Chattopadhyay's (2021) findings, which indicated that there is less of a performance difference between hands when using touchless input compared to other pointing devices like a computer mouse.

This section highlighted that participants needed to perform more selections with their non-dominant hand, which can be awkward since the dominant hand is preferred for most actions in a real-world task. Only three participants expressed a discomfort while seven participants preferred the layout as designed, which indicates that handedness does not play a significant role. That being said, the system can be improved by providing the ability for participants to adjust the layout according to their personal preference. Doing so provides the user with more control over their experience with the menu system. The implications for desiring customisation are further discussed in Section 5.4.4.2c.

b. Criss-crossing

Criss-crossing hands in this context refers to a selection that would be performed by using the dominant hand to reach over to something placed closer to the non-dominant hand (e.g., using the dominant hand to select the Paintbrush) or vice versa (e.g., using the non-dominant hand to select the Addbox).

Participant #10 assumed that selections performed by criss-crossing hands would be less efficient and avoided it. Participant #07 and #12 tried to perform selections by criss-crossing hands but it proved to be less efficient and awkward.

When asked about switching the layout of the Belt Menu (having the Addbox on the side of the non-dominant hand), participant #15 stated that they would criss-cross hands instinctively and select the Addbox with their dominant hand. This is because the focus of the task is on the blocks, which for participant #15 was understood to be the primary action for the task so they would still prefer to interact with the blocks by using their dominant hand. Thus, if the layout was switched it would still have been awkward.

Only four participants (#07, #10, #12, #15) discussed the idea of criss-crossing their hands and considered against it. Additionally, as discussed in the previous section (5.4.4.2a), three participants (#08, #14, #16) would have preferred the menu items to be different so that the non-dominant hand was used to select the blocks. Both of these discussions imply that users preferred to use the hand closest to the menu item, even when it was considered awkward.

c. Bimanual interaction

Based on the discussions above, themes regarding hand usage were identified that were interpreted to provide insight into how bimanual interaction played a role in using the Belt Menu.

The design of the Belt Menu and the task caused participants to perform more selections with the non-dominant hand than the dominant hand when the task became more complex. This was discussed in 5.4.4.2a and confirmed by the findings in Section 5.3.2.5. This resulted in participants needing to focus more when making selections with the non-dominant hand. The clumsiness of the non-dominant hand became more apparent when participants tried to do the tasks quickly. This caused some participants (#01, #05, #07, #09) to feel overwhelmed and press the trigger button excessively when interacting with the Belt Menu. During the focus groups, it was also discussed that "buzzing" was possibly related to the clumsiness, which is discussed further in Section 5.4.3.4.

5.4.4.3 Customisation for layout

Ten participants (#02, #03, #05, #08, #10, #12, #14, #15, #16, #17) expressed the desire for more customisation options regarding the placement of the Belt Menu. They desired to at least be able to adjust the height of the belt in accordance to their preferences, e.g., participants #16 and #17 both preferred the belt to be very low.

All three focus groups discussed that they would like more aspects of customisation. The conclusions from the three focus groups were distilled into the following suggestions for customisation:

- Being able to adjust the Belt Menu to be forwards and backwards (eight occurrences).
- Adjusting the Belt Menu to be either more condensed or more spread out around the user (four occurrences).
- Rotating the Belt Menu clockwise or anti-clockwise (three occurrences).
- Swapping the menu layout positions for the four items (six occurrences).
- Treating the menu items as quick slots and selecting tools from a larger inventory (five occurrences).

In Section 5.4.2.4a, it was discussed that the adjustable height may have been a cause of obscuring the visibility of the boxes. However, participant #17 also mentioned that "As the menu obscuring [*sic*] your task [seeing the required colour and size of the block], it was easy enough to adjust and move it [the Belt Menu] out of the way.". This suggests that further customisation can also be used to address the issue that menu items obscured vision of other objects in the IVE.

Typically, novice users are less concerned with customisation and more focused on becoming familiar with the menu, while experienced users develop and consider preferences that may optimise their performance (Shneiderman et al. 2009:64). The fact that there were discussions regarding some form of customisation suggests that some participants have surpassed being a novice user.

5.4.5 Developing familiarity and expertise

In the process of becoming familiar with the Belt Menu and developing expertise with it, participants experienced and developed preferences regarding the selection method, Hand usage, and Customisation for layout. Investigating the reasons behind these behaviours and preferences provides understanding of the participants' experiences in a way that can be used to improve the design considerations that guide menu system design for IVEs.

Gesture selection was the method of selection design for the Belt Menu, where participants #04, #06, #07, #08, #09, and #11 found it useful to perform eyes-off interaction. Three other participants (#01, #02, #03) also found the selection process to be smooth and satisfying. Eight others would have preferred an extra button press for confirmation but mentioned that this is a minor issue.

Findings regarding Hand usage provided insight that hand usage contributes to preferences with the layout. The design of the Belt Menu had considered this, which was the reason for providing different layouts for right-handed and left-handed users. However, it was discovered that the preference relating to hand usage was oversimplified. Participants had different preferences regarding hand usage for selecting specific menu items. Therefore, this suggests that customisation is more desirable than what was expected, even when it is a new system.

The desire for customisation was expressed in various aspects in addition to the simple option of moving the Belt Menu to various heights. In the literature, this desire is given as a user behaviour that is more prominent in experienced users because they are comfortable enough with the system to want to make personal adjustments (Shneiderman et al. 2009:64). The fact that customisation was discussed as a desirable option suggests that participants were able to establish a level of familiarity with the Belt Menu within a relatively short period.

Section 5.4.3.3 discussed how all participants exhibited varying reliance on visual guidance for menu item selection, with specific participants performing eyes-off interaction. These user behaviours indicate that it was possible to develop familiarity with the Belt Menu over time to the point that proprioception was relied on for menu item selection. For users to develop familiarity with a menu system, it must first provide support for users to establish awareness and understanding of menu items. Support for developing familiarity can also be supported by considering a selection method that is easy to understand, remember and master. The user should also be given the ability to adjust their interactions with the menu system through customisation.

5.5 Summary

This chapter provided a discussion of how the collected data about the participants' experiences were processed and analysed. The findings were categorised as Background experience with IVEs, User performance and Experience with the Belt Menu. The findings for each of these categories were discussed to determine how the Belt Menu supported participants in completing a task that became progressively more complex over three sessions.

Background experience that participants had with IVEs and VR technologies provided an understanding of their level of comfort with the IVE containing the Belt Menu and the given task, as discussed in Section 5.2. This was used in conjunction with the user performance data, which revealed that previous exposure to VR technologies has some effect on performance.

User performance was used as a point of triangulation to verify the participants' experience with the Belt Menu. Data for the following metrics were collected: completion time, selection accuracy, accuracy according to each menu item, accuracy relating to hand usage, and speed of selection. Having these metrics highlighted various aspects of the participants' experience. Selection accuracy was at the highest in Session 3, despite having the most complex task of all three sessions. The highest speed of selection did not directly correlate to quickest completion time. Participants progressively used their non-dominant hand more than their dominant hand due to the layout of the menu items. Despite this being less preferred, the accuracy was still the highest in Session 3. Main menu items caused more missed selections than submenu items.

Experience with the Belt Menu were identified as three areas, namely:
Unexpected experiences, Supporting awareness of available menu items, and What can be learnt from the above sections regarding visual representation, layout and positioning, visual guidance, and vibrations is that participants relied on these properties of the Belt Menu to establish spatial awareness and memory, even though there were varying preferences in doing so.

The various aspects of visual representation were discussed to help participants establish an accurate understanding so that they can be used appropriately. In addition, the data suggest that visual representations should be designed in a way that does not obscure, distract, or otherwise hinder, the user from completing the task.

Layout and positioning were discussed with regards to making menu items more accessible in a comfortable way and follow some level of consistency to guide users' expectations. Any exceptions to the consistency should have an obvious and logical reason to the user. Practice and exposure often provide a healthy space for learning. Erroneous and unnecessary selections with a menu system are inevitable and are naturally part of the process for improving the skills necessary to use the menu system. Identifying aspects of the menu system that caused erroneous selections provided direction for how the menu system can be improved.

