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MSc Human Computer Interaction Thesis

The Role of Force Feedback and Vibrotactile Feedback in Learning and Retaining Procedural and Factual Knowledge in an Immersive Virtual Training Simulation

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Abstract

Immersive Virtual reality (IVR) has been adopted for training systems across different domains. However, its impact and effectiveness on learning are inconclusive and contradictory. Based on the existing literature, implementing haptic feedback is one way to improve the learning process in virtual environments for training (VTEs). To date, there needs to be more literature on combining virtual reality and haptic feedback, aiming at increasing procedural and factual knowledge retention. This study investigates whether vibrotactile and force feedback can positively influence procedural and factual knowledge in VTEs and, if so, whether this learned knowledge is retained over time. Guided by the "Cognitive Affective Model of Immersive Learning" (CAMIL), this study examines the relationships among the interaction between haptic feedback and VR, presence, and learning outcomes. According to CAMIL, increasing presence and four key factors—interest, motivation, embodiment, and self-efficacy—through haptic feedback will lead to procedural and factual knowledge retention. A between-subject design employed the SenseGlove Nova and Oculus Meta Quest Pro in a virtual fire safety training simulation to empirically test these hypotheses. Participants were divided into experimental (HF) and control groups (NHF), with haptic feedback activation changing between the two conditions. Both groups completed pre-training questionnaires assessing their prior VR and haptics experience, knowledge of fire safety training, and existing procedural and factual knowledge. Following the training session, participants completed a second questionnaire about presence, interest, motivation, embodiment, and self-efficacy using the 5-point Likert scale; questions that measured procedural and factual knowledge retention post-training were also provided. Next, a follow-up survey was conducted one week later to evaluate knowledge retention. In total, 70 participants were recruited, but only 68 (M = 24.6 years, SD = 27.5 years) were considered due to the lack of two participants' responses after one week. Although no significant differences were found between the experimental and control groups, the current research shows increased retention of procedural knowledge through haptic feedback after the first training session; likewise, participants could retain procedural information one week after the training session. In the same way, there was no significant difference between the two groups regarding the sense of presence and the three factors, except for embodiment, where a significant difference was found. Finally, a positive correlation was found in the experimental group between the sense of presence and motivation; presence was also negatively correlated with the decrease of procedural knowledge after one week: increasing presence decreased the decay of the said knowledge. In addition to these findings, motivation had a negative and significant correlation with the same decrease in procedural knowledge retained after one week.

This finding has practical consequences and only partially answers the present study's main research question. Several reasons can explain the lack of significant results. These include participants' different learning techniques to memorise the information, the single try-out training session, a sub-optimal training simulation, and problems during the experiments.

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Contents

1. Introduction

1.1 Introduction

Teaching is a dynamic process that requires updating and following the pace of new approaches and technologies [1]. With technology development and improvement, scientists and companies have a unique opportunity to explore this need. In this regard, the extensive employment of technologies such as digital videos, eye-tracking, and simulations has been demonstrated to be promising training methods [2]. Not only educators but also researchers need to investigate new ways to increase the level of users' learning performance. The challenge here is understanding whether to adopt these future technologies or not.

In this context, one of the most successful tools employed to enhance learning outcomes in recent times is virtual environments for training (VTEs) [3]. In the last 30 years, virtual reality (VR) has been adopted for training systems across several domains, such as sports, emergency, and construction [4] [5] [6] [7] [8] [9]. Despite VR not being a recent discovery, its usage in the educational domain has been limited due to high equipment costs and past technical constraints, including hardware and software development for VR settings [10]. In recent times, in conjunction with the decrease in costs, VR has emerged as the perfect highly immersive tool to use combined with 3D viewing areas, such as Head-Mounted-Display (HMD) and a singular virtual environment called Cave Automatic Virtual Environment (CAVE) [10] [11] [12].

Immersive virtual reality (IVR) technologies in education and training offer several notable advantages. One of the main advantages of the said technologies lies in the possibility of trying specific tasks with unlimited time, reducing the risk of being hurt, focusing on situations that require training in hazardous circumstances, and acquiring knowledge to transfer to other contexts [13] [14]. Therefore, these technologies used in the development of IVR open up creative ways for involving learners in educational and training experiences [15]. In contrast to more traditional teaching backgrounds, where the teacher is the one in control of the way students learn, virtual simulations propose a learner-centred approach to education: the trainees control their learning process through active and critical approach interaction with the current situation presented in the virtual reality [16]. This distinct interactive element in IVR is fascinating and essential since it can facilitate learning [15].

In this highly interactive environment, the users can interact with the surrounding objects and the simulated world and finally make their own decisions. The user learns through their actions and conclusions, with the consequence of learning by doing [17], where practice can improve the learning process and memory retention [18] [19]. According to Morélot et al., [14], the VTE tool should first sustain knowledge acquisition and help the learning process in VTE, and second, should aim at learning "know-how" and skills building [20]. To reach this type of learning, immersion and a sense of presence are the two leading players in the learning process happening in VTE [21] [14] Section 2.5.2.

Simulations have been widely used to support training in specific domains. However, De Freitas et al. [22] highlight that more empirical data are required to support their and other researchers' work. Although already employed, more recent scientific research should be conducted regarding the data's validity and reliability [1]. Moreover, there is no consensus among the scientific community on whether training in a virtual reality simulation might enhance effective learning outcomes [23]. Recent studies, for instance, have shown no significant difference in learning in virtual reality simulation compared to learning through a desktop computer [11] [15].

Nevertheless, Makransky et al. [11] found an interesting result in how participants perceived themselves in a virtual environment (VE): the level of presence experienced in VR was more significant than in the science simulation via a desktop display (PC). Likewise, several researchers have found positive results in training in a virtual simulation. Participants in VR assessed immersion, engagement, and motivation more positively than the same experience in the real world. Said factors are seen as one of the main reasons for the success in increasing the trainees' knowledge [24]. It is said that immersion has generally been portrayed in a technological sense, focusing on the technical features of VR systems. However, immersion can also be acknowledged through subjective experience, referring to the feeling of being fully committed and immersed in a virtual environment [25].

According to researchers, the effectiveness of VR training simulations in enhancing learning outcomes remains a subject to be yet done. A possible cause of this discrepancy in their findings is the absence of haptic feedback implementation in the training simulation [26] [24]. The term "haptic feedback" refers to stimulating the human sense of touch by a virtual reality interface [27], Section 2.4. Agreeing on whether this feedback can lead to better learning effectiveness is complex; further complicating matters is the need to discern different learning outcomes, such as factual and procedural knowledge [25], which has become a recurring study matter [25]. Scholars must also determine whether other methods and devices have a role in increasing user learning and effectiveness in a virtual training learning environment.

As previously stated, there is a need to study further and distinguish different learning outcomes. Paths to acquiring conceptual knowledge have already been explored and validated. In contrast, there is an evident gap in the literature regarding the achievement of procedural and factual knowledge over time in IVR [21] [28] [29]. Procedural knowledge means exercising and performing a specific action to deal with problems and tasks, especially involving a series of steps or actions. This knowledge needs time and practice to master, unlike, for example, conceptual knowledge, which can be learned more rapidly [21] [30]. In this study, factual knowledge is identified with memorising specific information, as it concerns remembering and memorising specific details [30]. Furthermore, the few works that have tried to examine procedural knowledge carry mixed results [31] [11]. It is stated that the main reason for this uncertainty is the lack of haptic devices [11] [32] or, in the case of their presence, the lack of haptic feedback accuracy [31] [23].

