DEGREE PROJECT IN INFORMATION AND COMMUNICATION TECHNOLOGY
SECOND CYCLE, 30 CREDITS
STOCKHOLM, SWEDEN 2020

Exploring the effect of using vibrate-type haptic glove in the VR industrial training task

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Abstract

Is it a dream came true for you to experience a Virtual Reality (VR) and be able to touch virtual objects and manipulate them with your bare hands? The recent growth of the Virtual Reality market resulted in an intensification of the development of the haptics gloves technology. The newly haptics gloves, Bebop gloves launched and commercialized recently which will use for this study. Earlier research has explored a range of haptics effects mainly on VR surgery or gaming. Yet, VR industrial training has gradually received attention in recent years. Creating multiple scenarios in the virtual scene is not only cost-effective but also increases safety and reduces training time. However, not many research studies have explored using haptic gloves in the VR industrial training environment. This study tries to complement earlier research by investigating usability and user performance using bebop vibration gloves in VR industrial training. The purposes were to provide a usability review of bebop gloves and explored the effect of haptics in VR industrial training. Three different haptics settings (Non-haptics, Partial haptics, and Full-haptics) were being set up. Eighteen users were then recruited to try randomly two haptics settings. Each user had to complete a five steps VR industrial training task while "thinking aloud", followed by questionnaires and interviews after the task. The error and time recorded for each training step. These results confirmed several conclusions drawn in earlier research about how the haptics affect user performance in the VR environment, as well as how the behavior changes when using the haptics gloves in a VR environment. Last but not least the results also pointed to the importance of vibration haptics benefits in small-scale actions and provide the user with an interpersonal confirmation.

Keywords

Virtual Reality, Haptic Gloves, Virtual Reality Industrial Training, Bebop gloves

Abstract

Är det en dröm som förverkligades för dig att uppleva en virtuell verklighet (VR) och kunna röra virtuella objekt och manipulera dem med bara händer? Den senaste tillväxten av marknaden för Virtual Reality resulterade i en intensifiering av utvecklingen av haptikhandskar-tekniken. De nyligen haptiska handskarna, Bebop-handskar lanserade och kommersialiserades nyligen som kommer att användas för denna studie. Tidigare forskning har undersökt en rad haptiska effekter främst på VR-kirurgi eller spel. Ändå har VR-industriell utbildning gradvis fått uppmärksamhet under de senaste åren. Att skapa flera scenarier i den virtuella scenen är inte bara kostnadseffektivt utan ökar också säkerheten och minskar tiden. Men inte många forskningsstudier har undersökt användning av haptiska handskar i VR: s industriella utbildningsmiljö. Denna studie försöker komplettera tidigare forskning genom att undersöka användbarhet och användarprestanda med hjälp av bebop-vibrationshandskar i VR-industriutbildning. Syftena var att tillhandahålla en användbarhetsgranskning av bebop-handskar och utforska effekten av haptik i VR-industriutbildningen. Tre olika haptikinställningar (Non-haptics, Partial haptics och Full-haptics) inställdes. Atten användare rekryterades sedan för att testa slumpmässigt två haptikinställningar. Varje användare måste genomföra en femstegs VR-industriell träningsuppgift medan han ”tänker högt”, följt av frågeformulär och intervjuer efter uppgiften. Felet och tiden som registrerats för varje träningssteg. Dessa resultat bekräftade flera slutsatser som dragits i tidigare forskning om hur haptiken påverkar användarnas prestanda i VR-miljön, liksom hur beteendet förändras när man använder haptikhandskarna i en VR-miljö. Sist men inte minst pekade resultaten också på vikten av fördelar med vibrationshaptik i småskaliga åtgärder och ger användaren en interpersonell bekräftelse.

Nyckelord

Virtuell verklighet, Haptiska handskar, Industriell utbildning för virtuell verklighet, Bebop-handskar

Acknowledgements

I would like to thank Kai Hübner for giving me the opportunity to work on this project in Gleechi. It was an amazing experience working with you and I learned a lot about VR training and VR development. Also, thanks to the Gleechi family for all the support and gave me valuable feedback. I would like to thank Anders Lundström for guiding me through the thesis work and giving me the warm support in the COVID-19 quarantine period. EIT Digital, the University of Twente, and KTH, also deserve a huge thank you for providing me professional knowledge to complete my thesis work. Lastly, thank you examiner Ylva Fernaeus for reviewing my work and Chin-Yu Lai for all the support along the way.

Contents

Chapter 1

Introduction

Virtual Reality (VR) created the three dimensional (3D) immerse experience to allow the user to explore the new world. The main purpose of VR is to provide the user with an illusion that they are somewhere else, confusing the user's sense to feel and believe they are truly in the virtual environment. In recent years the VR and supportive technology have been developed and already commercialized worldwide. Several main VR companies are providing supportive software and hardware such as the HTC Vive, the Oculus Rift, Google, etc and the VR devices sales increased steadily. The companies provide controllers to allow users to manipulate in the VR environment, however, only in the recent year the haptic gloves start commercializing in the market to let the user use a hand shaped glove to manipulate virtual objects. With the intuitive haptic gloves, the new possibility of adding different types of haptics in actions in the virtual world could be carried out.

The research of adding force-feedback and haptics in systems or devices can be found as early as the 1980s (Lederman, S. J., & Klatzky, R. L., 1987), but this research area started to take shape in the 2000s. The relative research of evaluating adding haptics, or sound can be found in the Burdea, G. C. (2000) and Dinh et al. (1999), where they presented the experiment framework of adding force-feedback, haptics in the system or virtual environment. The problem of using haptic gloves in the VR environment has been the multitude of hardware setup, making it hard for researchers to conclude that using haptic gloves or adding haptic feedback benefits the user in the VR environment. However, the work of Hutmacher, F., & Kuhbandner, C (2018) found that the sense of touch can enhance one's memorization and effects linger in the brain long after the sensory experience ends, and often without being directly aware of it. Therefore, where to add the haptics in the VR environment and how using haptic gloves can enhance user performance are worth diving into.

Many studies support the idea that haptic feedback should be implemented onto VR simulators (Tholey, G., Desai, J. P., & Castellanos, A. E., 2005; Lamata, P., et al, 2006). Various forms of haptic feedback can only be felt up to four or five different intensities - important information for simulator calibration (Tholey, G., Desai, J. P., & Castellanos, A. E., 2005). Some results suggest that the addition of haptic feedback in an early training phase may enhance the trainee's performance, by enhancing the trainee's sensory perception capabilities and thus facilitating transfer of skill from simulation to the operating room (Ström, P., et al., 2006; Lamata, P., et al, 2006; Kim, Hyun K., David W. Rattner, & Mandayam A., 2003). Furthermore, the addition of haptics reduces surgical errors resulting from a lack of it, especially in knot tying, and is important during the early phase of psychomotor skill acquisition. (Van der Meijden, O. A., & Schijven, M. P., 2009). From the technical perspective, virtual reality haptic programming requires good physical modeling of user interactions, primarily through collision detection, and of object responses, such as hard-contact simulation, slippage, surface deformation, etc. (Burdea, G. C., 2000).

Currently, study results indicative for a positive value of using haptic gloves in VR simulation are blur. Many conclusions on the subject are drawn from study results primarily based on the possible importance of haptic feedback in minimally invasive surgery (MIS), not so much in VR training (Van der Meijden, O. A., & Schijven, M. P., 2009; Tholey, G., Desai, J. P., & Castellanos, A. E., 2005; Wilson, M. S., et al., 1997). Only a few haptic systems have been developed to fit into immersive environments (Loscos et al. 2006; Dettori et al. 2003).

In this study, to complement and extend this existing base of knowledge, we will explore the effect of haptic feedback using Bebop gloves (`https://bebopsensors.com/`), in the VR industry training environment. In the pilot study, adding haptics feedback to different actions, which most commonly appear in industrial training, to understand how adding haptics to different actions affect the user's behavior and user experience. Based on the result of pilot study, in the main experiment, we use the VR industrial training scenario, which is based on the real-case training system created by VR training company Gleechi for Scania company. Adding different vibrate-type haptic settings to observe whether or not the haptics feedback, using Bebop gloves, enhances the user performance, usability, and experience. The hardware we used will consist of Oculus Quest, Bebop gloves, and Oculus controller. At the end of the experiment, we will answer the questions related to what kind of actions adding haptic feedback, created by Bebop haptic gloves, can mostly enhance user experience in the VR industrial training system. And how haptic feedback, created by bebop haptic gloves, can enhance user performance in a VR industrial training environment.

1.1 Research Question

The overall objective of this study can be formulated in the following research questions:

- What kind of action adding haptic feedback, created by Bebop gloves, can mostly enhance user experience in a VR industrial training system?
- How different vibrate-type haptic settings, created by Bebop gloves, affect the user's performance in a VR industrial training system?

The purpose of answering these questions is to extend upon the existing knowledge about interactions within VR training and haptics feedback, providing new knowledge in the form of:

- Evaluating the usability of Bebop gloves and manipulation from a qualitative perspective.
- Using a real-case VR training scenario.
- Creating different haptics settings for different actions in the training task.