Visual guidance was relied on in varying levels and, although there is a tendency for experienced and expert users to have specific levels of reliance, people have individual preferences regarding how much reliance they want to have to optimise their own performance.

Vibrations, i.e., haptic feedback, can help to create awareness of touching menu items in a way that is not visual. However, it can cause an annoyance if users perceive the vibrations to be a negative feedback, e.g., in video games where vibrations in handheld controllers usually indicate an error or taking damage.

Supporting users to become familiar. Analysis of the participants' experiences according to these areas helped provide a clear indication of what was considered interesting but not directly relevant to the current study, and those experiences that were crucial to understanding the role of proprioception in helping participants to make selections from the Belt Menu.

Unexpected behaviours were investigated to understand how this may have affected the participants' ability to use the Belt Menu and to understand potential exploits that participants may have taken advantage of to improve the ability to complete the given task. Establishing this understanding provides direction that can be included in future design considerations. These unexpected behaviours included the approach for completing the task, use of shadows in the IVE, and general areas of improvement.

From investigating the interactions that participants had with the Belt Menu over three sessions, it was clear that participants made use of various aspects of the IVE to interact with the Belt Menu and to complete the task. Participants made use of various strategies and standing positions, which may have affected their performance. These approaches were investigated to see how this affected their ability to use the Belt Menu, instead of identifying variables that affected completion time. From this investigation, it was identified that menu items were always available to all participants despite varying approaches. This was the reason for designing menu items to always be around the user's body, which has shown to be an effective design choice through these various approaches.

The IVE included shadows that were only intended to create a more believable IVE, however, this was used by some participants to establish awareness of menu items. This awareness was also extended to be used for menu item selection through peripheral vision when menu items were not in line of sight. Participants also identified various aspects that they would have wanted to be added or changed. All of these aspects were discussed to highlight them as design considerations that should be included when designing for a menu system used in IVEs. Two design flaws were identified that caused frustration and potentially had a negative impact on the participants' ability to complete the task. Five areas were discussed, namely: providing an undo action, deleting blocks, having a confirmation action for selections, dipping as an alternative selection method, and having a default selection. These suggestions were explored in terms of adding and changing functionality that would provide the user with more control over their selections and interactions with the IVE.

Once unexpected behaviours were understood, they helped provide context to explore how the Belt Menu provided support for participants to become aware of the menu items. This included the following topics: Visual representation, Layout and positioning, Visual guidance, and Vibrations. Visual representation was discussed as the first impression that participants would have about the Belt Menu, which provided clues on how to use each menu item. Some of these representations caused an initial misunderstanding due to different expectations of functions. However, once the function of the menu items was understood, the visual representations made sense as well. Based on this experience, it was discussed that the use case can be investigated in more detail to provide visual representations that are directly related to the context.

Layout and positioning are properties of the Belt Menu that played a particularly influential role in affecting the participants' ability to make selections. Overall, participants found the layout to be logical for the task. The ability to adjust the height of the Belt Menu was included as a function to accommodate participants of different heights. This ability also created the awareness for participants to consider other options for adjustments, e.g., various dimensions for customising layout. Two menu items were intentionally placed to the sides of the user to test the limitations of what is considered comfortable to reach. This resulted in suggestions of how these positions can be improved. The metrics for the accuracy of each menu item were used to triangulate the findings in this discussion.

Visual guidance was particularly investigated as this determined the level of familiarity that participants developed with the Belt Menu. Four levels of visual guidance were identified based on studying participants' user behaviours, namely: directly looking, glancing, relying on peripheral vision, and performing eyes-off interaction. These various levels of visual guidance correlate to the levels of familiarity with the Belt Menu. Familiarity is important because it affects the ability of relying on proprioception to be used for menu item selection, which is a crucial aspect to the current study. The discovery from this investigation indicated that participants had varying preferences with regards to relying on visual guidance. Some participants preferred to look at all their selections for various reasons while others made use of eyes-off interaction. It is also important to note that an expert user will use all levels of visual guidance and possibly may use eyes-off interaction. It is not necessarily the case that only novice users will look directly at their menu items and only more experienced users will use other forms of visual guidance. Using eyes-off interaction is an option for optimising performance. This also means that proprioception is not only proven to be used when performing eyes-off interaction, instead, various levels of reliance on proprioception is used dependent on the level of familiarity with a menu system.

Vibrations were discussed as a method of providing non-visual feedback to make the user aware of menu items being accessible. Some participants made use of this to their advantage while some participants moved menu items to avoid the vibrations as much as possible. The cause of this avoidant behaviour is due to the fact that participants found the vibrations to be annoying and perceived this as feedback for errors.

The section regarding supporting users in becoming familiar with the Belt Menu covers discussions that explore the following topics: Gesture selection, Hand usage, and Customisation for layout. Gesture selection refers to the method of selection, which participants felt was smooth. The selection method was considered to provide sufficient support for memorability and learnability. The gesture selection was also discussed as a selection method that eases the process of reselecting menu items, which contributed to making erroneous selections easy to fix. In addition, some participants discussed that this method allowed them to perform eyes-off interaction. Other participants would have preferred more button presses in contrast to this selection method but expressed that this was a minor concern because accidental selections caused by this selection method were easy to rectify.

Hand usage was discussed as an aspect that was largely affected by positioning and layout. All participants made use of the hand that was closest to the menu item needed. The findings from this discussion are that participants have varying preferences for using their hands to select different menu items. As a result, the best approach is to provide more control so that they can personalise the layout through customisation.

The desire for customisation was largely discussed regarding various aspects of layout and positioning for menu items, further confirming that positioning and layout is important but is dependent on varied personal preferences. Customisation is normally desired by more experienced users who are familiar enough to consider personal optimisation, therefore this is an indication that participants had developed a level of familiarity to have this desire.

The results from this analysis indicate that the Belt Menu enabled participants to develop a level of familiarity with the Belt Menu that allowed them to establish some level of spatial awareness. This awareness enabled the ability to rely on proprioception for menu item selection, and thereby also provided evidence that the design considerations identified in Section 2.10 are feasible criteria for guiding the design of menu systems used in IVEs that enable users to develop the ability to rely on proprioception for menu item selection.

The next chapter provides an overall summary for the current study that highlights the significance of the findings for this study and includes a discussion of how the findings discussed in this chapter address the research questions presented in chapter 1 (Section 1.5).

6. Conclusion

This chapter provides a conclusion that summarises the findings of this study toward answering the research questions. The contributions made by the current study are then discussed and this dissertation is concluded with a discussion that highlights recommendations for future work.

6.1 Summary of the study

The current study investigated design considerations for menu systems used in IVEs by exploring the use of proprioception for supporting menu item selection. To do so, existing design considerations that informed various aspects of menu system design were explored, as well as existing approaches for designing interactions within IVEs. This involved establishing an understanding of the following concepts: various spaces in IVEs, perspectives in IVEs, immersion and presence, the role of spatial awareness and memory in IVEs, user behaviours in relation to expertise, various methods of interactions in IVEs, menu properties, and proprioception. The understanding of these concepts was used to inform the design and development of a menu system used in an IVE that aimed to support the use of proprioception for menu item selection. The menu system was designed by considering interactions in IVEs with regards to the following concepts from the literature:

- **Immersion and presence**: for a user to make use of their proprioceptive senses in an IVE, it is important to facilitate their sense of feeling part of the IVE. Doing so also enables them to establish an understanding of how they relate to virtual objects within the IVE and the influence that they have with these virtual objects, further enabling users to rely on proprioception to interact with the virtual objects (Section 2.4).
- **Spatial awareness and memory**: establishing a sense of awareness allows users to become familiar with the IVE and the virtual objects within that space. Through awareness of the virtual objects, details of the IVE are then committed to memory to help develop familiarity (Section 2.5). Initially, when familiarity is not well developed, users tend to rely heavily on visual feedback to guide their interactions with virtual objects and the IVE. As familiarity becomes more developed, reliance tends to shift from visual feedback toward other senses as well, such as touch through haptic feedback, sound through aural feedback, and proprioception through reliance on spatial awareness and memory.
- **Body-relative interactions**: this method of interaction consists of three components that supports the use of proprioception in an IVE: direct manipulation, physical mnemonics, and gestural actions. The combination of these three components provides a method of interaction that resembles actions performed in the physical environment, which is familiar and, therefore, easy to learn (Section 2.7). This also

makes it easy to transfer similar skills to be used in the IVE. Providing an interaction method that users find easy to learn and master allows them to quickly develop familiarity, which results in reliance on not only visual feedback, but a combination of other senses as well, e.g., touch, audio, and proprioception.