In Makransky and Petersen's "Cognitive Affective Model of Immersive Learning" (CAMIL) theory [21], they have reviewed existing immersive educational studies to define the process of learning in IVR. The final goal of the said model is to understand whether and how an immersive and interactive simulation can enhance learning. The relationship between technological factors (immersion, fidelity, and control factors) leads to a sense of presence and agency, which, based on the authors' theory, are identified as the primary psychological affordances of learning [24]. These affordances can positively influence six cognitive factors (interest, motivation, self-efficacy, embodiment, self-regulation, and cognitive load), which lead to four different learning outcomes: conceptual, factual, procedural knowledge, and transfer of knowledge.

1.2 Research Focus

The research project investigates *whether haptic feedback can influence procedural and factual knowledge in VTEs and, if so, over time*. The CAMIL model [21] justifies and demonstrates how the interaction between haptic feedback and virtual reality can achieve procedural and factual knowledge. The current study focuses only on achieving learning outcomes through immersion and interaction instead of considering "control factors" and "representational fidelity" (Section 2.5.1) as CAMIL model frames. Therefore, the present research considers only the sense of presence enhanced by haptic feedback in VR as the only single affordance of learning (Section 2.5.1).

Based on previous studies, force and vibrotactile feedback can influence the sense of presence in VTE [26] [33] [34] [35]. Likewise, four out of six factors described in Makransky et al.'s model have been found to have a positive correlation with haptic feedback (Section 2.5.3). As a result, this research focuses on interest [36] [37], motivation [38] [39], embodiment [40] [41], and self-efficacy [42] [43]. Regardless of being previously studied with positive results, never before had they been examined aiming at exploring procedural knowledge over time. Furthermore, these studies only focused on the individual components without questioning whether a related path to procedural knowledge might exist. The hypothesis is that enhancing these four factors through haptic device interaction will increase learning performance and memory retention in a short and long time.

Better evaluation procedures are needed to fulfil the aim of deriving best practices and describing functional application cases. Moreover, VR training simulations should be more thoroughly evaluated using quantitative and qualitative research methods to assess the users' increase in knowledge, skills, and learning experience. Evaluations of educational VR applications need to be conducted regarding technical feasibility and learning outcomes [44]. This lack in the literature needs further investigation. The data from this research through the experimental design analysis might contribute to revealing a correlation between haptic feedback adopted in VR and specific learning outcomes. A further contribution from this research might be made by consolidating virtual reality's role in the training domain. The scientific community has widely discussed the study of interest, motivation, embodiment, and self-efficacy as indicators of learning transfer. Therefore, this research might contribute to further explaining their role in learning.

Finally, based on the literature, the main areas of applications of haptic devices are medical rehabilitation, nursing, physics, chemistry, and video games [1] [44]. Safety and emergency virtual simulations like fire safety training [44] [45] are also widely studied. However, lacking haptic feedback only sometimes increases learning performance. In this regard, this research might contribute to proving the importance of haptic feedback in virtual training simulations with specific reference to the safety and emergency domain.

1.3 Outline

Chapter 2 presents the related work, including a comprehensive literature review covering procedural and factual knowledge and the learning process, embodied cognition theory, virtual reality and training simulation, haptic feedback, and the theoretical model that guides this research. This chapter also introduces the main research questions and hypotheses. Chapter 3 discusses the practical aspects of this study, describing the implementation of haptic feedback and the virtual training simulation used. The same chapter overviews the experimental procedure, data acquisition methods, and analysis techniques and briefly discusses ethical considerations. Chapter 4 presents the final results of this study. In contrast, Chapter 5 offers an exhaustive discussion of the findings, including their meaning in the context of existing literature. This chapter also addresses the study's limitations and suggests paths for future research, ending with the conclusion.

2. Related work

2.1 Procedural and Factual knowledge

In recent decades, procedural and factual knowledge has become crucial studies. Procedural learning tasks concern learning a specific task step by step, but as the tasks grow more complex, more human cognition load and effort are also required in the learning process. The second type of knowledge, factual knowledge, involves memorising specific information. Immersive virtual reality (IVR) training has recently occurred as a remarkable supplement method for increasing procedural knowledge acquisition. As a result, evaluating how powerful procedural and factual training in the virtual environment is and how long notions can last has become more relevant than ever. This chapter inquires into procedural skills, long-term and short-term memory, and transferring knowledge. It also addresses the lingering questions in the virtual reality training domain literature.

2.1.1 Different types of knowledge

There is a growing enthusiasm for using virtual reality (VR) in training and education; nonetheless, research findings on the advantages of VR training over traditional learning settings are mixed. This lack of agreement among scientists is because the cognitive mechanisms underlying the virtual reality learning process still need to be fully understood and further studied [46]. To develop effective VR educational and training systems, it is essential to identify VR features that influence specific learning techniques. [47]. Moreover, it is equally important to recognise and explore which learning outcomes may benefit from a VR training simulation [47].

Krathwohl et al. [30] declare the existence of four kinds of knowledge: factual, conceptual, procedural, and metacognitive. *Factual knowledge* can be described as "bits of information", and it focuses on remembering specific information [21]. A concrete example of factual knowledge is knowing that China is in Asia. Related to factual knowledge,*conceptual knowledge* can be defined as knowing how reality can be arranged meaningfully [30]. An example of this type of knowledge is understanding the concept of gravity as the force that attracts two entities with mass towards each other. The third kind of knowledge, *procedural knowledge*, means the ability to perform a specific action to deal with problems and tasks. Procedural knowledge needs time and practice to master, unlike conceptual knowledge, which can be learned more rapidly

[21] [30]. Being able to ride a bicycle, which involves a sequence of coordinated actions like pedalling, balancing, and steering, can be seen as a classic example to describe this type of knowledge. The last type of knowledge, *metacognitive knowledge*, refers to what people know about themselves as cognitive processors and a specific learning task [30], for instance, recognising that someone learns best when they study for 45 minutes and then take a 15-minute break, and applying this strategy to their study habit, is metacognitive knowledge.

2.1.2 Long-term and short-term memory

Memory, which in this study is related to factual knowledge, can be divided into two categories: long-term and short-term memory. In the current study, "short-term memory" refers to how well someone performs a task immediately after training, whereas "long-term memory" refers to their performance after one week. Cowan et al. [48] advocated two critical features characterising short-term memory: temporal decay and capacity limit. Temporal decay refers to items in short-term storage decaying relatively quickly, although the expiration time varies among different circumstances. The latter means there is a limit to how many items short-term storage can hold. If the number of items is smaller than the capacity limit, these items will stay in short-term storage until they are replaced by new knowledge.