1.2 Ethical Aspects

A VR experience that has a lacking purpose framework or the software is badly designed can cause the user to feel dizzy and uncomfortable. The wrong design of the haptic feedback might also be confused in the VR environment. To minimize the potential risk of making test users feel uncomfortable, the experienced experts available at Gleechi AB will be incorporated into the experiment both in the pilot study and our main experiment to pretest the VR environment before testing. A well designed VR experience can also cause the test subjects to feel uncomfortable if the test scenario contains violence, annoying background, or disturbing elements being carried out in the 3D immersive environment which will make a large difference when appearing in the 2D environment. Therefore, the offensive elements that need to be handled carefully in the test scenario design, will once again be ensured by the experienced experts at Gleechi AB.

To make sure that the test subjects feel entirely comfortable in the VR test scenario participation will be completely voluntary and the test subjects will also have the right to abort their participation at any time in the testing experiment. Before the test, we will let the test subjects sign the consent form and all the personal data will be kept confidential under the whole study, and after the end of the research, the data will be disposed of. Test subjects will be anonymous throughout the entire study process.

Due to the COVID-19 outbreak, the recruiting process for testers, especially above 40 years old, was extremely hard since the experiment requires the participants to wear both the haptics gloves and VR headset. To prevent the potential infection among the risk groups and the way to the testing location, we aimed to find the participants who live inside the KTH campus and took care of the improved hygiene of the equipment. In this case, the participants' backgrounds were similar to each other and more familiar with the VR environment.

Chapter 2

Background

In this background section, we start with introducing the general information of virtual reality, application and related research and then explore the area of haptics in virtual reality, its application and related research of interaction with haptics. Lastly, provide the information of User-Centered Design (UCD) method. This section aims to provide information about previous studies, existing applications, and future challenges.

2.1 Virtual Reality

Today's virtual reality technologies are based on the ideas that trace back to the 1800s, which was almost the very beginning of practical photography. The stereoscope which uses twin mirrors to project the single image was invented in 1838. The technology eventually developed into the View Master (Gass, J. D. M., 1970). The term "Virtual Reality", was first used in the mid-1980s by the founder of VPL research, Jason Lanier, when he began to develop the gear.

Before that, some technologists were developing simulated environments and one of the milestones was called Sensorama, which simulated a real city environment, and took you through the city view by motorcycle (Heilig, M. L., 1962). Multi-sensory stimulation can let you window shopping, hear engine, see the road and smell the food in the "virtual world". With ideas of adding layers of sensory stimuli to augment a cinema presentation, allowing people to experience virtual reality nowadays.

By 1965, the paper "the Ultimate display" by Ivan Sutherland, offered a head-mounted device that serves as a platform to "window into a virtual world". To address all human senses in VR correctly, thus reaching the vision of an ultimate display presented by Sutherland (1965) hardware and software have to evolve further. By 1985, the VPL Research center was founded by Jaron Lanier and Thomas Zimmerman. The VPL research center is the first-ever VR company to sell controllers and HMDs. By 1989, NASA started to study the potential of VR and wanted to use it to train astronauts in the virtual world. The project "VIEW" which runs the VR simulation, is the most recognizable example of combining the VR and training, and also created the touch interaction in the simulation. By 1992, with the help of the movie Lawnmower Man, the concept of virtual reality reached out to a larger public audience. Before 2012, the hype surrounding the product's high immerse 3D environment can hardly be produced due to the current technology restrict. After that, the invention of Oculus Rift HMD starts the first step toward a new generation of VR technology.

2.1.1 Application of Virtual Reality

Virtual reality can apply to a wide range of industries and purposes. VR technology creates a 3D immersive environment to stimulate different scenarios and scenes, which is much valuable to apply to various purposes, for example in rehabilitation (Schultheis, M. T., & Rizzo, A. A., 2001), education (Bell, J. T., & Fogler, H. S., 1995) or biology demonstration (Shim, Kew-Cheol, et al., 2003). Implementing VR technology can prevent potential injury in the extreme workplace by safety training in the virtual world (Schwebel, D. C., Gaines, J., & Severson, J., 2008) or improve the error reduction or training performance in operating room (Seymour, Neal E., et al., 2002). With the improvement of VR hardware and software, there already existed applications in the real world, some examples of these are:

- **Training and stimulation** related to surgical or industrial training. VR can stimulate different use scenarios which are costly to make, and can switch to different scenes without physically moving to the places especially when we have a large amount of people involved. More industrial companies would like to try using VR technology in their training system to prevent injury and enhance performance in future work, such as in mining industry (Van Wyk, E., & De Villiers, R.,2009) and Construction off-site production (Goulding, Jack, et al., 2012)

- **Visualisation and virtual experience** in the fashion and music industry. By allowing the people to equip VR devices in their home, they can experience the 3D immerse fashion show or concert right at their home instead of flying a long distance to experience the show. With VR technology, building the virtual fashion store is not a dream, allowing the people to browse the entire store without going out. (Lau, K. W., & Lee, P. Y., 2016)

- **The VR gaming industry** was a major factor when developing VR technology in the 1990s, but today VR gaming is a main engine to push the VR industry forward. VR Gaming not only can be an entertainment but also be applied into the educational use (Virvou, Maria, et al., 2002) such as improving walking performance in robotic assisted gait training for children (Brütsch, Karin, et al., 2010). With a high amount of demanding and supportive software created, the VR application sales started to climb steadily.

2.1.2 Interaction in Virtual Reality

A well-made immerse VR experience created the same interaction in the real world, allowing the user to explore the digital world with whole-body movement. For the current VR technology, it is still hard to completely duplicate exact the same detail as in the real world; however, some options might be adding different sense to immerse VR environment to improve user experience (Dinh, Huong Q., et al., 1999) or producing a sense of presence, or ”being there” in the user’s mind (Bowman, D. A., & McMahan, R. P., 2007). Furthermore, designing the highly immersive interaction in VR is hard because different components are affecting the results. Building on the work of Bowman, D. A., & McMahan, R. P., (2007) listed the components that need to be considered to create a visual immersion. The lists are as following:

- Field of view (FOV): the size of the visual field or visual angel that can be viewed instantaneously.
- Field of regard (FOR): the total size of the visual field that surrounds the user.
- Display size: the display you use for the users.
- Stereoscopy: the display technique for creating the illusion of additional depth cue.
- Head-based rendering: the display of an image which is based on the user’s physical position and orientation of the head.

- The physical light position.
- Frame rate.
- Refresh rate.

The list shows that both the hardware and software play an important role in creating a high level of immersion. Similar research can also be found in another work of Mcmahan, R. P., & Bowman, D. A. (2007), which however put more focus on the empirical aspects.

Instead of focusing on the factors affecting the level of immersion, many research put the focus on the challenges in commercializing the virtual reality hardware and software to the general public (Barnes, S., 2016; Lui, T. W., Piccoli, G., & Ives, B., 2007). The potential challenges in virtual reality are as follows.

- Simulator sickness: many research studies simulator sickness by design different virtual reality environments (Mourant, R. R., & Thattacherry, T. R., 2000; Hettinger, L. J., & Riccio, G. E., 1992; Häkkinen, Jukka, et al., 2006). The motion sickness can occur when there are inconsistent signals between the inner ear's vestibular which sense of motion and what the eyes are seeing.

- The screen-door effect: for some smartphone-powered virtual reality headsets, there is a line in between the displayed pixels to experience the virtual reality. However, not all smartphones are designed to be used as a virtual reality machine. Some research tries to investigate the methods to understand and solve the screen-door effect (Cho, Joung-min, et al., 2017; Sitter, Brett, et al., 2017).

- Movement in virtual reality: moving through in the digital world is still an issue. For some advanced headsets, such as Oculus Rift or Vive which can detect the user's room and if the user gets too close to the wall, the headset can alert the user. However, some VR software systems still require the user to have enough space to move around in order to stimulate the real-world scenario. Wide range to movements have been studied, such as tracking legs movement (Crane, Christopher Adam, et al., 2000), or head movement (Jaekl, Philip M., et al., 2002)

2.2 Haptic in Virtual Reality

The haptic technology can also be known as kinaesthetic communication or 3D touch, which refers to any technology that creates the touch experience by providing the vibration, force-feedback, motions to the user. These technologies can add to virtual objects in computer stimulation to control objects and improve the remote control of robots or machines (Vokrot, P., Peine, W., & Blanco, M., 2019). Haptic devices may include different sensors, e.g. tactile sensors, vibration sensors to measure force or create haptics to the user on the interfaces. The purpose of haptic technology is to facilitate the human senses of touch in the virtual object, allowing us to simulate the real-world scenario. Haptics does not refer to a singular sensory apparatus and also can be recognized to be composed of several sensors and motor elements though there is a degree of overlap among the tactile, force-feedback and preoperative elements (Dinh et al. 1999)

There are some components involved in the system to allow the haptics system to work. It required at least sensors, actuators (Motors), actuator contort system (Microprocessor), haptic software, and user interfaces (Application programming interface). The process of the haptics system work is as follows: When the micro-controller receives the input and then delivers to the mediator called driver, and the diver passes the signal to the actuator to activate the haptic feedback or start vibration. The haptic vibration is controlled by the microprocessor and it's embedded software system.