- **Selection techniques in IVEs**: the sole interaction with a menu system is selection, i.e., selecting and deselecting menu items as virtual objects. Therefore, it is crucial for the design of the selection technique to be carefully considered to ensure that the overall interaction with the menu system enhances the user's ability to complete a task. There are various methods of selecting virtual objects in IVEs, all of which have strengths and weaknesses that are dependent on various use cases (Section 2.8). Therefore, careful consideration is required to choose properties of existing methods that can be combined to create a selection technique to be used for completing specific tasks. Various considerations are also required to support selections to be made with more ease and higher accuracy, which can be supported with disambiguation mechanisms. A selection technique that is easy to learn and master is likely to produce reliable and accurate selections and will support the user's ability to develop familiarity with the menu system. This ultimately provides the option to rely on non-visual senses, such as proprioception.

Based on the aforementioned concepts of IVEs, design considerations were identified to inform the design of a menu system used in an IVE (Section 2.10). Following these design considerations, a menu system called the Belt Menu was designed and developed. Multiple sessions of usability tests were conducted, where the Belt Menu was used to complete a task. A total of 17 participants were involved in the current study and data collected from the participants included background experience, user performance data, and experience with the Belt Menu. The participants' experiences were used to identify how various aspects of the Belt Menu influenced their ability to complete the given task. The outcome of the current study was largely informed by user experience in the form of qualitative data and supplemented by recorded user performance in the form of quantitative data. Thus, a combination of constant comparative analysis and simple quantitative analysis was used. This was done by investigating participants' experiences that resulted in identifying user behaviours that correlated to expertise, which also indicated various levels of awareness and familiarity. These behaviours were then processed into themes, which were then analysed to find properties that relate themes to one another. This process provided an understanding regarding the user behaviours that informed the outcome of the current study. Results from the user performance data confirmed that participants were able to select menu items more efficiently and accurately as they became more familiar with the menu system. Investigating efficiency and accuracy provided insight for identifying menu items that participants struggled the most to select, which was then cross referenced with participants' experiences to understand what caused this struggle. Additionally, performance data also provided insight for hand usage, which indicated that handedness did not have significant influence on performance and when compared to findings of the participants' experiences, it was further found that hand usage was more dependent on position and layout of menu items as well as personal preference for hand usage.

6.2 Findings of the study

The discussions regarding the findings for the current study are conducted by addressing each sub-question identified in Chapter 1 (Section 1.5.2). Following this is a discussion that answers the main research question for the current study.

6.2.1 Synthesis of the sub-questions

The sub-questions of the current study are individually discussed and answered here to provide substance for the main research question to be sufficiently addressed.

6.2.1.1 Sub-question 1

Sub-question 1 was as follows: *What criteria can be used to inform the design of a menu system used in virtual reality that will allow users to take advantage of their proprioceptive senses?*

This question was answered by reviewing literature. Exploring existing work provided an understanding of the strengths and weaknesses for existing methods, identifying limitations, and investigating concepts intended for a different use case but which could be utilised for the context of the current study (Section 2.10). Based on this understanding, it was determined that the following design considerations could be used collectively to inform menu system design in a way that utilised proprioception to support menu item selection.

Below are the identified design considerations that were extracted from literature to inform the design of a menu system used in an IVE:

- **General usability**: following general guidelines and principles for usability ensures that the design of a menu system is intentionally considered to provide an experience that is satisfying, while still supporting functional requirements (Section 2.10.1). These considerations help to address commonly known issues that cause frustration and negatively impact the user's effectivity and efficiency to complete a task.
- **Four characteristics of a menu system**: for a menu system to be designed to be fit for purpose, it is helpful to follow criteria that define the fundamental properties of how a menu system should function. These four characteristics emphasize parameters that ensure a menu system provides tools that help users to complete a task, i.e., to provide a means to an end for completing a task, and are as follows (Section 2.10.2):

    - Menus should provide a list of items for a user to select a command, which represent functions that facilitate users in completing a task.
    - Menus should present the list of items in a visually structured manner.
    - Menus should be transient with information temporarily displayed and easily dismissible.
    - Menus should be quasimodal, with the menu kept in place through some constant action on the part of the user.
- **Five requirements that a new menu system should meet**: an investigation that intends to guide designing new menu systems needs to consider what is required to produce menu systems that are helpful. These five requirements provide a benchmark that ensures a resulting menu system proves to (Section 2.10.2):
    - help users to be at least as efficient and accurate as existing menus
    - be comfortable to use
    - not obstruct the user from interacting with the VE
    - support novice users to learn the menu system
    - support experienced users to perform eyes-off interaction
- **Guidelines for selection techniques**: since the selection process is crucial to menu interaction, it is important to explore various aspects that make a selection technique effective for the task. A selection technique can be decomposed as three sub-actions: object indication, confirmation, and feedback. This decomposition enables the selection technique to be designed with granular detail to ensure a simple and effective selection process. Specifically, object indication can be supported by investigating a disambiguation mechanism that enhances the accuracy of selection, thus making it easier to control. Overall, a good selection technique is defined by the following requirements (Section 2.10.2):
    - The selection technique must be able to provide rapid selection.
    - It must be accurate and error-proof selection.
    - The selection technique needs to be easy to understand and control.
    - It must produce low levels of fatigue.

These criteria were identified to provide guidance for designing a menu system that enables the use of proprioception for menu item selection. These criteria were followed to design the Belt Menu, which served as a prototype to test the feasibility of the criteria to inform menu system design that allows users to rely on proprioception for menu item selection. Proprioception is a sense that is commonly used with other senses, e.g., sight and touch, to establish awareness of surroundings and for interacting with objects in one's surroundings, whether for a physical or virtual environment (Section 2.7). Based on the outcome of the current study, the identified criteria can be followed to design a menu system that allows users to rely on proprioception for selections, which can be used to supplement reliance on these other senses to further enhance the user's ability to select menu items. The level of reliance on proprioception amongst other senses varies according to an individual's personal preference.

6.2.1.2 Sub-question 2

Sub-question 2 was as follows: *How effective are the perceptual properties of the designed menu system in supporting users to rely on proprioception to interact with menu systems?*

This question was answered by empirical data. For users to rely on proprioception, they need to first establish a level of awareness of the objects and the environment around them. The same is true in a virtual environment. To do so, virtual objects and the encompassing virtual environment need to provide perceptual properties that enable the users to become aware of the virtual objects, i.e., the various menu items of a menu system. Commercially available virtual reality (VR) technologies, such as the technology used in the current study, are currently able to provide visual, aural, and haptic feedback. The current study made use of visual and haptic feedback to support users in establishing awareness of menu items (Section 5.4.3).

The empirical data collected from the participants' experiences informed the following aspects of the Belt Menu as contributors to their ability to establish awareness of the menu items:

- **Visual representation**: this aspect of the menu items gives the first impression of what functions are available to the user. The representation should therefore be provided in a way that helps the user to correctly identify, understand, and remember the function of each menu item (Section 5.4.3.1). When correctly understood, users can rely on this to establish awareness of functionalities available to them through the menu system.
- **Layout and position**: establishing spatial awareness is primarily dependent on the layout and position of menu items relevant to the location of the user's body. Findings determined that, even though all menu items were within reach of the user, the level of comfort for reachability varies and is dependent on the position of menu items (Section 5.4.3.2a). This is based on the range of motion of each individual's arms, which are specifically reliant on the length of the arms combined with the bending angle of the elbows. Another finding indicated that participants found it helpful to relate different menu items to specific directions of their hands' movements. Based on this, the user's memory can be supported by the use of direction for selection, which aligns with the fact that committing objects to memory is easier when objects are related to oneself or to other objects, as discussed in Section 2.5. In the same way, the current study has shown that menu items are easier to remember when menu items are positioned in a specific direction, e.g., upwards, from the hand (Section 5.4.3.2a). Having menu items easy to remember based on position relevant to the hand allows for less reliance on visual guidance to make selections.
- **Vibrations**: when touching the menu items, haptic feedback was provided to users in addition to visual feedback so that they could feel that they were touching menu

items. Vibrations served two purposes in the Belt Menu: experientially, the vibrations provided a more immersive experience because users could feel some form of feedback when they touched the menu items, and functionally, in addition to visual guidance the vibrations alerted the user and made them aware that they were touching menu items (Section 5.4.3.4). These two purposes were important to enable the user to establish awareness with menu items using more than one sense of perception, i.e., not relying solely on visual guidance. Participants had varied experiences with this, with some of them finding this to be helpful, a few of them not noticing the haptic feedback, and others finding it to be annoying (Section 5.4.3.4). Those who perceived this to be annoying stated that they either did not understand what the vibrations indicated or that they misunderstood it as an indication that they had made an error.