Regarding long-term memory, Cowan et al. [48] concluded that it is a knowledge pool where it is possible to store all the previous notions or events. Almost every average person will have unique long-term memories, but the said memory is not excluded from flaws. In contrast to short-term memory, long-term memory typically has a larger capacity and longer duration. When an item needs to be recalled from long-term memory, there is a retrieval progress to make it happen, and this retrieval process will grow the cognitive load. Data from Baddeley and Warrington's experiment [49] showed that an immediate recall of the last few items presented in a serial list in the amnesic participants was well preserved and remembered. However, were they tested again after a relatively long period, these individuals encounter difficulties retaining the serial positions. The findings demonstrated that short-term memory perishes after a while if not practised.

2.1.3 Procedural knowledge and transfer of learning

Procedural knowledge can be defined as knowing how to do something. It is also described as the knowledge gained by practising or exercising a task or skill [50] [21]. This knowledge can be acquired by trial and mistake or by learning from somebody who already knows how to accomplish a specific action [51]; thereby, the actions learned by the users, once fully remembered and comprehended, can be automatised after some practice. IVR provides optimal conditions for rehearsing procedures and thereby acquiring procedural knowledge by employing sensors such as hand-control devices or hand-tracking cameras; as a result, trying the simulation out as often as required to retain the information is possible [21].

Transfer of learning refers to cases where knowledge that was acquired in one context affects the performance in another [21]. As a result, experiencing VR simulations of real-life situations can improve the transfer of learning from the VE to real-world situations [52]. It is essential to state that the transfer can differ, depending on the type of knowledge we want to transfer: it can be procedural (in the case of using skills learned in a VR simulation to apply in a real-life situation) or conceptual (e.g., when a virtual training of how the human brain works via IVR impacts user performance in rel-life during an anatomy test).

2.1.4 Learning Style: Kinesthetic Learning, Verbal Learning, and Visual Learning

When discussing the concept of learning, it is also essential to highlight the many different learning styles. Learning styles can be defined as the unique features which affect how people learn. The literature [53] [54] described these styles as a collection of theories where the human brain can absorb, process and maintain new information and skills. These different styles are divided into neurolinguistic, visual, auditory and kinaesthetic. The current study focused on the kinaesthetic and visual learning styles in a VR training scenario.

The ***neurolinguistic*** approach believes that if a person can understand how another accomplishes a task, the procedure may be reproduced and communicated to others so they, too, can achieve the task. The ***kinaesthetic theory*** of learning happens when users learn using their hands or having a physical experience; the learning outcome has transpired due to what has been done instead of verbal or read instructions [53]. ***Visual learning*** users usually prefer watching training videos or reading the instructions as a learning process. They need graphical images to process complex ideas and thoughts and connect them to words. ***Auditory learners*** are receptive to sounds. Usually, this kind of learning happens in classrooms, university lectures and sporting coaching sessions, for example.

In theory, users will have different learning performances when given various modalities of stimuli [54]; to be more specific, how learners absorb and retain knowledge depends on whether the information is provided in their preferred learning styles [54]. It comes naturally to question which learning styles will benefit trainees and instructors; the learners can be trained better when suitable learning methods are provided, while the latter can tailor their training session to accommodate learners better.

Offering learners multiple learning modalities could increase their learning performance, regardless of their learning style. Compared to more traditional training, for example, in class where a plant cell is taught and the new knowledge is provided through visual and verbal learning [55], IVR training can also offer the kinaesthetic modality to trainees [54]. According to Chang et al., [56], the kinaesthetic system receives inputs from the cognitive system passively and is also deeply connected to the system: they are intricately related. Cognitive improvement impacts bodily states and actions, while bodily states and actions can shape cognitive improvement. In other words, kinaesthetic training can effectively influence training outcomes. In the current research thesis, we hypothesise that IVR training could enhance the trainee's learning performance with an extra kinaesthetic modality, compared to when this modality is not applied.

Learning with motor feedback can give users the authentic experience of a particular action and may contribute to procedural memory. IVR training offers trainees the incredible opportunity for hands-on procedural training. The said opportunity might contribute to acquiring procedural knowledge and, finally, to memory retention after performing the IVR training simulation. Fèry et al.'s study [57] further proves the kinesthetic influence on motor skills. Their conclusions suggested that kinesthetic training was better than visual representation training regarding speed scores and form performances.

2.1.5 Procedural knowledge in Virtual reality

In the past few years, VR has gained the attention of researchers who have seen it as a perfect tool for training methods [4] [5] [6] [7] [8] [9]. Unlike traditional training methods, VR training simulations can decrease training costs and guarantee the learners' safety [13] [14]. Therefore, researchers have been looking at what trainees can gain from the training, whether the skills acquired are good enough or even better than the traditional training procedure, and the potential factors that might affect the final training outcomes. Moreover, Jensen and Konradsen [58] showed that learners benefit from the IVR environment to learn spatial and perceptual knowledge and improve their procedural learning performance.

Despite the VR training prospect, researchers also care about the training transfer pace from the VR training process. The notion gained in VR training simulation should be able to transmit to a real-life environment [54]. Lam et al. [59] conducted a study on a VR training method to help medical students get used to cataract surgery procedures. Their system consists of an interactive module for the whole operation and an assessment system to evaluate the student's performance. The student's efficacy was enhanced thanks to the repetition of the training process. These findings demonstrated that VR training could be beneficial for acquiring cognitive skills linked to procedural knowledge learning [58] [60].

Li et al. [61] compared different training methods in the context of earthquake safety training. The VR group experienced a realistic simulated earthquake scenario, and its participants engaged with three variations of the said scenario, where the main goal was to minimise injury as best as possible. Meanwhile, the Video group was given an earthquake safety video training by the Southern California Earthquake Center. As for the third group, the Manual, learners were asked to study a manual for safety training procedures to actuate during an earthquake from the Earthquake Country Alliance. The manual contains graphical illustrations and information explaining the safety procedures during an earthquake. Finally, the None group got no specific training related to earthquake safety procedures. Their findings demonstrated that the VR group had equal or better procedural knowledge acquisition and retention information than those that underwent traditional or desktop training methods. Their results hold significant relevance regarding procedural knowledge acquisition in VR training settings.

In the context of the dental surgical anatomy experiment, a comparison was made between a group of novice surgical residents that used VR training study surgical content and a control group using a PowerPoint presentation material [62]. The VR training group showed significant improvements in both knowledge acquisition and self-confidence before and after the training. In contrast, there were no significant differences in these metrics between the group that received the training in VR and the control group using the PowerPoint method. However, it is worth mentioning that the change in knowledge and self-confidence levels from before to after training was significantly greater in the VR group compared to the baseline scores. While there was no difference in knowledge gain between VR and PowerPoint training groups, they suggest the critical difference in training outcomes that was larger within the VR group and the different learning strategies that can enhance VR training results [62].

2.1.6 Limitations in the literature

To date, factual and conceptual knowledge is the most investigated, as they are relatively simple to test and study in a short time [63] [64] [65] [11] [45]. Makransky et al. [15] stated that introducing touch sensations, weight perception, and force feedback in IVR might positively affect procedural knowledge and skill acquisition. The "Embodiment Cognition" theory (Section 2.2) supports their belief, which suggests that how people think and make sense of the world depends mainly on the sensorimotor system and bodily interactions with the surrounding environment [63]. Based on the theory, learning procedural knowledge can be enhanced when the learner performs physical tasks that are meaningful to the learning concept and when represented in a way that guides particular motor actions.