Haptics make use of actuators to apply forces to skin or interfaces for controller and touch feedback. The first mechanical force feedback master-slave manipulator was developed in Argonne National Laboratory by Raymond Goertz in 1948. The master arm is the early prototype for today's haptic display. Due to the steady improvement of the computing system, the haptics display evolved accordingly. However, the small number of sensations and the independent controller of vibrates limit the haptics technology (Díaz, I., & Gil, J. J., 2009). Around the 2000s, with the lower cost of believable sensory stimuli, haptic technology has appeared to be a huge enhancement and become commercially available within different firms and the general public. In the 2010s, the haptics came about just when head-mounted displays (HMD) commercialized in the market. The HMD created the virtual work, and the haptics feedback gave the people to feel and touch experience in the virtual world. Apart from the virtual reality environment, haptics feedback is already in wide use in the mobile, personal computer, robots, etc.

2.2.1 Application of Haptics in Virtual Reality

VR haptics technology is now growing beyond only creating the vibration in controllers. In the near future, you can experience the touch of holding the cup or feel the tactileness of clothes. The most recent example is in the movie "Ready player one" based on the sci-fi novel. It described the possibility of VR haptic technology in the future. In the movie, the main character explores the virtual reality game using a headset and whole-body haptic suit. All the haptic feedback he experienced in the virtual world will reflect on the suit, which provides a highly immersive experience. The VR haptic technology is now implemented in the wide range of purposes, e.g. enhanced organic chemistry instruction (Edwards, Bosede Iyiade, et al., 2019), cardiopulmonary resuscitation training (Almousa, Omamah, et al., 2019), basic piano education (Pala, F. K., & Türker, P. M.,2019), or surgical robot systems (Park, K. C., 2019). With the improvement of VR haptics technology hardware and software, there already existed applications in the real world, some examples of these are:

- **Training and simulation** related to surgical, educational and industrial training. With adding haptic feedback in VR, can reduce surgical errors, psychomotor skill acquisition (Van der Meijden, O. A., & Schijven, M. P., 2009), and performs better compared to visual feedback only (Kreimeier, Julian, et al., 2019). The benefit of adding a sense of touch in VR environment creating the deeper immersive experience and enhance the user experience in different ways, even though study results indicative for a positive value of haptic feedback in VR simulation are low (Van der Meijden, O. A., & Schijven, M. P., 2009; Tholey, G., Desai, J. P., & Castellanos, A. E., 2005; Wilson, M. S., et al., 1997). The haptics in VR still has high potential in future development in the training area.

- **The VR gaming industry** plays an important role in applying the haptics to create a deeper immerse environment for users. Haptics feedback can be applied in the different types of games, e.g. shooting, sport, car racing, etc. For example, in the car racing game, players might receive vibrations in their steering wheels as they drive through a rough road. As Chang, D. (2002) mention the haptic technology will become an integral part of the game design process and require creative planning to take full advantage of this bi-directional modality.

- **Visualization and virtual experience** in the fashion industry - By adding haptics to create the illusion in the VR, the user can feel the tactile or fabric of the clothes in the 3D immersive environment and do not need to go into the stores. Furthermore, the fashion companies can cut costs due to VR haptics technology, remotely monitor the development of new tactile or fabric prototypes. For the customer, they can try on the new clothes and feel tactile in the 3D immersive environment at any time of the day. As the Flosdorff, M., Döring, M., & da Silva Wagner, T. (2019) indicates the potential of Virtual Reality in the product development for the fashion industry and showing major opportunities at different stages of the product development process.

2.2.2 Interaction of Haptic Gloves in Virtual Reality

Previous research has shown that haptics also might cause negative effects, such as being uncomfortable over a long period of usage (Okamoto, S., Konyo, M., & Tadokoro, S., 2011), and little is known about the optimal and most realistic type of haptic feedback to be implemented into VR simulators (Van der Meijden, O. A., & Schijven, M. P., 2009). Furthermore, Chamarra et al. (2008) warn about a negative learning effect that may occur when performing tasks were pulling and pushing forces to play a major role in surgical task outcomes. However, compared with the traditional use of only visual feedback, a combination of haptic and visual feedback improves training accuracy, fastens task completion times, and decreases the number of errors in the surgery environment (Jacobs, Stephan, et al, 2007).

Some research using a glove to creating illusionary touch feedback in the virtual reality (Bickmann, Raoul, et al., 2019; Pala, F. K., & Türker, P. M., 2019; Popescu, V., Burdea, G., & Bouzit, M., 1999). As Bickmann, Raoul, et al., (2019) mention high usability of haptic illusion gloves when grasping a cup, a hammer, and a water can, studying how the grasping different virtual objects with touch feedback affect users. Building on the work of Shor, Daniel, et al. (2019) focus on design factors of haptics interfaces glove. The facts list as following:

- Realism: the user's ability to experience the force feedback without distraction based on the level of immersion experienced by the user. A realistic product should also maximize the realism of haptic feedback curses. The use case haptics in the virtual world should be as much the same as possible in the real-world scenario to enhance the immersive experience.

- Performance: the performance in the study is defined as the durability, stability, and repeatability of a glove. For the high-level performance glove can be donned and doffed without issues and repeated recalibration. The gloves should be able to be calibrated for each user, perform the same as the user movement and fit the well to the user's hand.
- Comfort: the comfort of the glove is the user's ability to put on and keep on the glove for a period of time. A comfortable glove is also adjustable, fitting different sizes, lightweight, and non-disruptive for the user.

Instead of focusing on the haptics gloves, some research put the focus on how haptics in virtual reality can improve the task-based performance (Kreimeier, Julian, et al., 2019) or perceive the size of a virtual object (Park, J., Han, I., & Lee, W., 2019). Building on the work of Kreimeier, Julian, et al., (2019), the results list as follows:

- Haptic feedback performs better than visual feedback only: This result is also supported by the work of Jacobs, Stephan, et al. (2007), who mentions that a combination of haptic and visual feedback improves training accuracy in telemanipulator-assisted surgery. The addition of haptics can also reduce surgical errors resulting from a lack of it (Van der Meijden, O. A., & Schijven, M. P., 2009)
- Significantly lowered the execution time for throwing and stacking tasks: building on the work of Jacobs, Stephan, et al. (2007) indicate adding haptics in the virtual reality can fasten task completion times in virtual surgery training environment.

Even though the technology is not yet in the consumer level, still provide a strong indication of connection between presence, task fulfillment and the type of haptic feedback (Kreimeier, Julian, et al., 2019)

2.3 User-Centered Design (UCD) Method

User-centered design (UCD) is an iterative design process, which focuses on the users and their needs on each development process. Vredenburg (1994, 1999) identified a core set of practical methods and techniques for UCD; however, only got attention until Rosenhaum et al. (2000) and Hudson (2000), used an informal survey of UCD to collect the data. The result found that informal and less structured methods tend to be used much more widely than more formal and structured methods. The previous surveys have produced valuable insights into the UCD practice, with different aims and purposes. Also, as Dinka & Lundberg (2007) mention, in the development of a product, collecting user experience must be part of a UCD methodology. Data collection involving this methodology usually depends on questionnaire-based tools, such as surveys or interviews. Our study aims to use an informal survey including different types of questionnaires, with a follow-up interview to collect the user's quantity and quality data. Aim to understand the user experience and measure task performance after the VR training testing.

Chapter 3

Implementation Overview

In the implementation section, to be able to test a VR training scenario as close to a real end-user experience, a scene from a real VR training environment, initially developed for the Scania Company by Gleechi AB, was chosen to serve as the base of the implemented scenario. Along with introducing the industrial actions in the Scania demo. Lasty, this section ends with introducing VR hardware and software used in this study.

3.1 Choice of Industrial Actions

This study aimed to explore the effect of haptic feedback using vibrate-type haptic gloves (Bebop globes) in the VR industrial training environment. There were different actions in the VR industrial training environment and based on Gleechi's experience in developing the VR industrial training, summarise the most common user actions in the previous work of VR training scenario. The total actions were list below:

- Press button
- Grab (Hold) object
- Touch object
- Push object
- Rotate / Spin object
- Clash Object (Collision) object

- Lift Objects with two hands

The experiment chose the actions most close to the end-user scenario and the most common usage in the industrial training system.

3.2 Experiment Environment - Scania Demo

The experiment training demo was built for the Scania company, aiming to simulate the car assembly. There were a total of five training steps. The first step was pressing the start button to start training. The second step was installing a plastic washer, which grabs the plastic washer to the right place and pushes it into a specific position. The third step is placing the seat bracket, grabbing the seat bracket and putting it to the specific place. The fourth step is placing the seat, in this step, grabbing the seat with two hands, put it to the right position and push down the seat. The last step is installing the seat screw, which grabs the screw and puts it to the right place and then rotates the screw to a certain angle. The Scania demo environment includes a lot of different industrial training actions, such as grabbing, pushing, pressing, touching, lifting, and rotating. Therefore, choosing this Scania training system matches the aims of this study and experiment framework. See in figure 3.2.1.

Figure 3.2.1: Scania VR training environment

3.3 Tools

In this section a short description of the key hardware and software tools used throughout the study is described.