- **Visual guidance**: existing literature discusses that visual guidance is a behaviour that changes in correlation to the user's level of expertise. Therefore, this user behaviour was carefully observed. Findings indicated that visual guidance is an indication of the user's level of awareness. Additionally, visual guidance can be identified as four different types of behaviour ranging from heavy reliance to no reliance, which are listed progressively as follows: directly looking, glancing, use of peripheral vision, and eyes-off interaction (Section 5.4.3.4). The findings regarding this user behaviour also indicated that the reliance on visual guidance may decrease as participants increased in their level of expertise. However, the shift in reliance is not solely dependent on the user's expertise and can vary according to personal preference. What can be said is that participants who are more familiar with the menu system developed more than one way of relying on visual guidance, with some relying more heavily on visuals than others, which provided them with more options for visual guidance in addition to only directly looking at menu items (Section 5.4.3.4).

Investigation around the use of the Belt Menu yielded results that provided more in-depth understanding of how various aspects influence a user's behaviour and their overall experience. It was determined that the aforementioned four aspects have the potential to support users to establish awareness if these aspects have the following properties: understood correctly, comfortable to reach, supported the use of other senses in addition to vision, and easy to remember. Supporting memorability is an important factor for enabling users to develop familiarity.

6.2.1.3 Sub-question 3

Sub-question 3 was as follows: *How can users be supported to become familiar with the menu system?*

As users establish awareness of the various menu items in a menu system, they begin to develop familiarity as well. Increased familiarity may also result in more awareness regarding aspects of the menu system that were previously unnoticed, thus leading to a cyclic dependency of increasing awareness and familiarity that originates from establishing awareness. To support users in becoming familiar with the menu system, design considerations were made based on existing literature to inform the design of the Belt Menu.

The following findings from the empirical data were discovered with regards to the participants' experiences of using the Belt Menu:

- **Selection method**: as mentioned in sub-question 1 (Section 6.2.1.1), the selection technique needs to be carefully designed to ensure that the interaction with the menu system is simple and easy to use. Providing such a selection method enables participants to focus more on other interactions because less focus is required to master the selection technique. The sooner users can master the selection technique, the easier it is for them to develop familiarity with the rest of the menu system. A selection method for the Belt Menu was created that considered a button press as two halves of an action, button press down, and button release. Splitting the button press into two halves enabled two actions to be made with one button press as discussed in Section 4.4.4. Button pressed down was used for selecting a main menu item, which then provided submenu options. Submenu items were selected by releasing the same button that was pressed. Based on the participants' experiences, some of them dubbed this selection method as "wave selection" and "gesture selection" because they felt that they made selections by moving their hand in a direction to finalise their selections (Section 5.4.4.1). The findings regarding the participants' experiences with this selection method yielded mixed feedback with some participants preferring to have a second button press to provide a more explicit confirmation of their selection. Other participants felt that it provided a "smooth" selection and that it contributed positively for error corrections because the selection method was simple enough that they did not mind re-selecting menu items to correct a mistake (Section 5.4.4.1).
- **Hand usage**: in general, people have personal preferences for interaction based on handedness. Menu items that are placed around the user's body inevitably have positions that are easier to select for one hand than the other. The function provided by a menu item determines which hand users want to use for that function. Because of this, handedness was considered in the design of the Belt Menu, which resulted in different layouts to accommodate right- and left-handed participants (Section 4.6.1). Results indicated that preferences for hand usage depended on the individual. Some participants preferred to do the primary task with their dominant hand while others preferred to perform more selections with their dominant hand (Section 5.4.4.2). Therefore, layout and positioning of menu items should not be pre-determined based on handedness; instead, the users should be in control of the layout and positioning. Despite different preferences for hand usage, participants discussed that hand usage

had a minor influence on their ability to become familiar with the Belt Menu (Section 5.4.4.2b). The menu items were still easy to remember and access. It was mentioned that selections made with the dominant hand enabled less reliance on visual guidance.

- **Customisation for layout**: the Belt Menu provided the ability to adjust the height as a simple form for customisation to accommodate participants of different heights (Section 4.4.1.4). Novice users typically focus their attention on learning the system as designed so that they can develop familiarity. The desire for customisation is typically more visible with experienced users, which indicates that familiarity is developed enough to consider personal preferences. The ability to adjust the height of the Belt Menu was to accommodate the fact that the waist area, i.e., where a belt would typically be worn, is at varying heights for individuals. However, having this option inspired considerations and desire for more adjustments to be made available. Various aspects for adjusting the layout and position were discussed, which also included further accommodation for hand usage as well (Section 5.4.4.3). The desire for more customisation was an indication that participants have developed enough familiarity to have personal preferences. Novice users place their focus on learning to use the system and prefer to work with a basic layout, therefore, having a default layout and positioning can accommodate this preference (Section 2.6.2). More experienced users tend to have personal preferences that may deviate from the default layout and positioning. Ultimately, providing the ability to customise the menu system enables users to have more control over their interactions with the menu system and enables users to adjust the experience according to their personal preferences of what is considered to be satisfying.

Developing familiarity and expertise is dependent on awareness. As familiarity increases, awareness also increases, thus indicating a correlation between these user behaviours. As mentioned in the beginning of this section, increased familiarity enables menu items that were previously unnoticed to be known, e.g., using a menu item that was previously not required to complete the task. The above three aspects of the menu system were experienced by participants as supporting the development of their familiarity (Section 5.4.4), which was prominently indicated by their desire for customisation. Additionally, providing customisation also allowed users to have more control of their experience with a menu system, which allowed them to adjust their experience until they could find the interaction with the menu system to be satisfying.

6.2.2 Main research question

With the sub-questions answered, the main research question can now be addressed: *How can interactions with menu systems in virtual reality be designed to effectively take advantage of proprioception to help with menu item selection?*

Sub-question 1 (Section 6.2.1.1) discussed how literature regarding the design of menu systems and interaction in IVEs was explored to identify a set of criteria that provided guidance for menu systems used in IVEs. The exploration of literature consisted of the following concepts to inform the current study: existing design guidelines for menu systems, immersion and presence, spatial awareness and memory, body-relative interactions, selection techniques in IVEs, hand usage, interactions that rely on proprioception in IVEs, and development of expertise. Informed by the understanding of these various concepts, criteria were chosen based on their ability to inform design in a robust variety of use cases, allowing them to also inform a design space that these criteria were not intended for, i.e., menu systems in a 3D virtual environment. This set of criteria considered the immersive nature of IVEs that could allow users to rely on proprioception, typically used in the physical environment, to enable the transfer of this reliance to be used in an IVE for menu item selection. The findings for the current study indicated that the Belt Menu enabled participants to rely on proprioception in the IVE for menu item selection, thereby supporting the use of this set of criteria to inform menu system design used in IVEs.

To test how the identified criteria could practically support users, thereby answering the main question, these criteria were followed to create a menu system that was used to complete a task in an IVE. Doing so provided the opportunity to study participants' experiences with the designed menu system, which were used to confirm expectations of existing theory and to identify points for improvement for the usage of the identified criteria in a new context.