Research has investigated different paths to acquiring conceptual knowledge in short and long time. In contrast, studies have yet to be done on assessing procedural and factual knowledge over a long time in VTE [66] [67] [68]. Huegel et al. [69] claimed that short-term procedural knowledge can be improved when providing haptic feedback. They based their statement on previous studies showing that implementing haptic feedback to VEs can provide advantages over visual and auditory displays for performance enhancement, improving the sensation of realism and sense of presence [70] [26] [71]. Furthermore, in contrast with conceptual knowledge, the different nature of procedural knowledge requires considering the core features of the investigated domain. Procedural knowledge is more oriented to the physical application and execution of specific tasks within a specific domain, while conceptual knowledge concerns more general and versatile concepts that have wider application in different situations, regardless of the domain of investigation. Instead of clear procedures that are usually possible for other types of knowledge, it is necessary to simultaneously consider different perspectives, such as social factors, the nature of problems, and institutional characteristics [72].

Different domains require different instructional methodologies. The lack of instructional design and the lack of utilising VR capabilities has led to inconclusive or inconsistent training effectiveness results [73] [11]. Thus far, research shows that VR training can be practical when integrated with haptic feedback (Section 2.4.3). Further, supplementing instructor-led training with VR training may increase the effectiveness and improve training outcomes for psychomotor tasks. It is recommended to leverage the unique characteristics of VR (e.g., fully encompassing, whole-body multimodal interactions, and first-person point of view) integrated with theoretical learning approaches to generate context and device-appropriate instructional designs [74].

2.2 Embodied Cognition Theory

According to the Cognitive Load Theory (CLT), human working memory has limited space [63]. The said theory also refers to dealing with mental effort when the user's working memory is processing load in response to a specific task. This load can be partially manipulated by interaction with the context and environment of the presented information. Two distinctive information types characterise this theory: "biologically primary" and "biologically secondary." The first type of knowledge refers to reports that the brain processes earlier in evolution, such as movement and facial expression. The second knowledge, in contrast, is essential for cultural reasons and does not concern human evolution [75].

Embodied Cognition theory [63] is a cognitive process under the biological primary knowledge umbrella. This theory asserts that the user's motor and sensory systems affect one's cognition. Overall, this approach explains how it is possible to comprehend an abstract concept in terms of bodies and physical actions. It is stated that "biologically primary" knowledge does not have the same restrictions on working memory as humans have evolved and learned to develop this information over the centuries. Researchers and educators must attempt to use biologically primary knowledge to collect secondary information. Haptic implementations offer a unique path of using "biologically primary" processing to teach biologically secondary notions. Thus, having another information channel in a separate modality, e.g., haptic feedback, might alleviate the cognitive load and lead to effective learning [23].

This theory suggests that how people think and make sense of their surroundings depends significantly on our sensorimotor system and bodily interactions with the world [15]. Relevant to learning procedural knowledge in VR, embodied cognition theory argues that direct physical manipulation of external representations is imperative to the learning process. Based on this statement, acquiring procedural knowledge can be enhanced when the learner executes physical tasks that are meaningful to the learning concept and when defined in a way that guides specific motor actions.

Concerning learning interaction, a unique feature in a VE is the ability to undertake embodied actions, including view control, navigation and object manipulation [76]. Based on their literature [76], it is argued that e-learning (e.g. Web-based) educational environments are more prone to be designed to facilitate disembodied ways of learning and knowing, which is at odds with theories that emphasise contextual and embodied knowledge, such as embodied cognition theory. The new learning and training tools, such as VR simulators, have the power to overcome this issue by embodied actions.

The example offered by Shapiro et al. [77] might help better understand the concept of embodied cognition in education and why it is fundamental to implement it in future technologies for learning. They took a hypothetical classroom scenario where a science teacher wanted to introduce a new instrument, such as two bicycle wheels that could spin independently on a single axle, to their class for the first time. The teacher had a variety of options available to show the bicycle mechanism:
1) They could describe the mechanism verbally.
2) Show a video demonstrating the instrument's physical properties and how to use it.
3) Take students to a science laboratory to observe an experiment conducted with the instrument and the opportunity to experiment with the tool themselves.
The core message highlights how physical experience (example 3) can enhance learning through instructional manipulatives. The reason behind this can be seen in adopting the embodied cog-

nition theory: taking students to a science laboratory aligns with the principles of embodied cognition. It provides them a firsthand chance to engage with the environment and sensory experiences, enabling a deeper understanding of scientific concepts. Just as embodied cognition suggests, this hands-on approach allows students to acquire knowledge through active interaction and enhances their learning process [77].

In the prospect of VR for learning, haptic technologies that let learners feel force and pressure while interacting with the environment are now being applied to education in VE. Consequently, it is now reasonable to include kinaesthetic force and tactile feedback, along with spatial audio and video, as characteristics of the representational fidelity of the environment [77].

2.3 Virtual Training Simulations

2.3.1 Virtual Reality for Training

As mentioned, a new flow of interest and hype has emerged for IVR [78]. In particular, there is the belief that there will be more and more of a shift from low-immersive technology to high-immersive technology in several fields, explicitly focusing on education [52] [79]. Usually, the literature refers to low immersion as desktop VR. In contrast, high-immersion VR involves a head-mounted display (HMD) [52] [21]. The HMD unit consists of a helmet and displays built inside a pair of goggles [80]. HMDs also have a tracking system, allowing users to be located in the virtual environment [81] [78]. The previously mentioned excitement is partly driven by the heavy investments that big companies have employed and the introduction of new technologies [52] [1].

As a result, big companies, educational institutions, and researchers have been investing substantial resources in adapting high-immersive tools instead of traditionally standard educational desktop computers. The motivation is that a higher level of immersion is believed to increase users' learning outcomes [52] [15]. VR technology has assured a low-cost context, compared to physical training, where different skills can be acquired, and new knowledge can be achieved [3]. As a logical consequence, VR has been seen as a powerful tool to increase learning outcomes in a virtual environment for training (VTEs) [3] [82] [83]. As discussed above, a VR learning environment is an alternative and more immersive approach to the traditional lower-immersive one. The first can increase motivation and interest in learning, encouraging new knowledge acquisition [84]. Furthermore, Chen et al. [17] suggested that VR technology can provide new paths for reaching tactile and visual interactions, leading to better user performance.

Another enormous advantage of employing VTE is the repeatability of tasks in unlimited time, with the results of avoiding getting hurt and focusing on acquiring knowledge to transfer in other contexts [13] [14] [85] [82]. It is no surprise that VR has been used to train employees and students: virtual training is a training method that allows companies and institutions to provide computer-based and efficient training programs [85] [86]. Virtual training is a powerful tool where trainees may 1) acquire or increase their previous knowledge and skills, e.g., the fundamental know-how [21] [14] to perform effectively and time-saving, and 2) train their skills associated with their work or task, such as abstract reasoning or display complex information[86] [17]. Makransky et al. [21] and Morélot et al. [14] suggest that to reach this type of learning, immersion and sense of presence play a crucial role in the learning process in VTE.