3.3.1 Unity

Unity is a cross-platform engine developed for games and interaction experience which include a wide range of supportive hardware systems, such as using the mobile phone (Samsung Gear VR) or Oculus Quest which is used in this study (Unity, 2019). Unity is most commonly coded with C# or Javascript and in this study was solely program in C#.

3.3.2 Bebop Glove

Bebop glove is wireless, vibrate-type, and all-in-one size gloves and combines with Oculus Quest to provide the complete VR headset/data glove solutions which fit into small bag sizes easily to transport. The bebop glove can allow people to have a realistic experience when touching objects, feeling clothes textile, or pressing the button, and aims to provide an accurate immerse experience. The Bebop glove takes workplace training to the next level by stimulating hand movement and providing haptic feedback to help you create the most intuitive and immersive VR training experience for skilled workers. The sensor which creates the vibration is in the five fingertips and the palm, see in figure 3.3.1. Bebop sensors had applied to many different purposes, for example, sensing pressure on contoured surfaces, gesture recognition capabilities, correlating the insole sensor's reported output to weight, deploying the steering wheel sensor in an armrest. Bebop gloves are commercialized at the end of 2019, the hardware is still in the iterating process, which includes some usability problems, e.g. all-in-one size issues, sensor sensitivity issues.

3.3.3 Oculus Quest

The VR set: headgear, controllers, for calibration, are all part of the Oculus Quest VR set (See in figure 3.3.2). The Oculus Quest uses two diamond Pentile OLED displays, each with an individual resolution of 1440 × 1600 and a refresh rate of 72 Hz. The visual artifacts such as god rays are less prominent but still visible in scenes with high

Figure 3.3.1: Bebop gloves (`https://bebopsensors.com/`) with six sensors on five fingertips and palm. Picture originally from Courtesy BeBop Sensors Thomas PR.

contrast. The device is fully standalone, features two, six degrees of freedom (6DOF) controllers, and runs on a Qualcomm Snapdragon 835 system on a chip. The Oculus Quest features the inside-out tracking system which relies on four wide-angle cameras located on each corner of the headset to spatially track the headset. The Quest's headband features built-in headphones, with two 3.5 mm audio jacks embedded in the headset, allowing the user to use external headphones. The controllers tracking ring of Quest moved to the top of the controller, enabling the rings visible to the tracking cameras in the headset.

Figure 3.3.2: Oculus Quest and Controller. Picture originally from Oculus website (`https://www.oculus.com/`)

Chapter 4

Methods

In this section, we evaluate using Bebop gloves with vibration feedback affecting the user performance and user experience in the VR industrial training environment. The content can be split into three phases: 1) preparation for the user tests, 2) explaining the user test plan, and 3) introducing the experiment procedure, participants, and questionnaires of the pilot study and main experiment. Each phase is detailed in the following sections.

4.1 Preparation for User Tests

In this within-subject study, the purpose is to measure the user performance in different haptics settings: the number of errors in each step, the time taken to finish the VR training process in each step. The aim was to compare the same environment with three different haptics settings. There were two independent variables; training steps, and action haptics setting. The training set has five steps: press the start button, install the plastic washer, place the seat bracket, place the seat, and lastly install the seat screw. Action haptics settings had three levels: non-haptics, partial-haptics, full-haptics. The dependent variables were the number of errors and the time it took to complete the VR training task. The amount of time will be measured for each step and total completion time. Three questionnaires were handed out to all the participants. The first questionnaire was given before the start of the experiment, to collect the participant's background information. The other two of the questionnaires were given at the end of the experiment and measure the user experience regarding haptics.

4.2 Test Plan

The user studies conducted in this experiment have followed the guidelines, as the test plan structured below, provided by Rubin & Chisnell (2008), including on how user studies should be prepared, executed and analyzed. In the preparation for user tests the following tasks had to be completed:

Establish a Test plan

- Including:
  - Determine end-users (participants)
  - An introduction script
  - A consent form
  - A background questionnaire
  - Tasks
  - Post-questionnaire
  - Data to be gathered
  - How data should be analysed
- Initial Pilot tests

In the following two experiment subsections the design of the test plan, procedure and questionnaire will be detailed, along with the changes based on the initial pilot test.

4.3 Pilot Study - Action Haptics Experiment

The action haptics experiment aimed to understand which actions are more suitable adding vibrate-type haptic feedback compared to non-haptics. The purpose was to get a general review of how people's reactions and expectations of vibrate-type feedback when conducting different actions. There were a total of two settings, with haptics and without haptics. The results, actions which are most suitable to add the haptics, will be used for partial-haptics setting in the main experiment.

4.3.1 Participants

Participants were asked to participate in a virtual reality experiment that would take about 20 minutes. A total of 15 (N=15) participants were recruited with an age range of 23 to 45 years old, with an average age of 30.5 years. Participants were required to have had previous knowledge and experience with new technology. Gender distribution with 6 of participants being female and 9 participants being male.

4.3.2 Choice of Industrial Actions

Action haptics experiment aims to understand which actions are more suitable adding vibrate-type haptic feedback compared to non-haptics. This experiment total tested 6 most common actions in industrial training. The actions were list below:

- Press button
- Grab (Hold) object
- Touch object
- Rotate / Spin object
- Clash Object (Collision) object
- Lift Objects with two hands

The experiment chose the actions most close to the end-user scenario and the most common usage in the industrial training system.

4.3.3 Procedure

The instructions included what to expect and that they were assigned some tasks to finish. They were also told that they would try two different experiment settings, with no information regarding the difference between them.

Once instructed, the participant then put on the Oculus Quest, bebop gloves and "stepped into" the virtual reality environment where they could see a room with a table of many different tools and buttons (see in figure 4.3.1). And then assigned different tasks to the participants. The task lists were as follows:

- Grab three different tools.

- Press the Reset button multiple times.
- Touch three different objects.
- Grab the Mask and hit something else multiple times.
- Rotate the switch multiple times.
- Lift the chair with both hands.
- Press the switch button.

After they finish the tasks, they will be asked to press one button switching to another setting. And then assigned the same tasks as before. When they finished two experiment settings, the participant was asked to answer a questionnaire about experiencing the actions with and without haptics. All participants remained standing throughout the VR part of the test and sat down for answering the post-questionnaire. The questionnaire was mainly focusing on how they felt about each action with and without vibrate-type haptics, and which actions felt most suitable or most strange to add vibrate-type haptics. (e.g. "Which actions do you feel the most suitable for adding haptic feedback" or "Which action do you feel the most strange adding the haptic feedback?")(see the appendix B)

Figure 4.3.1: The table with tools in Scania training task

4.4 Main Experiment - VR Training Experiment

After getting the feedback and data from the pilot test, the main experiment aimed to determine among the three haptics settings (list below) which one has better user performance based on time, errors and user experience. The purpose was to provide information for future implementation of using Bebop gloves in the virtual reality industrial training task. The research question aims to answer how different vibrate-type haptic settings, created by Bebop gloves, affect the user's performance in a VR industrial training system? The three settings used in the VR training experiment as follow.

- **Non-haptics Setting**: The VR training process will not include any haptics feedback only visual.
- **Partial-haptics Setting**: Only add haptic feedback to press button and positive feedback action. The positive feedback action is when you achieve each step, you will be noticed by the short vibration. (Adding the action which the user thinks most suitable to add haptics based on pilot study result.)
- **Full-haptics Setting**: Add vibrate-type haptic feedback to all actions in the VR training process.

The type, duration, and volume of haptics were consistent for all the actions, using vibrate-type, and the initial setting recommended by the Bebop glove company.

4.4.1 Participants

Participants were asked to participate in a virtual reality experiment that would take about 30 minutes. The participants were aware that they were timed during the tasks, but were told not to hurry for the sake of doing it fast. Participants had either very little or no previous experience with the VR training environment generally and only one participant experienced the haptic gloves before. More background information can be found in figure 4.4.1.

A total of 18 (N=18) participants were recruited with an age range of 24 to 38 years old, with an average age of 27.5 years. Participants were required to have had previous knowledge and experience with new technology. Gender is fairly distributed with 8 participants being female and 10 participants being male.