Sub-questions 2 and 3 (Sections 6.2.1.2 and 6.2.1.3) each discussed specific properties of a menu system that result in enabling certain user behaviours. These properties of a menu system support users to establish awareness of the menu items available to them and help them to learn and remember the functions of these menu items, which contributes towards developing familiarity with the menu system. Familiarity can be further reinforced through providing a selection technique that is easy to master so that the focus is placed on the menu system and how it can be used to complete a task. Through awareness of and familiarity with the menu system, users may develop varying reliance on visual guidance and a desire for customisation to accommodate their personal preference, so that they can be more in control of their experience with the menu system.

Therefore, the Belt Menu, which was created by following the identified criteria, was able to support participants to establish a level of awareness and develop familiarity to the point where they were able to rely partially on proprioception for menu item selection, but the preference of this reliance varied with individuals. For this to be possible, design considerations needed to be reviewed for the following properties of the menu system: visual representation, positioning and layout, haptic feedback, supporting varying reliance of visual guidance, simple selection technique, hand usage, and customisation. A menu system consisting of all these properties supports learnability for novices and accommodates experienced users to customise and control their interaction with the menu system. Accommodating users with varying levels of expertise enables them to rely on the aforementioned properties of a menu system to establish awareness and develop familiarity through visual and haptic feedback, which ultimately also supports the use of proprioception for menu item selection in a way that they are comfortable with.

In an unfamiliar environment, i.e., an IVE new to the user, the senses of sight, sound, and touch are often initially used to perceive and make sense of the IVE, along with the virtual objects contained in the IVE, e.g., menu items, so that a sense of familiarity can be developed. Familiarity may enable a sense of comfort to a point of accepting the IVE as more than something that is just perceived through various senses but can also be interacted with. As familiarity increases, proprioception can also be used to enhance the aforementioned perceptions to select menu items. This was evident as participants developed enough familiarity to rely less on visual guidance in favour of relying on other senses, e.g., proprioception and touch, at various levels, with some participants performing eyes-off interactions to select menu items. This allowed them to focus more on the task, resulting in higher efficiency for completing the task.

For a menu system to be designed to ease the process of becoming familiar with the menu system, thereby supporting reliance on proprioception, it was found that a menu system should feature the following properties:

- **Virtually attached near the user's body:** this ensures that menu items are reachable and always accessible to the user, allowing them to perform body relative interactions.
- **Visual representations of menu items:** functions that are provided with an understandable representation for the user make the menu items easier to learn and remember.
- **Selection technique should be simple:** this is the sole method of interaction with menu items and should therefore be easy to learn and quick to master, ensuring that the user can focus on the task instead of struggling to make selections.
- **Provide feedback for more than one perceptive sense:** the use of haptic and audio feedback in addition to visual feedback enables familiarity to be developed quicker and allows more than one way to be aware of menu items when one perceptive sense is pre-occupied, e.g., menu items can provide haptic feedback when they are touched while looking in a different direction.

These properties ensured that awareness of menu items was perceivable and that menu items were always accessible, which supported the user to learn, memorise, and familiarise themselves with the menu items to a point of relying less on visual guidance for menu items for selection. Interactions in virtual environments that are presented using a 2D flat screen display are limited to only user-interface (UI) elements that are visible within the screen. This typically also only allows one selection process to be done at a time, e.g., selection using one mouse cursor. However, with VR technologies that make use of a head-mounted display (HMD) and handheld controllers, interactions are no longer limited to virtual objects that are in view of the user through the display, as discussed in Section 2.7. With this benefit, providing support for reliance on proprioception enables the ability to perform eyes-off interactions with virtual objects outside the visible area in an IVE, e.g., looking forward to keep focus on the main task, while interacting with a virtual object behind oneself. Additionally, this also allows both hands to make selections independently from one another, as the hands are no longer limited to interact only with visible objects. In the context of menu systems, this allows more than one action to be done with one hand selecting a tool while the other hand can be used to interact with virtual objects or another tool from the menu system.

Based on the discussions above regarding the synthesis of the research questions, a visual representation that shows the link between the overall approach for the current study is shown in Figure 6-1 below and was created by using X Mind (https://xmind.app/).

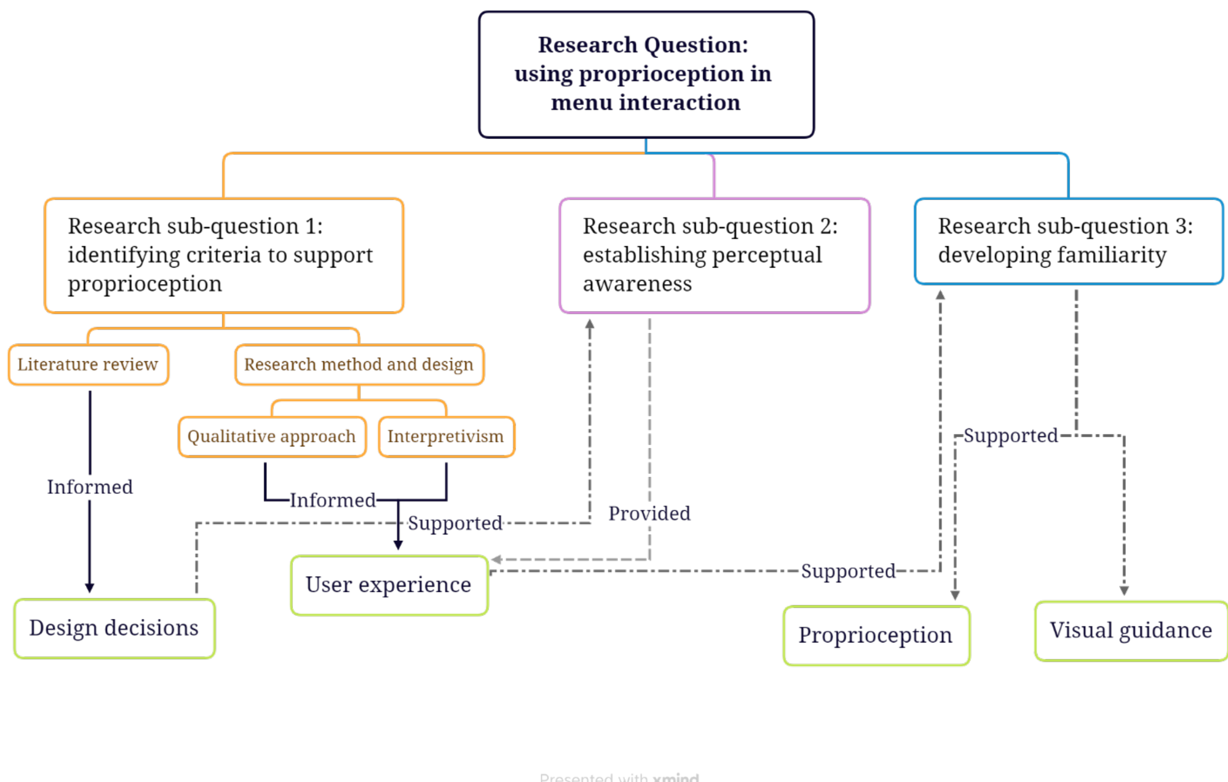


Figure 6-1: Overview for the synthesis of research questions

6.3 Contributions of this study

Menu system design has been thoroughly explored in existing literature. However, most existing design guidelines are intended for menu systems used in a 2D flat screen display. The current study investigated how existing design guidelines for 2D flat screen displays can be transferred to provide guidance for menu systems in a 3D IVE that is presented using immersive 3D technology. In the context of designing interactions in an IVE, the reliance of proprioception has previously been explored. The current study also included an investigation of how proprioception can be used specifically for supporting menu item selection. Therefore, the contribution of the current study is to identify design considerations for menu systems used in IVEs that support users to rely on proprioception to enhance the use of other perceptual senses for menu item selection. The significance of providing the option to use proprioception in conjunction with other senses, e.g., touch, is that proprioception can be used by taking advantage of the immersive nature of IVEs, i.e., being able to establish spatial awareness and memory, to enhance non-visual perception. Taking advantage of this immersive nature enables the ability to perform selections with menu systems with less visual guidance, ultimately allowing the focus that would be placed on menu interaction to be redirected to carrying out a task in the IVE. As mentioned in Section 2.1, a menu system is a means to an end, thus support for having more focus on the task and less focus on menu interaction elevates the menu system's function of helping users carry out their task.