2.3.2 Increase Learning Performance Through Virtual Training

In a 3D VR environment, users can interact with virtual objects and circumstances that can happen in the real world. The ability of this technology to simulate real-life situations is highly beneficial for learners [42]. Using VR systems in education is the most suitable alternative to traditional methods, such as textbooks and video [55] [42]. Furthermore, the application of VR in education can allow students to intuitively learn from their personal experiences [42]. Users can improve and learn from their errors by partaking in and making mistakes during the training sessions; consequently, they can learn from experience. In the virtual environment, as in VTE [82], trainees can experience circumstances close to the ones in the real world [42] [87].

These simulations are replicas of reality where actions have the same, but simulated, consequences as they would have in the real world (e.g., medical simulators) [87]. Hence, they are differentiated from serious games, where, despite sharing the features of simulations, they do not present the consequences of reality that a user would encounter in a simulation [87]. The unique use of VR and simulations can link theory and practice, allowing the users to understand abstract concepts and transport their knowledge in other contexts [86] [17]. For this reason, researchers emphasise the role of VR in education [78]:

1). It Increases the development of problem-solving skills [83].

2). It helps learners discover new concepts that were difficult to grasp before (due to the traditional learning method) [55].

3). It allows users to gain new knowledge with less effort than through standard methods [78] [79].

4). Finally, it makes the dangerous learning process more realistic [82] [9] [88].

Allcoat and von Mühlenen [55] conducted a study to consider the effects of using VR headsets for learning. They designed a 3D plant cell model for three conditions: 1) VR, 2) textbook style, and 3) video condition. Overall, the participants in VR and video groups showed better learning improvement than the textbook scores. This research demonstrated how VR can replicate or complement traditional learning methods. Finally, it was stated that VR seems to be a potential alternative to conventional textbook-style methods, with similar performance levels, improved mood, and engagement.

In Schwarz et al.'s study [82], the data results demonstrated that workers trained in VTE had positive retention and could transfer the newly acquired knowledge in real-life situations. After a training-free duration of five or seven days (depending on the workers' availability), the retention performance test was repeated to check the long-term learning transfer (retention test). Set up under natural training conditions, the trainers operated the VTE to teach a beginner learner assembly of line staffers a specific task: a car centre console assembly. The positive transfer of learning applied from the virtual to the physical domain points to the fact that the skills gained in VTE were used successfully and then retained; as a result, there was an increase in performance over time.

Once again, the previous results showed how training is fundamental for industries. In this regard, it was demonstrated how a VTE could help workers learn new procedures effectively [89]. Moreover, the results showed how, after a week's break, the results were similar to those studied at the end of the first trial. This study confirms that virtual reality training allows the learners to acquire an accurate knowledge of the procedure over time. In the same assemblage field, Babu et al. [90] showed how the implementation of VR could increase the recall rate in the experimental group during the delayed evaluation and enhance memory in the participants.

In education, a study using VR in science classrooms targetting middle-school students was designed to examine lessons' effect on learning performance [91]. The results revealed that the experimental group (VR setting) obtained significantly higher academic accomplishments and engagement scores than the control group, who completed the same content through traditional teaching methods in a regular classroom. Likewise, Angel-Urdinola et al.'s [92] research shows the positive effect of VR training on learning performance. The outcomes are indicative of the capacity of VR training to improve student's knowledge positively. The mentioned results are encouraging in the fields related to health and safety, engineering, and technical education [92].

Having discussed the possibility that VTE can transfer new knowledge to those who train, the next part of this paper will focus on the most studied fields researchers have focused on. In this regard, the current study takes Renganayagalu et al. paper [93] as a point of reference to divide and discuss VR application domains in training. The overall benefits of VR mentioned in their study are the chance for trainees to understand spatial relationships and concepts, retain information, and have contextual learning experiences [93]. Furthermore, VR helps to form realistic simulated experiences, enhancing training skill retention and performance. Finally, according to Renganayagalu et al., motivation and engagement are seen as particularly important, e.g. in safety training, as they were found to be more effective than in traditional training.

2.3.3 Healthcare virtual training

In healthcare, VR has emerged as a powerful tool, mainly for doctors and medicine students, that can virtually interact with the human body and training without risking the patient's life. With many successful training applications, healthcare is seen as one of the most mature domains where VR simulation-based training is applied. The reason is the wide range of applications studied in this specific domain [93].

Among the VR training applications, the medical area has adopted VR simulations for surgical training, showing excellent results in transferring technical skills [94] [95] [96]. In addition, VR has been demonstrated to be a helpful tool for clinical competence training for nurses [97] and improved performance in safety procedures in operating rooms [98].

VR technological tools can be employed to provide training in the sphere of the human anatomy. The results showed how VR techniques can be an incredibly advantageous tool compared to traditional instruments regarding knowledge transfer [99]. Finally, It must be said that VR systems in surgical training are more sophisticated and developed than in other fields due to the implementation of haptic devices that resemble the behaviour and real surgical tools. The findings stated that VR and haptics are useful in the early acquisition of complex motor skills [100].

2.3.4 Industrial training

Industrial training is one of the most studied domains regarding VR systems' benefits, as it allows learning and executing hands-on tasks in a safe environment [93]. Carlson et al. [101] showed positive results about long-term procedural knowledge transfer in training assembly workers: after two weeks, the VR-trained participants improved their test assembly times. Similarly, VR training was associated with a meaningful increase in knowledge and technical skills in the construction robotics and automation domain compared to in-person training. [102].

Despite research on whether VR training can improve task performance, skills behaviour, and task retention in construction, more studies are needed [102]. This limitation partly exists because evaluating skill transfer from VR-based training to real-world settings is challenging. In addition, if the task and the training are not performed correctly, the result can lead to an incomplete training experience for the learners. Consequently, knowledge transfer cannot happen as the learning transfer can occur only when a task is similar to the domain knowledge, and the person can perceive this similarity [101].

2.3.5 Aviation training

As mentioned in the previous Section 2.3.2, VR training is beneficial as it allows the trainers to acquire skills through unlimited time without being at stake repeatedly [13] [82]. Naturally, the space domain has adopted VR as a practical training. VR training for space operations is crucial due to the restricted chances to perform hands-on tasks, which are limited in the real-life world [17]. VR training for pilots [103] showed positive results comparing pre and post-training sessions in the VR simulation. In general, the use of flight simulators at all levels of pilot training has been demonstrated to positively affect students' performance during the training courses [103]. However, more research needs to be conducted as, to the best of my knowledge, there still needs to be more studies on this field.

2.3.6 Defense training

Simulation methods, including virtual reality, have substantially developed and improved skills training in several domains. The military is no exception: this specific domain has relied upon simulation-based training in VR to keep soldiers ready. The army has employed VR in defence training programs, from basic shooting training [104] to more immersive simulations. VR simulations have been confirmed to be a soft transition for younger generations of troopers who have grown up with computer games such as Nintendo and PlayStation. With sophisticated tools like HMD products, soldiers can adapt effortlessly to immersive VR simulation training [105].