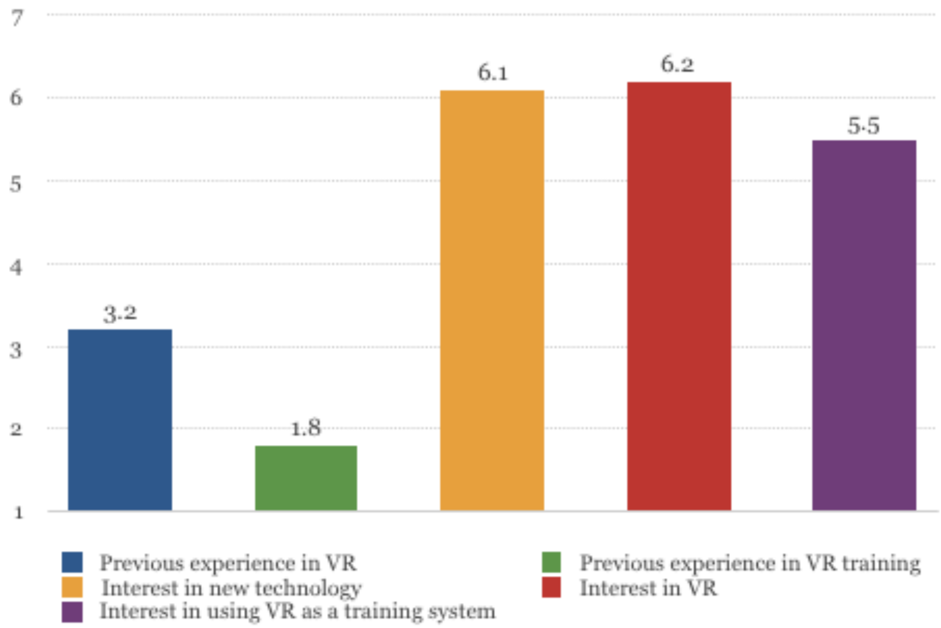

Figure 4.4.1: Background information on participants

The participants were recruited through a Facebook event. The study was anonymous and ID numbers were given to the participants instead of names. Testing was conducted in the physic department laboratory space in the Q building at KTH Royal Institute of Technology in Stockholm. The laboratory space was little noise disturbance, making it ideal for testing. All testing was done in the afternoon between 12 pm - 6 pm.

4.4.2 Choice of Industrial Actions

VR training experiment aimed to provide information for future implementation of using Bebop gloves in the virtual reality industrial training system. In this experiment, time and error in each step will be measured.

Setting A: Non-Haptics (No vibrate-type haptics added to any action)

Setting B: Partial-Haptics

- List of actions added vibrate-type haptics:
  - Press button
  - Positive feedback

Setting C: Full-Haptics

- List of actions added vibrate-type haptics:
  - Press button
  - Grab object
  - Touch object
  - Rotate / Spin object
  - Push object
  - Positive feedback
  - Lift Objects (With two hands)

4.4.3 Procedure

The participants started the test by signing a consent form and then were verbally instructed on the test. The instructions included what to expect and that they were supposed to go through a VR training process. They were also told that they would try two different haptics settings, with no information regarding the difference between them and randomized the experiment settings. And then asked the participant to fill the background questionnaire. Once instructed and finished the background questionnaire, the participant then put on the Oculus Quest and Bebop gloves and "stepped into" the virtual reality environment where they could see a room with one table with some tools and buttons, and some foundation structure of the car.

This experiment had three experiment settings, and each setting was tested by 6 people with a total of 18 people. The experiment setting flow listed below:

- Experiment Setting A:
  - Introduction
  - Background Questionnaire
  - Non-Haptics Setting
  - Partial-Haptics setting
  - Questionnaire
  - Interview

- Experiment Setting B:
  - Introduction
  - Background Questionnaire
  - Partial-Haptics setting
  - Full-Haptics setting
  - Questionnaire
  - Interview
- Experiment Setting C:
  - Introduction
  - Background Questionnaire
  - Full-Haptics setting
  - Non-Haptics Setting
  - Questionnaire
  - Interview

In VR, the participant started with playing with some tools on the table and got used to the environment. After they were ready, pressed the start training button and followed the instruction in the VR, there were a total of 5 steps in the training process. In the meantime when the participant finished each step, record the time and error. In each step, there were visual instructions and signs supporting the participant. After they finished all the training steps, they were asked to press the switch button in the VR scene to change to the second experiment setting. Repeated the same training steps; however, in the second setting, the participants were asked to pay attention to the actions and user experience rather than complete the task and only the user behavior be observed. After they finished the second setting, they were asked to take off the VR headset and Bebop gloves.

All participants remained standing throughout the VR training task and sat down to answer the questionnaires.

4.4.4 Data and Evaluation Measures

The data collected was used to complete two evaluations: user performance for each experiment setting and the general preference (comparison) among the three experiment settings. Two metrics will be measured.

- **Total complete time and complete time in each step:** When the participant completes each step, we will count the time.
- **Total errors and error in each step:** When the participant fails to complete the tasks for the first time, we will count for an error in this step.

4.4.5 Questionnaire

Designed three different types of questionnaires based on which two scenarios participants took. Only change some comparison questions between haptics and non-haptics settings. There were three parts of questionnaires, part A, had 7 questions, aimed to collect the participant background information, and were given before the experiment. Part A questionnaire was on a 1 ("Low") to a 7 ("High") scale score to understand the participant's experience in VR general, and VR training experience ("Previous experience in virtual reality")

Part B collected participants' user experience, usability issues, and haptics functionality issues by comparing the two haptics settings. There were a total number of 16 questions, 5 of 16 were taken directly from the VR testing questionnaire, created by Witmer and Singer (1998), related to the natural movement and haptic. Participants were asked to answer questions regarding presence on a 1 ("Low") to a 7 ("High") scale score. The higher score mostly means having better user experience, fewer usability issues, or easier identifying the benefit of haptics. Including comparison questions ("Which scenario had better usability experience, A or B" or "Which training setting you would like to use for future training purposes?") and open-ended questions ("What improvement would you wish to see in haptics setting A?" and "What improvement would you wish to see in Bebop gloves?") to collect specific feedback from users.

Part C, had 1 question, aimed to test the memorization, the participants had to put the training steps in order. This part was given in the last to check the relation between the different experiment settings and memorization.

Chapter 5

Results

In this study, the aim was to investigate whether using vibrate-type haptic gloves in the VR training environment would increase the user performance and user experience, also exploring how different haptics settings affect the user's performance.

The result showed that the main hypothesis was supported: using vibrate-type bebop gloves with the full-haptics setting rather than non-haptics or partial-haptics settings will result in better user performance both for shorter complete times and fewer errors during the VR training tasks. However, not all participants in a full-haptic setting perform less time or fewer errors compared to participants with partial-haptics or non-haptics settings. User performance and the scale of how helpful the haptics achieved the participant's goals seemed to be higher when participants with a full-haptics setting. Lastly, in the second haptic setting each participant conducted, the mean average time and error decrease regardless of the haptics settings.

5.1 Error

There was an average 4% of error difference in each type of haptics setting (Non-haptics, Partial-haptics, and Full-haptics). However, there was an average 60-70 % of error difference between Non-haptics setting and Full-haptics setting in the training step 1 (Pressing the start button), step 2(grabbing the washer), and step 5 (grabbing & rotating the seat screw).

It was also observed that almost all the participants (66.67%) had problems in step 5, rotating the screw, no matter which haptics setting they conducted. Seven participants mentioned that the rotating action in the scene is not similar to the real-case scenario. See in figure 5.1.1.

Figure 5.1.1: Rotate the seat screw in Scania training task

The mean average amount of errors was 4 of 18 possible errors (22.22 %) for the Non-haptics setting, 3.2 of 18 possible (17.78 %) for Partial-haptics setting, and 2.6 of 18 possible errors (14.44%) for Full-haptic setting. See in figure 5.1.2.

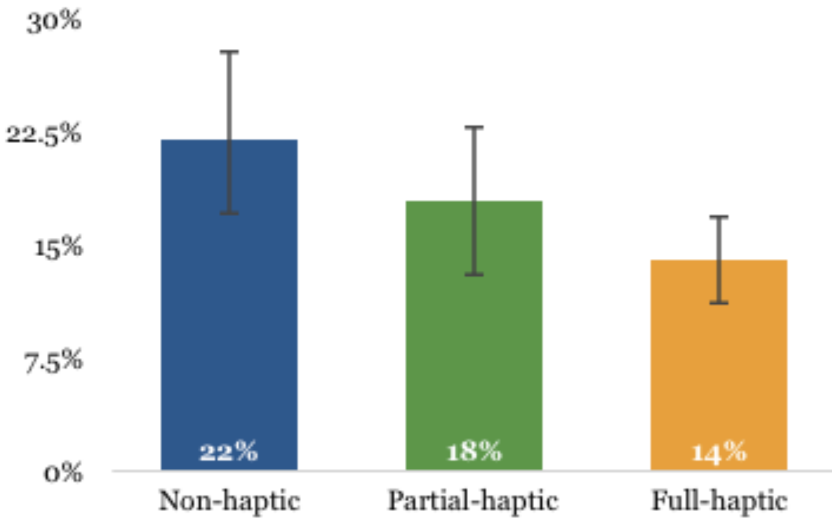

Figure 5.1.2: Error rate for each haptics setting

5.2 Time

There was an average 16 seconds difference for completion of the training task between the Non-haptic setting and Full-haptic setting. However, there was only average 2 seconds difference between the Non-haptic setting and Partial-haptic setting for completing the training task.

6 people (33.3%) did not read the step instructions, only following the visual arrow sign to complete the tasks, which made them spend less time (6%) than the participants reading the instructions. Few participants (22.22%) used both their hands as the result of average 6% less completion time compared to the participants using one hand.

The mean average for the time to complete the training task in the Non-haptic setting was 2 min 3 seconds, in the partial-haptics setting was 2 minutes 1 second and in the full-haptic setting was 1 minute 46 seconds. See in figure 5.2.1.