To do so, the design considerations identified in Section 2.10 were followed to design and develop the Belt Menu, which was used to complete a task. The Belt Menu was found to be a success for enabling participants with menu item selection, with various levels of reliance on proprioception. Thus, this provides evidence of the utility of the identified criteria toward designing proprioception-driven menus in IVEs.

The reliance on proprioception for interaction in an IVE is dependent on the user's ability to establish spatial awareness and memory. Informed by this knowledge, menu items were placed around the user's body. Findings confirmed that this design decision allowed participants to always have menu items accessible to them as they moved around in the IVE. Additionally, the persistent availability of menu items was found to contribute towards establishing awareness and developing familiarity with menu items. The study also identified factors that were found to influence the ability to become aware of menu items, which include: visual representation, layout and positioning, vibrations, and visual guidance. Visual representation contributed to the user's ability to establish awareness by providing representations that were understandable and recognisable in regard to the functions that the menu items provided. Carefully considered layout and positioning ensured that menu items were selectable in a way that was reachable and comfortable. The use of vibrations in handheld controllers enabled users to rely on haptic feedback to feel positions of menu items. Lastly, visual guidance is a user behaviour that is dependent on the level of awareness established. More awareness enables less reliance on visual guidance, however, the level of reliance on visual guidance was also found to vary according to personal preference.

In addition to awareness, the use of proprioception was found to be dependent on establishing familiarity with the surroundings, in this case with the menu system. Based on the discussions from participants, layout and positioning was largely discussed as a factor that they relied on to develop familiarity. Findings also indicated that the development of familiarity with a menu system can be supported in providing a selection technique that is simple and easy to learn, to remember, and to master. Most commercially available VR technologies, such as the one used in the current study, support bimanual interaction and, therefore, the support for hand usage in the selection process should also be considered for developing familiarity. The current study found that participants who had developed a level of familiarity with a menu system tended to become comfortable enough to desire various aspects of customising the layout of menu items according to personal preference. This was evident as discussions regarding customisation only started in the later sessions of usability tests. Based on these discussions, providing support for customisation enables users to be in more control of their interaction with a menu system. As familiarity increases with the menu system, awareness levels also increase and it becomes a cyclic dependency that can support the use of proprioception for menu item selection.

In summary, the design of menu systems used in IVEs made use of existing design guidelines that were originally only intended for informing UI design for 2D flat screen displays. For the existing design guidelines to be applicable for IVEs, they needed to be adjusted to support the immersive nature that is inherent to IVEs. These adjustments created a set of criteria that enables the design of these menu systems to take advantage of the fact that spatial awareness and memory can be established in IVEs that, in turn, enables the ability to rely on proprioception for menu item selections in addition to relying on visual and haptic feedback. Enabling the reliance of proprioception to be used in an IVE for menu item selection allows the immersive nature of IVEs to be used to optimise the user's ability to carry out tasks by interacting with menu items with varied reliance on visual guidance.

6.4 Limitations of this study

The scope of this study was defined by focusing on the investigation of user behaviours experienced by participants while they interacted with a menu system in an IVE. Because of this defined focus, there were potentially influential factors that were considered beyond the scope and were therefore excluded from this study. These exclusions were identified as limitations of this study and are discussed below.

The findings for this study cannot be precisely replicated, nor was this the intention and, instead, the purpose of this study was to determine the feasibility of a system through understanding user behaviour which was done with a qualitative approach by focusing on the richness of experience rather than an investigation through a rigorous statistical analysis. Performance data were used in this study with the purpose of supplementing the findings relating user behaviours. As a result, the performance data were collected and analysed to understand user behaviour and not to identify potential statistical inferences such as performance differences. This approach is also the reason for making use of a small sample size as the investigation focused on understanding experience rather than seeking generalisable outcomes that represent a population.

Demographic differences and the impact that these differences may have in the results were not pursued as part of this study therefore, institution's ethics committee did not find enough justification to collect such data. With regards to other demographic factors that influenced this study, there was a technological literacy requirement that was used as part of the recruitment criteria which automatically excluded those with no or little technological literacy. Doing so removed an opportunity to investigate the extent to which the Belt Menu was learnable for those who are less familiar with technology.

There was a particular interest in this study on the use of visual guidance to help with the selection process. Because this study focused on discussions of the participants' experience, visual guidance was determined by observations, self-reporting, and reflection via discussions with other participants. Using eye-tracking technology to supplement these findings may have provided a different perspective for this study as this would have provided additional objective data that can specifically provide evidence of where participants were looking while making selections. However, this was considered beyond the scope of this study as it would have shifted the focus away from investigating the experience from the participants' own perspectives.

6.5 Recommendations for future research

Based on the investigation of the current study, a number of concepts were identified that would yield beneficial findings if they were pursued with more focus and depth. These concepts were identified while exploring literature and through the empirical findings.

6.5.1 Belt Menu rotation

As mentioned in section b, a known design flaw was that the rotation of the Belt Menu was disabled because it was fixed to the position of the head-mounted display (HMD) instead of the user's body. A solution to this rotation issue was not pursued in the current study because the focus was placed on establishing awareness and developing familiarity, and the task only required the participant to face one direction. Further research that investigates this rotation issue could potentially use the distance between the HMD, both hand-held controllers, and the floor to calculate an estimated position and direction that the user is facing.

A commercially available video game “Arizona Sunshine” (Jaywalkers Interactive & Vertigo Games 2016), which uses VR technology, has an implementation of a menu system that resembles a belt and rotates with the player. However, the method of implementation is not public knowledge and there is little literature that covers design guidelines for such menu systems. Future research investigating the rotation issue may refer to this existing implementation and other examples to identify design guidelines for menu systems that resemble a utility belt. Such research could also include a comparison of VR experiences with various implementations of diegetic menu systems that are placed around the user similarly to the Belt Menu. This could either be an exploration of past experiences, exposing participants to various implementations of menu systems, or a combination of these approaches.

6.5.2 Handedness for menu item selection

Handedness was addressed in the current study by providing two different layouts for right-handed users and left-handed users. However, the findings of the current study indicated that preference for hand usage is more complex. As discussed in Section 5.4.4.2, different participants had different preferences with regards to hand usage for selecting different menu items. Some participants preferred to use their dominant hand for selecting the menu item used for the primary objective of the tasks while others preferred to use their dominant hand for selecting menu items that support the primary objective of the task. Although handedness was considered as part of the design for the Belt Menu, this was only done to minimise any bias that would have disadvantaged some participants when completing the task.

As discussed in Section 6.2.1.3, hand usage was based on personal preference rather than handedness. The basic findings from the current study found that some participants preferred using the dominant hand due to stability while others preferred using their dominant hand for more rapid selections due to accuracy. Future research could investigate how handedness affects user performance with relation to menu item selection. The results from such a study could then be used to inform design guidelines regarding handedness in IVEs.

6.5.3 Layout customisation

The ability to adjust the Belt Menu was limited to one option: adjusting the height. The intention, as discussed in Section 4.4.1.4, was to accommodate participants of different heights. However, the findings discussed in Section 5.4.4.3 indicate that participants would like to have more options to adjust the Belt Menu to their personal preference, specifically for layout.

Future work can be done on understanding the effect that layout customisation has on user performance. As per the discussion from participants, more options for customisation were desired than what was provided. The foreseeable challenge of researching customisation would also include exploring the representation for various options of adjusting the menu system. Since these adjustments are mostly actions, they would be difficult to represent without understanding the action itself. As with the Arrow adjuster in the Belt Menu, participants expressed that they had no idea what the arrow was for until they interacted with it. That being said, participants expressed that the representation made sense after using it and had no further issue with it. There is already existing literature that covers learning through exploration within the context of UI design (Sharp, Preece & Rogers 2019:119). However, this application was not specifically for menu systems in IVEs. Therefore, a potential solution that is worth pursuing is investigating how to encourage exploration within an IVE and how that could aid a user's understanding, specifically for menu systems in IVEs.