For instance, VR-based training for military training showed higher values in terms of interest, reality, immersion, and understanding compared to the existing training method of video content-based training [106]. One significant example is Singer et al.'s study [107], which investigated the effects of different VE parameters on spatial knowledge acquisition by comparing learning in advanced VE, restricted VE, and traditional map training. The final results demonstrated that employing more interactive VE leads to better spatial knowledge than through the equivalent practice with topographical maps.

2.3.7 Safety and emergency virtual training

VTE can effectively simulate several situations of work and life and, at the same time, support the learning process [9] [3]. VR simulations are promising when training under real-life conditions is hazardous for human lives [9] [88]. Therefore, remaining with a passive training programme will only keep the performance and learning outcomes low, compared to a more dynamic and engaging training process through VR technology [79]. Several researchers adapted and employed VR training simulations for risk assessment in different areas, such as construction [88] and mining [9], to close the gap between hazardous situations in the work fields and the poor management of safety procedures.

In the construction industry field, Patil et al. [37] suggested a significant benefit of using VR technology within construction safety training: workers would be encouraged to be more engaged within the learning environment; moreover, they might also increase their long-term knowledge retention —likewise, Hafsia et al. [88] raised the discussion around the risk of injuries that is present in the practical session during the training. They believe that VR might offer risk-free training and, at the same time, raise awareness of health and safety problems in the construction field. The researchers developed a training virtual reality application for construction workers to demonstrate that. The results show a positive interest from the experts who tried out the simulations. However, the testers underlined the negative aspect of not having tactile sensation or force feedback.

As previously mentioned, VR seems incredibly valuable in situations where the lives of human beings are at stake. Workers can recognise better hazardous operations by enhancing human abilities and training them [9]. Results revealed the outstanding use capability of IVR for risk estimation [7], and how the use of VR training simulation improved trainee's procedural learning, motivation and quality subjectively assessed of the overall learning experience [8]. Similarly, Cooper et al. [108] demonstrated in their study how training in VR systems improved performance for real-life tasks.

2.3.8 Disagreement in the literature

The previous paragraphs showed how simulations had been universally embraced to support training in several domains, resulting in increased learning outcomes and technical skills. Nevertheless, limitations and challenges are included, and more research needs to be conducted to test the data's validity and reliability [1] [22]. Regardless of the consistent benefits VR training simulations can bring, the scientific community tends to differ on whether training through VR simulation can enhance learning outcomes [23]. The literature, for instance, reports studies where there is no noteworthy difference in learning outcomes between physical training and desktop computers compared to virtual mediums on learning gain [11] [15].

One remarkable example [109] attempted to determine the effects of having participants interact with virtual scenarios using their hands compared to using physical materials in a scientific research context. The results showed no differences between training through VR and physical hands-on activity. Likewise, it was demonstrated that while VR training is an effective and encouraging teaching technique for maintenance tasks, traditional approaches with hands-on experience still lead to better learning outcomes [110]. Finally, regarding the level of presence, usability, and recall performance, no differences were found between the two VR interaction methods and the desktop training condition to study and decide the influence of the factors mentioned [111].

The experiment cited above aimed to compare and determine the effectiveness of training procedural tasks in two simulated environments: VR (gesture-based and voice-based) and desktop. Based on a previous theoretical framework [112], more immersive simulations, such as the VR method, should enable a greater sense of presence and foster higher learning outcomes. However, The experiment results were contrary to the said theory; as a consequence, more studies need to be carried out to investigate further the role of presence in the learning outcome gain process. Furthermore, future researchers should investigate the role of other design factors affecting recall information, such as interactivity (e.g., natural gestures) and sensory feedback, like haptic feedback [111]. As previously stated by different researchers, a possible cause of the difficulty in determining the true impact of learning through VR training simulations might be the absence of haptic feedback implementation [26] [24].

Despite the ambiguity regarding the sense of presence and its link with the learning gain process, a previous study has shown that presence and the subjects' performance increase as more sensory stimuli are performed in the VE, thanks to the multisensory integration [113]. Multisensory integration is the procedure through which the brain merges information from independent, temporally aligned signals derived from multiple and different sources, such as vision, auditory and tactile, into coherent representation [114]. The experiment aspired to investigate whether and how auditory and vibrotactile stimuli (alone or combined) proposed together with the visual targets in two distinct conditions of perceptual load (low and high) could: 1) improve the learners' detection performance, 2) enhance their sense of presence in VE, 3) control the mental workload, 4) increase the processing and detection of environmental stimuli.

From what has been said above, integrating different stimuli is essential to enhance the learner's performance [100]. Just like visual and auditory cues, the sense of touch can affect attitudes, behaviour and judgements [37]. Incorporating haptics feedback (e.g., vibration) in the VR training for military and emergency personnel made the training process more effective, meaning that trainees made fewer errors and finished the simulation faster [115]. In this regard, haptic feedback enhanced interaction, spatial guidance and learning in VE. Meanwhile, multisensory integration feedback can improve overall task performance and the sense of presence [26]. In addition, integrating force feedback in virtual training has enhanced participants' completion times and task performance better than those trained without experienced haptic feedback [116].

While VR tools and haptic feedback have been employed in several domains, their use has been mutually sole of each other. However, studies, including the ones mentioned in the previous paragraphs, suggest that providing haptic feedback within VE can enhance learning performance, sense of presence and realism [37] [117]. There is progress in implementing haptic cues in VR training, although notable challenges can negatively impact tasks' overall efficiency when haptic cues are presented [108]. It is clear then that agreeing on whether these features can lead to better learning effectiveness is complex; further complicating matters is the need to discern different learning outcomes, which has become a recurring study matter. Scholars must also determine whether other methods and devices have a role in increasing user learning and effectiveness in a virtual training learning environment.

2.4 Haptic feedback

2.4.1 Kinestheric and cutaneous senses

Haptic feedback has been widely the object of attention of several researchers [32] and used to increase the realism of VR environments. The term "haptic feedback" refers to stimulating the human sense of touch by a VR interface [27]. Two classes of haptic feedback for virtual reality simulation can be distinguished: kinesthetic (inertia, shape, weight, and deformation) [34] [118] [119] using motors or other actuators that sense the position and movements of muscles and bones, and tactile feedback (temperature, vibrations and texture) that uses small actuators (usually on fingers) to evoke the cutaneous tactile feel [120] [121] [27] (Figure 2.1).