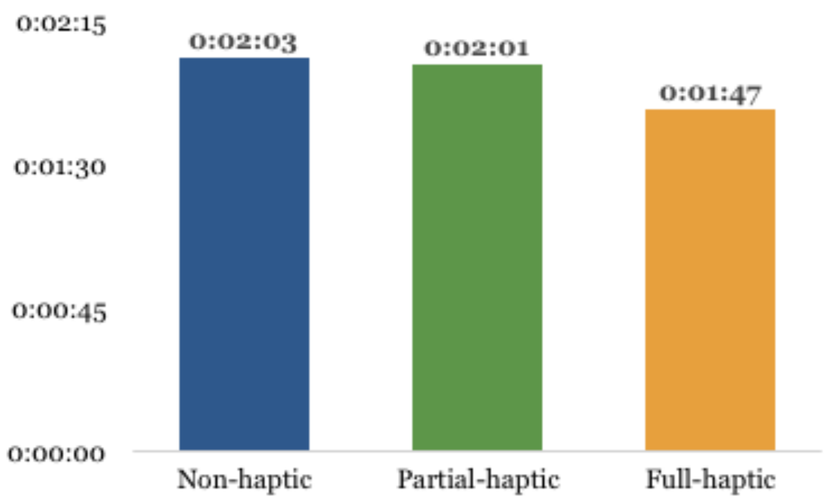

Figure 5.2.1: Time for completing the training task in each haptic setting.

5.3 Participant Demographic

Additional analysis of participants' background was done to see if the participants' background matters with regards to the number of errors and times. Results show that there was no statistically significant relationship between error and previous experience with VR, and interest in VR. There was also no statistically significant relationship between error and age nor error and gender.

5.4 Questionnaires

The results show that when asked about the benefits of haptics in achieving goals of task, participants scored a mean average of 5.67 for full-haptics setting and a mean average of 3.5 for Partial-haptics setting on a 7-point scale when asked about the benefits of haptics in achieving task goals. See in figure 5.4.1.

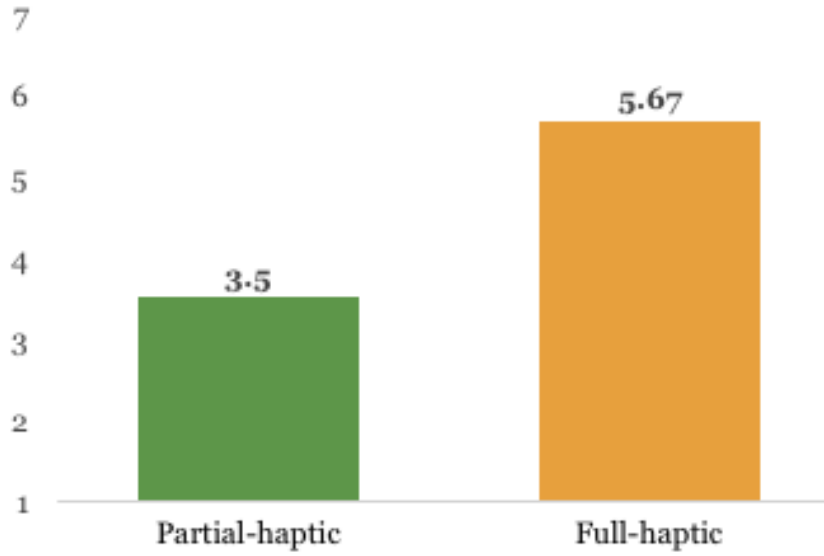

Figure 5.4.1: "How well the haptics benefit in achieving task goals?"

When asked about how well the participants move or manipulate objects, participants scored a mean average of 5.33 for a full-haptics setting and a mean average of 3.83 for non-haptics setting on a 7-point scale when asked about the movement and manipulation of the task object. See in figure 5.4.2.

When asked about the preference of haptics setting only 1 (5.56%) participants preferred non-haptics setting, 15 (83.33%) participants preferred full-haptics setting, 2 (11.11%) participants preferred both full-haptics and partial-haptic settings.

Furthermore, seventeen (94.44%) participants stated that the haptics helped them complete the task and provide confirmation. When asked about the user experience for haptics setting, participants scored on a 7-point scale 4 for non-haptics setting, 4.2 for partial-haptics setting, 4.33 for full-haptics setting. Non-haptics setting scored 4.33, partial haptics setting scored 4.8, and full-haptics setting scored 4.83 when asked about the user experience from a usability perspective.

In the questionnaire, the overall experience and usability in virtual reality were enhanced with the full-haptics setting compared to partial-haptics setting or non-

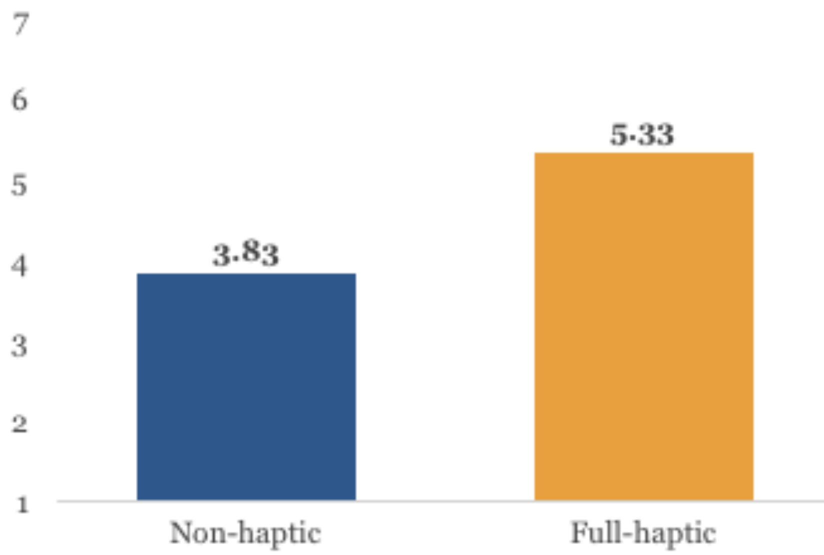

Figure 5.4.2: "How well could you move or manipulate objects in the virtual environment?"

haptics setting. On questions such as "how important did you feel the haptics in this training process?" participants scored 5.5 on a 7-point scale for full-haptics setting, 4.33 for partial haptics setting. When asked how naturally participants felt about the haptics in the training task, the partial-haptics setting got a score of 5.33 and the full haptics setting got a score of 4.5. Moreover, when asked in which haptics setting they would like to use for future VR training implementation, full-haptics setting got a score of 6.33, partial-haptics setting got a score of 5.33, and non-haptics got a score of 4.5. (see in appendix A)

Regarding interference and disturbance, Full-haptics setting scored overall higher; when asked "How naturally did your interactions with the environment seem" participants gave full-haptics setting the score on a 7-point scale 4.6, gave partial haptics setting the score 4.17 and gave non-haptics setting the score 4.17. Lastly, asked from the VR training scenario itself, how did you feel about the difficulty of the training task, non-haptics setting scored 2.67, partial-haptics setting scored 2, and full-haptics setting scored 1.8. (see in appendix A)

The last part of the questionnaire tested the participants to recall the training steps, asked about "Please list the training steps in order", all the participants in three different haptics settings scored 100 percent correct.

5.5 Interview

During the interview, 12 of 18 participants complained about the usability issues of Bebop gloves when they put on the Bebop gloves, for example, "The angle of the virtual hand is different from my real hand", "I can not feel about the haptics", "My hand is too small, Bebop glove is too large for me", "The haptics sensor of fingertips got loose while I was moving my hands", "The virtual hand disappears when I flip my hands", "The gloves are a bit heavy for me" or "The bebop gloves constrict my movement". However, 7 of 12 participants stated that after a few minutes or during the training task, they got used to the Bebop gloves and felt less annoyed.

8 of 18 participants stated that they felt disappointed after using the Bebop gloves, like "I image the haptic glove can create a more immersive experience not just vibration gloves", "The haptics gloves experience not as good as using VR controller", "The gloves have the functionality issues and hard to use it", "The haptic gloves not as good as I thought"

15 of 18 participants expressed the vibration haptics provide confirmation and help them achieve the goals; however, 12 of 18 participants mentioned that the Bebop gloves need to improve its functionality and usability issues and 6 of 18 participants said that they would prefer using VR controller rather than the Bebop gloves for future VR training task.

7 of 18 participants stated that the haptic gloves provide them more immersive VR experience compared to using a VR controller due to same hand interaction and similar real-case scenario; however, they all mentioned the hardware of bebop gloves need to be improved for a better experience.

12 of 18 participants mentioned that the positive feedback which creates vibrate-type haptics when completing each step provides them a sense of achievement and confirmation which leads to the higher usability experience.

Chapter 6

Discussion

In this section the results of the study are discussed, starting with the achieved task usability (numbers of errors, complete-time, and usability issues) and Bebop gloves limitation, to give an overview of the results achieved for using Bebop gloves in a VR training environment. Thereafter the potential factors of causing the results are discussed and focusing on the main issues encountered in the user test. This section is then followed by a discussion on the experiment design, the choice of haptics feedback, and the potential further research. Lastly, there is a section, which describes the recruiting limitation of this study.

6.1 Achieved Task Usability

In this study, we wanted to observe user performance between the metrics (time and error) and different haptics settings. In other words, will adding the vibrate-type haptics in actions reduce the complete time, decrease the error and enhance the user experience?