6.5.4 Selection techniques for menu systems

There are a variety of selection techniques that make selection possible either within arm's reach or beyond arm's reach. Selection techniques used to select objects within arm's reach were considered for the current study. The reason for this was because the intention of the current study was to design a menu system where menu items were always accessible by placing the menu items within arm's reach, i.e., around the user's body.

The current study explored the use of body-relative interactions, specifically around the torso area of the user's body. Future research could consider creating design guidelines that explore other applications for body-relative interactions with other areas of the body, e.g., the head, hands, forearms, and upper thighs. Another possible direction for research is to investigate selection techniques for menus that are beyond the users reach, e.g., menu systems that are not attached to the user and are elsewhere in the IVE.

6.5.5 Non-visual feedback

The vibrations designed for the Belt Menu made use of different vibration patterns for touching main menu and submenu items. Section 6.2.1.2 discussed that the vibrations were either found helpful, unnoticed, or caused annoyance due to misunderstandings. Future work might investigate the design of proprioceptive menus with a focus on haptic feedback rather than primarily visual feedback as was the case in the current study. Additionally, this investigation in future works can also consider how audio feedback can be used for supporting menu item awareness.

6.5.6 Menu item representation

Participants discussed, in Section 5.4.3.1, that some menu items were initially misunderstood. The intended meaning was misunderstood due to the literal meaning but was understood once the menu items were used. Existing literature provides guidance for design icons for a 2D flat screen display (Sharp, Preece & Rogers 2019:205–207), so investigating how these concepts transfer to a 3D space could be beneficial. Representation can also be inspired by physical items that are directly related to the given task, which can then rely on existing knowledge of a specific profession or skillset.

6.5.7 Accessibility

This study specifically involved participants with two functioning hands so that handedness could be investigated as part of this study and as a result, these findings also provided grounds to consider ways to accommodate and support those who have physical impairments relating to hand usage, e.g., those with dexterity impairments in their hands and loss of use for one hand. The discussions below provide some suggestions for future studies to use as a foundation to explore solutions regarding menu systems used in IVEs that are similar to the Belt Menu.

This study found that some menu items were easiest to select with the hand that was closest to the menu item, as discussed in Section 5.4.4.2b which led to the idea of placing menu items that require frequent interactions on one side of the user of their unimpaired hand. That way, frequent interactions can be placed closer together for quicker access. This recommendation is also based on Fitts' Law, which implies that objects are easier to point to if they are close (Fitts 1954; Sharp, Preece & Rogers 2019:576–577). In the context of interaction design, this concept can also be applied when considering the change of a pointer from one target to another, i.e., switching between selecting menu items closer together (Sharp, Preece & Rogers 2019:576–577). Additionally, if the impaired hand is able to hold a controller, this can be used to hold objects in place without need for much further movement, e.g., a shaped block, while it's colour and size is being changed by the unimpaired hand. This idea stems from the fact that some participants suggested that it would be easier to hold the blocks with their non-dominant hand since it would only need to hold the block, as discussed in Section 5.4.4.2a.

Following the discussion of needing less effort to hold the block, a virtual holder, e.g., an additional virtual hand, can be provided as a Belt Menu item to hold virtual objects in place while the other hand can be used to select other menu items. Providing a virtual holder may enable those with only one unimpaired hand to make a menu item selection, place a virtual object into the holder, and continue with other menu item selections.

The task specific to this study involved placing virtual objects in the correct box which required the participants to move between these boxes, as discussed in Section 4.5. Should a similar task be created in a future study, this task could be challenging for those with mobility impairments. A potential solution could be to encourage throwing these objects. This approach was discussed by some participants as their way of placing blocks into the boxes, as discussed in Section 5.4.2.1. To provide further support for those with motor impairments, some form of an aim-assistance can be used to increase throwing accuracy of blocks into the correct boxes. Exploring the use of aim-assistance can be informed by investigating different methods of refining selections through a concept known as disambiguation mechanisms (Argelaguet & Andujar 2013). Those with low accuracy for throwing may also benefit from having an undo action which was discussed as a suggestion by participants in Section 5.4.2.4c. These same approaches can be used to assist those with lower dexterity in their hands. Should eye-tracking technology be available, gaze-assisted target selection can also be used to refine the selection process when interacting with the Belt Menu. This has already been done for menu item selection but not specifically explored with the intention for assisting those with physical impairments and disabilities (Sidenmark et al. 2020; Hirsch 2021).

6.6 Summary

This chapter concludes the research conducted and discussed in this dissertation. An implementation of a menu system was designed and developed that successfully enabled proprioception to be used for menu item selection. This enabled participants to establish awareness and familiarity with the menu system and make selections with varying levels of reliance on visual guidance, with some users performing eyes-off interactions.

This chapter provided a summary of the current study and discussed findings that addressed the research question and sub-questions. Contributions and recommendations for future work were also highlighted and discussed.

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Appendices

Appendix A – Consent form

Informed Consent Form: A menu system for Virtual Reality

Alias: ______________________
(Please use the same alias as the one you used for the questionnaire)

This study will be conducted by:

Department of Information Science

Researcher: Kwan Sui Dave Ka (dave.ka@up.ac.za)
Supervisor: Prof. TJD Bothma
Co-supervisor: IDV Bosman

What is this document?

This is a consent form that, if signed by you, allows the researcher to use your data for this study.

What is the purpose of this study?

The purpose of this study is to create a menu system that can be used in immersive 3D virtual environments, like virtual reality (VR). The design of this menu system intends to make use of the virtual space around a user's body in a virtual environment. As a part of this study, you will be asked to interact with the menu system using VR equipment.

What is expected from me?

You will be asked to make use of VR equipment that places you in a virtual room. In this virtual room you will be asked to place various shaped blocks into three boxes. Each box will be labelled with a block of a specific shape, colour, and size. You will have to place a block that matches the label on the box. To do this, you will have to make use of the menu system that was developed for this study.

As you interact with the menu system, please verbalise your thoughts. Thinking aloud will help us to understand your thoughts as you interact with the menu system. You should try to figure things out on your own. You should still voice your questions, but the researcher will not help you in figuring out how to use the menu system. You may ask for help regarding the physical VR equipment.

After each session, you will also be interviewed about your experience.

Your interaction with the menu system will be observed by the researcher. This will take place over three sessions of around 30 minutes each. Each session will be on different days. This is to see if the menu system is easy to remember over time. At the end of all three sessions, a group discussion will also be scheduled on a different day so that you have a chance to discuss your experience with other participants of this study. The duration for the group discussion will be 1 hour. In total, four sessions (three sessions of 30 minutes, and one session of one hour – altogether around 2 hours 30 minutes) will be required from you.

Please understand that you are not being tested. Any measurement of performance will only be used to understand how effectively the menu system has enabled you, as the user, to carry out a given task (placing blocks in the correct boxes). Your contribution will be used to help make the menu system more user-friendly. Therefore, your honesty and criticism will be very much appreciated.

Are there any risks involved?

A small number of people experience VR sickness, which has temporary symptoms similar to motion sickness (e.g. headaches, dizziness, and sometimes nausea). All precautions have been taken to minimise anything that may cause VR sickness. Should you start to feel uncomfortable, please inform the researcher. Symptoms of VR sickness can be remedied by taking a break from VR.

How will each session play out?

Each session will start by you putting on the VR equipment and being virtually placed in a room. You will then be instructed to begin placing blocks into the boxes when you are ready.

If you have never had any experience with VR technologies before, you will be given a short introduction to the equipment in the first session. You can take this opportunity to interact and familiarise yourself with the equipment.

Each interaction session will have the following phases:

- Practice attempt
- Timed attempt
- Short interview

Practice attempt: Before you begin each timed attempt, you may familiarise yourself with the virtual room along with the positions of various virtual objects (the three boxes and the menu system).

Timed attempt: When you are ready, you can grab a black sphere to begin the timed attempt. During the timed attempt, you will be required to place five blocks correctly into each of the three boxes, as indicated by the labels. Therefore, you will be required to place a total of 15 blocks correctly into the boxes. Every time you finish placing all 15 blocks correctly into the boxes, it will be considered a timed attempt. You may redo your attempt for that session as many times as the scheduled time allows.