The ***kinesthetic*** sensation delivers information on the position and limbs in time and space and notions about the muscular effort to the central nervous system to guide the body's movement. An example of kinesthetic sense is the force feedback type, which exerts forces on the human body's parts like limbs [123] [119]. Force feedback devices can display force and torque,

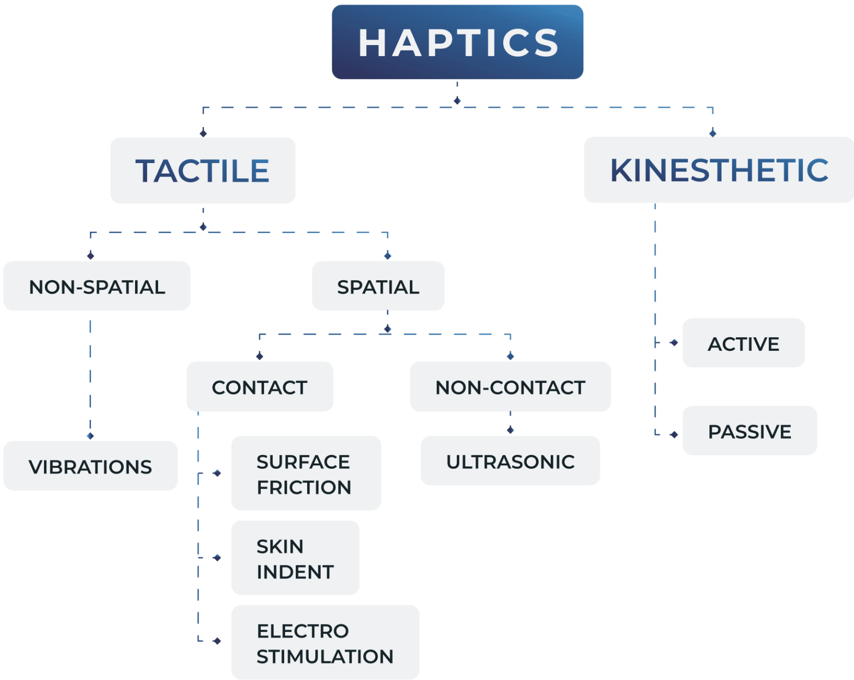

Figure 2.1: Haptic feedback diagram [122]

allowing users to feel resistive force, friction, etc. [124]. The second type of feedback, the ***cutaneous***, provides the central nervous system input from various skin receptors. An example of cutaneous feedback is the vibrotactile one [123] [120].

Some elements are involved to allow the haptic system to work successfully. It requires sensors, actuators (motors), actuator contort systems (microprocessors), haptic software, and user interfaces. The haptic system works as follows:

1) What the haptic feedback or notification alerts symbolise must be considered to transmit information to the user. These inputs can be an external physical sensor or an internal trigger like a pre-set time alarm for a watch.

2) Whatever the information is, a host processor must make alerting decisions and communicate with the haptic driver. Today, cheap and highly integrated haptics processors are available; they include the actuator driver libraries of haptics effects and are fully licensed and royalty-free.

3) Once the processor decides, a haptic driver is required, as microcontrollers and processors cannot supply enough current to drive a haptic actuator. The haptic driver receives a control signal from the microcontroller and drives the actuator.

4) Finally, the haptic actuator produces the output (for instance, vibration feedback) [125] (Figure 2.2).

One example of a traditional kinesthetic haptic device is the Phantom Premium [120]; it en-

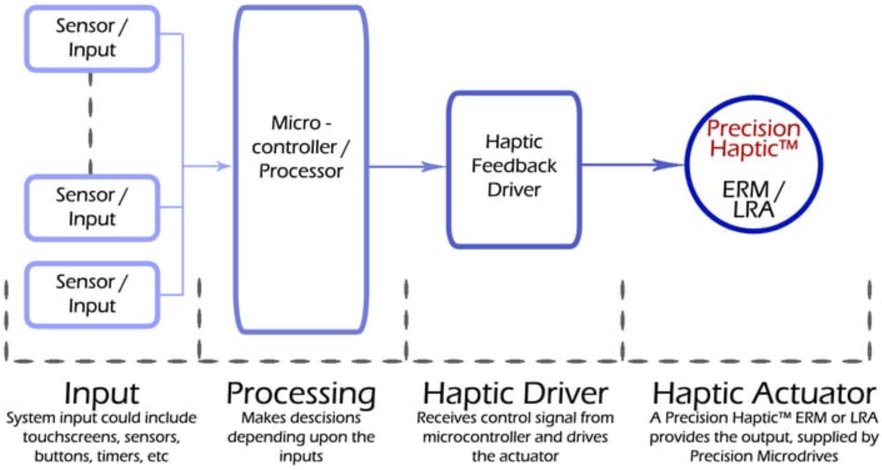

Figure 2.2: How a basic haptic feedback system works [125]

ables three degrees of freedom (DoF), high force, and high-bandwidth force feedback. Another visionary haptic device is the CLAW controller [34], which includes the expected functionality of a VR, such as buttons and thumb joystick, controller and allows a variety of haptic feedback, such as grasping, triggering, and touching. The haptic feedback included are finger forces when the user grasps an object and the realistic trigger feedback while shooting.

Regarding tactile feedback, one of the most widely studied and generally used is vibrotactile feedback (e.g. game controllers and mobile phones) [126]. Benko et al. [126] designed two controllers, NormalTouch and TextureTouch, to investigate the role of mechanically actuated held controllers' role in rendering virtual objects' shapes, enabling the users to feel 3D surfaces, textures and forces that matched the visual rendering. Their findings suggested that both haptic feedback significantly increased the accuracy of VR interaction compared to two standard VR controllers that used only vibration or visual feedback.

2.4.2 Benefits and limitations of haptic feedback in VR in the literature

Based on Webb et al.'s literature review [23], whether haptic feedback is crucial for students' learning, adding haptic feedback to a VR system provides a more complete and authentic experience. Therefore, haptic feedback might be a convenient feature enabling users to acquire different types of knowledge, such as retention of information and procedural knowledge, in an immersive virtual training environment. Moreover, implementing haptics has been shown to have positive learning outcomes across various disciplines [63]. Haptic feedback interactions between learners and technology have been demonstrated to be beneficial for developing procedural skills [114]. In contrast, research into whether haptic feedback may affect the development of understanding and memory retention is much more limited [23]. In this regard, Webb et al.'s study [23] mentioned the understudied area concerning VR of haptic feedback's importance for learning, particularly regarding the possibility of haptic feedback in improving factual knowledge. They also added that short-term performance can be enhanced by providing haptic feedback.

In the same way, only a few published studies exist to determine the long-term training efficacy and outcomes of VTEs that provide augmentation or guidance in objective tasks. The current results are inconclusive or contradictory [69]. Previous studies have shown that adding haptic feedback to VTEs can provide benefits over visual and auditory displays for performance enhancement, increasing agility and the sensation of realism and presence. Haptic feedback effectively enhanced interaction, spatial guidance, and learning in VTE [26]. Overall, haptic feedback and stimuli of other senses besides visual and auditory senses can impact the quality of immersion in VR [26].

Nevertheless, only a few studies have explained how two types of learning outcomes, procedural and factual knowledge, can be achieved over time in IVR, compared to short-term performance [21] [28] [29]. Furthermore, the few works that have tried to examine it carry mixed results [31] [11] and the main reason for this uncertainty can be seen in the lack of haptic device employment [11] [32]. Agreeing on whether adding haptic feedback in VR can increase the learners' performance and, equally important, what type of learning outcomes can be improved is a problematic matter. The scientific community needs to debate haptics' role in VR further and conduct more studies regarding their implementation in virtual training simulations.