Based on the result, the Full-haptic setting had better user performance (less complete time and less errors) compare to the Non-haptic and Partial haptic setting.

The result supported the previous work of Jacobs, Stephan, et al. (2007) that combining haptic feedback performs better than visual feedback only and adding haptics in the virtual reality can accelerate task completion times (virtual surgery training environment).

6.1.1 Numbers of Errors

The number of errors was, as predicted, higher for the less vibration haptics setting. One explanation is that the participants while doing the task, the haptics provide confirmation, warning or alert (Suhonen, K., Väänänen-Vainio-Mattila, K., & Mäkelä, K., 2012), so the participants can be aware of the grabbing or rotating object and reduce the errors.

In the experiment, we observed that almost all the participants (83.3%) conducting with the non-haptic setting or partial haptic setting had problems with grabbing the small objects (plastic washer and seat screw) and felt frustrated; however when it came to grabbing the large objects (seat or seat bracket) the three haptics setting have the same error rate (16.67%). A potential explanation is that the visual plays a more important role when it comes to the large size object; however, due to the small size visible, the small object needs to add additional senses to support the user. We can thus see that the haptics have more impact on dealing with small objects rather than the large objects.

Figure 6.1.1: Grab the washer in the Scania training task”

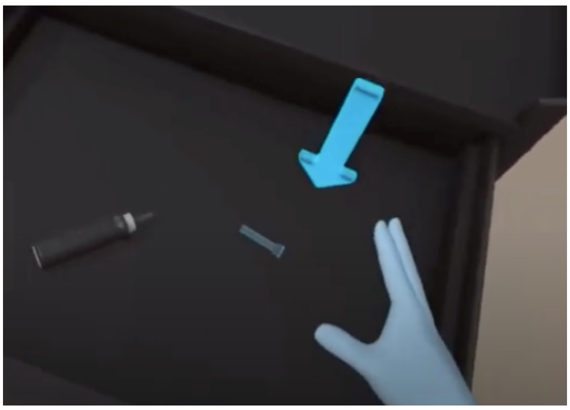

Figure 6.1.2: Grab the seat screw in the Scania training task

Due to adding haptics that can reduce the error rate, it is useful to apply to reduce surgical errors or psychomotor skill acquisition (Van der Meijden, O. A., & Schijven, M. P., 2009). In summation, it seems like adding vibrate-type haptics using bebop gloves reduces the error in the VR industrial training environment, especially dealing with a small object.

6.1.2 Complete Time

The complete time was, as predicted, higher for less vibrate-type haptics setting. The explanation for this is that the participants made more errors during the training task especially for step 2, grabbing the plastic washer and step 5, grabbing and rotating the screw. In the experiment, we observed that the complete time varied from individuals regarding which haptics setting they conducted.

One potential explanation is that among all the participants there were 6 people (33.3%) not reading the step instructions, only following the visual arrow sign to complete the tasks, which made them spend less time than the participants read the instructions.

Another potential explanation is that during training tasks in VR, 12 of 18 (66.6%) participants only worked with one hand in the training task, except the lifting action which is supposed to grab with two hands. The participants worked with two hands spending less time on the tasks compared to the participants who only worked with one hand. In summation, it seems like adding the vibrate-type haptics using bebop gloves reduces the complete time in the VR industrial training environment.

6.1.3 Usability Issues

During the experiment, it was observed that almost all the participants (94.4%) had problems in rotating the screw no matter which haptics setting they conducted. Seven participants mentioned that the rotating action in the scene is not similar to the real-case scenario; however, six participants mentioned the rotating action is like the real-case scenario but the bebop glove constricts their movement.

Observed from the task and post-experiment interview, we found that the participants had different movements in mind when it comes to rotating the screw, some people prefer using only two fingers (thumb and index finger) and some people prefer using three or four fingers. Furthermore, participants had a different definition of real-case scenario, some people think they should use the tools and other people think the rotation should not involve the wrist. One potential solution is that improved bebop gloves action sensitivity be able to capture the user micro movement. Another potential solution is using the VR controller rather than haptic gloves because when using the haptics gloves they are expected to work like the real-hand and have higher expectations.

In the second haptics setting each participant conducted, the mean average time and error decrease regardless of the haptics settings. Half of the participants stated that they get used to some usability problems (rotating screw and grabbing small objects) and bebop gloves when they switch to a second haptic setting, thus they had higher performances and usability experience.

A further finding in the experiment is that adding positive feedback, that creates vibrate-type haptics when completing each step, enables the participants to have a sense of achievement, which is the reason that partial haptics setting, adding the positive feedback, has a higher overall experience score than non-haptics setting. Several participants emphasized that positive haptics feedback provides a sense of confirmation which largely enhances their training experience.

Much like any technology, there were minor technical complications throughout the testing. On a few occasions, the demo crashed which resulted in having to stop testing and restart the demo. There were some complications with tracking the bebop gloves which caused the strange hand movement or temporary stop. All the technological problems that appeared before the task started and thus deemed not to be disturbing to the experiment. Some technological problems are inevitable and fortunately, these problems were minor and not during the actual testing; however, the participants need to spend extra time to start the actual testing, and avoiding any difficulties would be preferable. VR technology is not perfected and thus it is one of those factors that need to be adapted to become a new medium, as explained by Slater and Sanchez-Vives (2016).

Based on the experiment results, we could not see how the different haptics settings affect the user's memorization of the training tasks, in which all the participants in three settings achieved a 100% correct rate. Moreover, time spent on tasks and the error did not matter, across all variables. These results can simply mean that time and error did not factor in when spending more attention and memorization of the training task. Nevertheless, this training task only includes 5 steps, which is easier to remember in a short amount of time. Further research on different haptics settings affects the user's memorization of more complex industrial training tasks is needed.

6.2 Bebop Gloves Limitation

Bebop glove is wireless, vibrate-type, and all-in-one size gloves and combines with Oculus Quest. In the experiment, we observed that there were several limitations and usability problems using bebop gloves in the VR industrial training task:

- Higher psychological expectations: Due to the participants never experiencing the haptic glove before, they had higher psychological expectations before using it. After the experiment, several participants stated that they were frustrated when the movement in the scene was not sensitive enough especially for the small-scale motion (rotating, grabbing small objects).

- All-in-one size: The bebop gloves were designed all-in-one size which caused some usability problems, for example some participants with a small hand had problems feeling the fingertips haptics.

- The weight: When using the bebop gloves, the Oculus controller needs to attach to the bebop gloves, in this case, as Okamoto, S., Konyo, M., & Tadokoro, S. (2011) stated that the participants will feel uncomfortable over a long period of usage.

- Haptics limitation: Each participant had different levels of feeling the vibration haptics feedback since people had a different thickness of finger skin. In this case, few participants had a problem feeling the vibrate-type haptics feedback which resulted in a lower score of haptics questions such as the benefit of haptics achieving their task goals.

- Hardware limitation: The bebop gloves only have six sensors in the five fingers tips and palm which generate the vibration feedback, the hardware limited overall haptics experience and need further development.

Despite the limitation of the bebop gloves, some participants stated that the gloves created a more immersive VR experience and natural movement compared to using the VR controller. In summation, based on the results and interviews, we observed that the vibration haptic feedback enhances the user performance and user experience when conducting the VR industrial training task.

6.3 Experiment Design - The Choice of Haptics Feedback

In this experiment, we used the same type, duration, and volume of haptics for all the actions, using vibrate-type, and the initial software setting recommended by the Bebop glove company. Based on the finding in the pilot study, some actions (grabbing large objects and rotating object) felt strange and unnecessary to add the vibration feedback; however, there were no further experiments of changing the factors like the types, duration, and volume which we can not conclude whether the actions are suitable for adding haptics or not. The following questions need further investigation: What types of haptic with what duration can mostly enhance user performance? What volume of haptics can mostly increase the user experience? or what types of haptics add to which actions can mostly enhance user performance? As Kreimeier, Julian, et al. (2019) stated that the haptics in virtual reality can improve the task-based performance; however, the VR industrial training task involved different actions and not all the actions haptics benefit to improve the user performance.

Despite the choice of haptics setting limitation, this experiment aims to understand whether or not the haptic feedback, created by bebop gloves, enhances user performance in the VR industrial training environment and the results supported the hypothesis.

Chapter 7

Conclusions

In this section, the final conclusions of this study are summarised in a short point format to easily be accessed to future VR developers or haptics designers working with immersive VR, along with questions that could be researched in future work.

7.1 Vibration Haptics Feedback as a Confirmation

One very important conclusion, initially drawn by Suhonen, K., Väänänen-Vainio-Mattila, K., & Mäkelä, K., (2012) was that the haptics feedback plays as interpersonal communication and support the user with the confirmation. The results of this study fully confirm their conclusion and thus it is restated here.

As results showed, the full-haptics setting dominated partial-haptic setting and non-haptic setting as preferred VR training setting, with better user performance, and overflowing number of comments on the benefits of haptics in VR training tasks. Yet, as a VR training developer, you must consider whether or not adding vibration haptics to all the actions and be aware of the role of haptics, such as the haptics should play the same role, as a confirmation, alert or warning, consistency during the training tasks.