Short Interview: Once you are satisfied with your timed attempt(s), you will be interviewed about your experience with the menu system.

What kind of data will be collected from me?

The following data will be collected. Please note, all data will be kept anonymous and no personal information will be used or requested from you.

- On-screen activity.
- Your performance in correctly placing 15 blocks into the three labelled boxes.
- Video and audio recordings (only if you sign consent for it).
- Observations of your overall interaction with the menu system.

Why is it necessary to sign this consent form?

By signing this consent form, you indicate that your participation is completely voluntary, and it ensures that your data will only be used for this study. Your signature also serves as an indication that you understand the purpose of this study and that you understand what is expected from you.

What if I decide to opt out?

You are permitted to discontinue your participation at any given time. No specific reason for discontinuing is required. If you choose to discontinue your participation, all data collected from you will be discarded.

Giving consent

I hereby give permission for my data to be collected in the above stated ways for the purpose of this study. I understand that any data I provide for this study will only be accessible by the researcher and the research supervisors.

Participant's signature: ______________________ Date signed: ______________________

Witness' signature: ______________________ Date signed: ______________________

Researcher's signature: ____________________________ Date signed: _________________________

Signing for video and audio recordings

If you sign below, video and audio recording will be used while you interact with the menu system through the VR equipment. You will only be recorded when you wear the VR equipment that obscures your face, meaning that your identity will still be kept confidential.

I give permission to be video and audio recorded while I interact with the menu system through the VR equipment.

Participant's signature: ____________________________

If you sign below, audio recording will also be used during the interview.

Participant's signature: ____________________________

Thank you very much for your participation!

Appendix B – Questionnaire

Experience with Video Games and Virtual Reality

This study is about creating a menu system for Virtual Reality that makes use of the ability to be aware of objects around the human body. People who have past experiences in virtual environments (e.g. video games) are not overwhelmed by virtual reality as it is somewhat familiar to past experiences.

To understand your experience with the menu system developed for this study, some information is needed about your past experience with virtual environments. There are 8-15 questions in this questionnaire depending on your answers.

Please note that all data collected for this study will be kept confidential. You will be required to provide an alias for yourself so that your data can be kept together. All data will only be used for the purpose of this study and will only be accessible by the researcher and the supervisor.

This study is conducted by the Department of Information Science
Researcher: Kwan Sui Dave Ka
Supervisor: Prof. TJD Bothma
Co-supervisor: Mr. IDV Bosman

If there are any issues or questions, please feel free to contact the researcher at dave.ka@up.ac.za

*Required

1. By answering this questionnaire, I give permission for my data to be used according to the above stated conditions. *

   Mark only one oval.

   ◯ Yes
   ◯ No

2. Please give yourself an alias: *

   This is a fake name that the researcher will use to keep all your data together.

   ____

Gaming

The following questions are about your experience with video games.

3. Do you enjoy playing video games? *

This is inclusive of all platforms (e.g. mobile, computer, consoles)

Mark only one oval.

- Yes
- No

4. How often do you play video games? *

Mark only one oval.

- Daily
- Weekly
- Twice a month
- Once a month
- Other: ______________________

5. On average, how long do your gaming sessions last? *

Mark only one oval.

- Under 30 minutes
- Under 1 hour
- 1 - 3 hours
- More than 3 hours

6. Have you ever developed or designed a video game? *

Mark only one oval.

- Yes
- No

Virtual Reality

The following questions are about your experience in Virtual Reality. If you are not sure what Virtual Reality is, please watch the following YouTube Video.

What it feels like to be in Virtual Reality (YouTube video)

http://youtube.com/watch?v=TckgNdrdbgk

Example of a head mounted display

7. Have you ever experienced any form of Virtual Reality that uses a head mounted display (see example image above)? *

Mark only one oval.

- Yes
- No

Virtual Reality (cont.)

The following is a continuation of the questions regarding your experience with Virtual Reality. If you have not had any experience with Virtual Reality, please go back to the previous section and select "No" as your answer.

8. How many times have you experienced Virtual Reality?

Mark only one oval.

- Once
- A couple of times
- I have a lot of experience with Virtual Reality

9. In total, how much time have you spent in Virtual Reality?

Mark only one oval.

- Less than 30 minutes
- About 1 hour
- A few hours
- Other: ____________________

10. What is your general impression about Virtual Reality? *

Mark only one oval.

I don't like it at all

1

2

3

4

5

I really enjoy it

11. What attributes of Virtual Reality made you enjoy your experience? *

(e.g. graphics, immersive experience, controls, ease of equipment usage, others)

____

____

____

____

____

12. What attributes of Virtual Reality made you dislike your experience? *
(e.g. graphics, immersive experience, controls, difficulty of equipment usage, others)

____

____

____

____

____

13. Have you ever developed or designed a Virtual Reality experience? *

Mark only one oval.

- Yes
- No

Appendix C – Interview questions

(At this point video and screen recordings were stopped and audio recording began.)

VE experience

- How was your overall experience with the virtual environment in this session?

Navigation and layout

- Did you find the placements of the menu items to be logical?
- What was your experience when working through each menu item?
- Other comments?

Selection

In reach

- Were the menu items comfortably in reach?
- Did you use your dominant or non-dominant hand? Which one did you use for certain tools?

Representation

- What indicated to you that you touched something?
- Was the function of the tools obvious when you first saw them?
- What about after using them?

Visibility

- Was the state of the menu changing from a menu to a submenu clear?

Error recovery

- Was it easy or difficult to fix your selection if you mistakenly selected something?
- Was there anything that makes you blame the system for an incorrect selection?

Easy to become familiar

- Did you find the menu system easy to become familiar with?
- Do you think that your past experience with VEs (or lack thereof) contributed to you finding the menu system familiar/unfamiliar to you?

Comfort and fatigue

- Would you say that this menu system would cause more/less/equal amounts of fatigue compared to other VR interactions you've used before?

Eyes-off interaction

- Did you always look directly at the menu items when you were selecting them?
- Were there any menu items that you had to focus on more than others when selecting these menu items?

Appendix D – Focus group questions

(Questions labelled "extra" were only asked if there was still time in the session. The focus group sessions started with an explanation of the fact that this menu system design drew inspiration from a utility belt and that utility belts provide quick access to useful tools without always looking.)

1. Which part of the menu system did you enjoy using the most and why?

2. Some people pointed out that grabbing the measuring tape was difficult to perform.
    a. What are your opinions about this?

3. Some people found the vibrations to be annoying when they were just moving their hands around. It felt like they did something wrong or it just kept buzzing.
    a. How do you feel about this?
    b. Extra: buzzing due to gaming controller experience.

4. Some people would move the belt menu to a specific position and leave it there for the whole session. But others moved the belt menu more than once to adjust the positioning for specific subtasks.
    a. What are everyone's thoughts on this?

5. Some people would position the belt menu so that it was always visible. How do you feel about that (Extra: potential for HUD)?

6. Some people mentioned that the menu items would block their view of the size labels.

   a. What changes would you make to the menu system to deal with this issue?

7. The purpose of putting some menu items (e.g. measuring tape) out of direct eyesight was to see if you would try to select them without looking.
   a. Did any of you try to select menu items without looking at them?
   b. If so, what did you rely on to do so (e.g. vibrations, shadow, gesture/waving based on position remembered)?
   c. Did you try to apply the tools to the blocks without looking (e.g. painting the block)?
   d. Do you think that it would be easier to select from the various submenus if "dipping" was used instead (i.e., holding the block and dipping them into different buckets of paint)?

8. If there were one or more aspect(s) of the menu system that you could change:
   a. what would it be
   b. and why?

9. <u>Extra</u>: Some people mentioned that they would want to customize the placement of menu items.
   a. Is there anything else that you would want to be customizable?
   b. If so, how would you want it to be done?

10. Do you think that this kind of menu system is a feasible solution to be used in immersive 3D virtual environments?

11. <u>Extra</u>: Was there any aspect of the task (placing blocks correctly into boxes) that you struggled with that was not caused by the menu system?

12. <u>Extra</u>: For those who have experience with any other VR equipment (e.g. Oculus Rift), how transferable do you think this kind of menu system is to other VR equipment?