7.2 Bebop Gloves Opportunity and Difficulty

The result of this study showed that the gloves provided a more immersive VR experience, in discussion 6.2, and the hand movement also similar to the real-case scenario. Furthermore, the result supports the work of Bickmann, Raoul, et al., (2019) that adding the haptic to grab the small objects using bebop gloves results in high usability to manipulate the objects in the VR training tasks. However, this experiment also found out that when grabbing large objects with haptics, such as a seat or a seat bracket in the training task, the performance result does not make a difference compared to visual-only (see the discussion 6.1.3).

We discussed the bebop gloves limitation in discussion 6.2 and proposed the potential solution of using the VR controller to solve some usability problems of bebop gloves (See discussion 6.2) until hardware and software improved. However, due to the experiment limitation of using only bebop gloves in the VR training tasks, drawing any conclusion of whether the bebop gloves are more suitable than using the VR controller is outside the scope of this study and is a research topic on its own.

7.3 Haptics Benefit Small-Scale Actions in VR Industrial Training

Last but not least our results demonstrate that the haptics plays a very important role when conducting small-scale action (grabbing plastic washer and rotating the screw). If taking away the vibration haptics in the non-haptics setting, the error rate of operating small-scale action increases dramatically based on the experiment result.

However, haptics seems to be unnecessary when dealing with large-scale action (lifting the chair or grabbing a seat bracket) based on the experiment results and interviews. This finding also supports the work of Van der Meijden, O. A., & Schijven, M. P. (2009) that the haptics reduces the error of small-scale action in surgery environment but take one step further.

In the end, commercial haptics gloves are just in its starting grounds, and if it manages to improve the haptics gloves hardware and motion detection, the potential application of VR headset with haptic gloves would be unlimited. Future studies should aim to learn more about the benefits of using haptic gloves in different VR scenarios. This current study takes us one step closer to learning more about the many benefits of using haptic gloves in virtual reality industrial training.

Chapter 8

Reference

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Appendix - Contents

Appendix A

Results of main experiment questionnaire

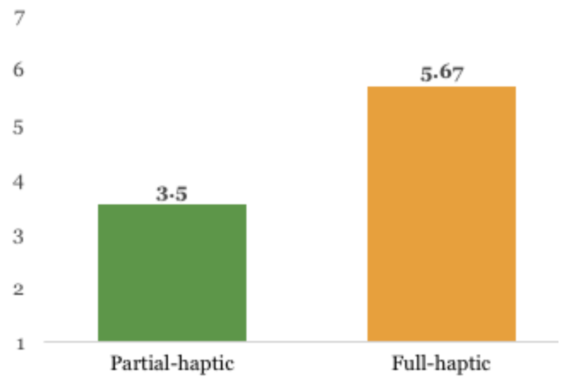

Figure A.0.1: "How well the haptics benefit in achieving task goals?"

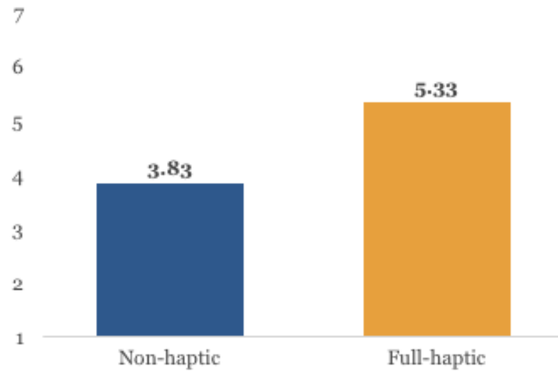

Figure A.0.2: "How well could you move or manipulate objects in the virtual environment?"

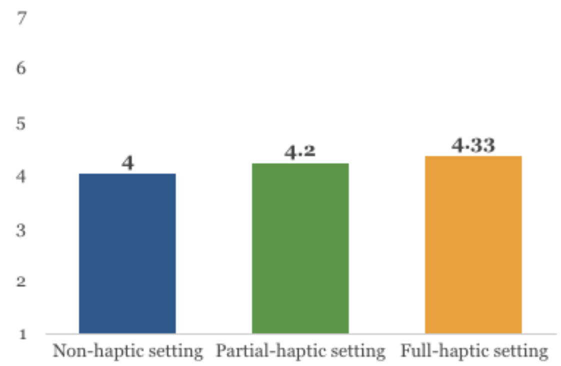

Figure A.0.3: "How's your overall experience?"

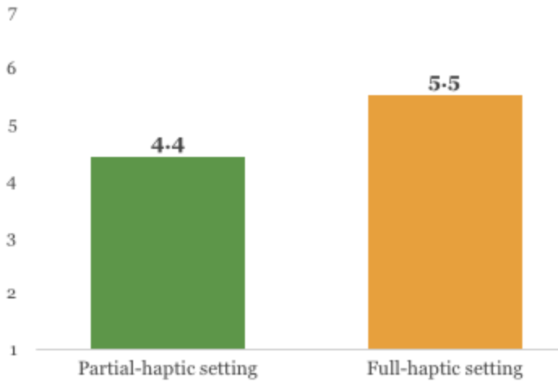

Figure A.0.4: "How important did you felt the haptics in this training process"

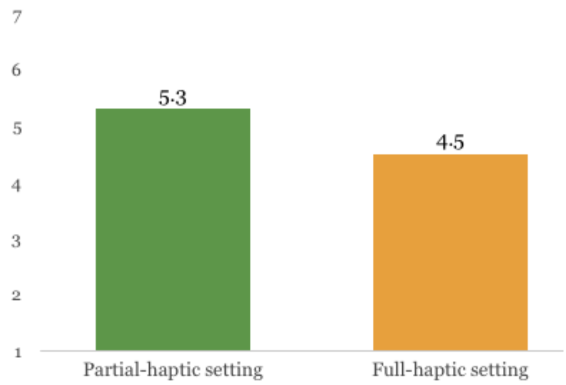

Figure A.0.5: ”How naturally did participants felt about the haptics in the training task”

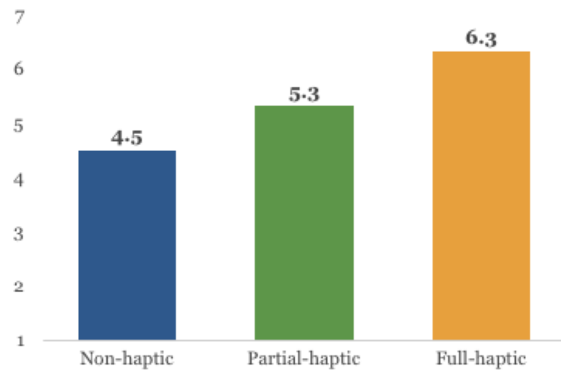

Figure A.0.6: ”Which haptics setting they would like to use for future VR training implementation?”

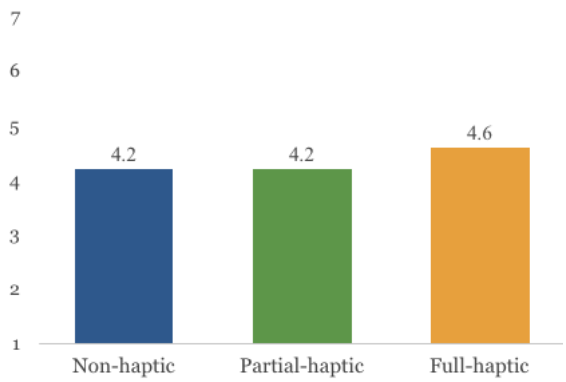

Figure A.0.7: ”How naturally did your interactions with the environment seem”

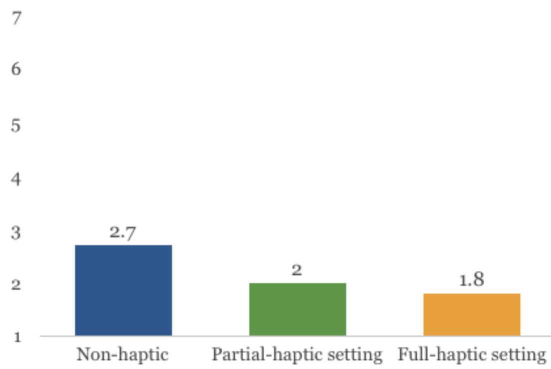

Figure A.0.8: ”How did you feel about the difficulty of the training task”

Appendix B

Pilot study questionnaire

1. Do you prefer adding haptic feedback or not adding haptic feedback in the VR environment?
2. Which actions do you feel are most suitable for adding haptic feedback? (Multiple choose)
3. Which action do you feel the most strange adding the haptic feedback? (Multiple choose)
4. How do you feel about adding haptic feedback in the ”Pressing Button” action?
5. How do you feel about adding haptic feedback in the ”Touching Object” action?
6. How do you feel about adding haptic feedback in the ”Grabbing Object” action?
7. How do you feel about adding haptic feedback in the ”Spinning the Object(Rotation)” action?
8. How do you feel about adding haptic feedback in the ”Clashing Object(Collision)” action?
9. How do you feel about adding haptic feedback in the ”Lifting objects(With two hands)” action?
10. In general, which one has a better user experience?