2.4.3 Haptics for virtual training simulations

A big area where haptic devices and feedback are employed is virtual training simulations, particularly within the medical field; nonetheless, this is slowly growing to other training applications [127]. Multiple studies support the use of simulators together with haptic feedback, showing positive effects in skills training. The following section will focus on the research using haptics in a VTE to increase two specific types of learning outcomes: procedural and factual knowledge.

Gani et al. [117] conducted a study to evaluate the educational influence of integrated haptic feedback in an IVR bone drilling simulation regarding the performance of a cohort of junior surgeons. All participants completed an immersive VR training module with either haptic feedback activated or no haptic feedback, in which they had to drill three bicortical holes in a virtual tibia bone model in preparation for screw insertion, followed by a similar task on a virtual tibia sawbone model; again, the participants had to drill three holes through both cortices and tibia. Their findings supported the role of haptic integration in a VR training simulation in better performing an orthopaedic surgical task than without implementing haptic feedback.

Han et al. [128] investigated in their study the effectiveness of a haptic simulation in learning physics. The experiment was conceived to examine the efficacy of haptic feedback in an augmented simulation of elementary students' creation of a multimodal model of how gears work. Their findings indicated that haptic feedback, both the force and kinesthetic and the purely kinesthetic simulations, were more effective than the equivalent one with no haptic feedback in providing perceptual knowledge. In addition, the force and kinesthetic simulation effectively transferred knowledge to a new learning situation, improving memory retention.

Jian et al. [115] reported in their study the effectiveness of haptic feedback in a low-cost VTE for military and emergency staff during two experiments. The participants participated in a simulation where they had to clear a damaged building. This first experiment aimed to investigate the effects of haptic feedback on a user's ability to remember and execute functions in VR. It showed fewer errors by users performing a task with either vibration or force feedback. After the first tests, both feedbacks resulted in tremendous and equal positive results regarding performing fewer errors, compared to a situation where haptic feedback was not involved. On the other hand, the second experiment evaluated the effects of vibration feedback on a subject's body during VR training. It improved speed and accuracy recall, using small vibration feedback devices mounted to the participants' heads and legs.

Qi et al. [64] studied how an educational simulation could impact learning physics concepts related to buoyancy. They designed a desktop virtual environment to emulate and visualise different characteristics of a buoyancy simulation in real-time. To date, mine, the effects of haptics and visual feedback on participants' learning, performed a 2 (haptics: yes and no) x 2 (visual: yes and no) between user study. The results highlighted that participants improved their understanding of buoyancy, as calculated by a pre and post-test assessment when both haptics and visual feedback were employed. However, the same increase in performance was not seen when participants delivered haptics or visuals alone.

The reviewed studies consistently prove the positive impact of haptic feedback in virtual training simulations across various domains. Together, these studies highlight the beneficial role of haptic feedback in enhancing learning outcomes, from medicine to education fields and emergency training.

2.4.4 Interaction of Haptic Gloves in Virtual Reality

Several studies on the advantages of employing haptic feedback in a VR training simulation were illustrated in the previous paragraphs. Nevertheless, it is essential to acknowledge that implementing haptic feedback in VR may have some drawbacks. For example, prolonged use of haptic devices, such as haptic vests, can lead to discomfort; furthermore, little is known about the best and most lifelike type of haptic feedback to be integrated into VR simulators [129]. Finally, the development of VR requires a new kind of haptic feedback that allows the user to move in a large workspace and supports the user to use different gestures with the full Degree of freedom (DoF) of fingers for the most natural manipulation [130].

Here, haptic gloves appear as a promising solution. A haptic glove is a typical wearable haptic device; its primary functions incorporate multi-DoF whole-hand motion tracking and providing distributed force and tactile feedback to fingertips and the palm [130]. Haptic gloves allow users to employ the feedback mentioned to touch and manipulate virtual objects naturally and intuitively via hands' dexterous manipulation and sensitive perception capabilities [130], addressing the need for accurate and immersive interactions within the VR landscape. More studies developing prototypes of force feedback gloves have been created to provide more realistic haptic sensations [131]. In addition to these developments in the research on haptic feedback's potential, some researchers have used gloves and thimbles to create the illusion of touch in VE [132] [121] [133] [118]. These studies sought to assess the usability and performance of the haptic illusion when interacting with the VR environment.

Based on Yi et al. literature [129], the design of haptic gloves should take into consideration three main factors:

1) Realism. The user should experience the force feedback without distraction based on the level of immersion experienced in the virtual simulation. The use of haptics in VR should be as much the same as possible as the simulated one from the real world to increase the immersive experience.

2) Performance. Performance can be defined as the glove's durability, stability, and repeatability. The gloves should be recalibrated for every user, perform the exact as the user moves and fit well to the user's hand.

3) Comfort. The user can put on and keep on the glove for a relatively long period without discomfort. A comfortable glove is also adjustable, available in different sizes, relatively light, and non-disruptive for the users.

The current study implemented vibrotactile and forced feedback haptic gloves (SenseGlove Nova, Section 2.4.5) that provide haptic feedback in a VR training simulation. The present research will illustrate only a few devices closely aligned with the one utilised in the current research.

To begin with vibrotactile feedback, Cheng et al. [134] can be mentioned among the earliest publications. They designed haptic gloves, including spatial tracking and vibrotactile elements at the fingertips, to compensate for the high price and complexity that force feedback interfaces usually presented. During the 2000s, further developments focused on enhancing tactile sensitivity [135] and even new application domains. One of these new areas was the medical and rehabilitation one; for instance, enabling blind people to detect facial expressions through vibration patterns non-visually [136]

Regarding force feedback, the CyberGrasp is the most famous and trendsetter of all commercial exoskeletons [137]. It is an example of "portable hand masters." It can apply forces to the fingertips, but the reaction forces are used locally to the user's hand or forearm rather than a stationary platform. Consequently, the realistic recreation of forces internal to the hand, such as grasp forces, is possible. Still, pursuing external forces, such as those that occur from reaching a surface in the environment, can give rise to unrealistic feedback.

In Shor et al.'s study [133], they explained the development of a custom-built interface between a force-replicating VR haptic glove and a user. As they stated, the capacity to convey haptic information – both kinesthetic and tactile – is a critical obstacle in creating comprehensive simulations. Their goal was to get effective interactions with virtual objects, such as grasping, squeezing, and pressing, by improving one haptic interface gloves, the SenseGlove DK1, by redesigning the user-gloves interface, the Soft Glove. The redesign revolves around three critical design factors, also mentioned by Yi et al. [129]: realism, performance, and three essential areas of design: thimble/fingertip, palm, and haptic feedback.

The initial version of the SenseGlove product line, DK1, integrated unidirectional force feedback into finger movements related to grasping. This was achieved by employing a magnetic friction brake for each finger, preventing further extension, and incorporating vibration feedback. To date, no or little research has been conducted using force and vibrotactile feedback implemented in a haptic glove. Moreover, SenseGlove haptic gloves respond to the three main factors reported in the previous paragraphs compared to CyberGrasp; SenseGlove DK1 can deliver a complete experience in a VE, thanks to its maximum force between 12N and 20N against 12N of the CyberGrasps and the ergonomic features that enable the user to move freely around the space [133] [138]. Finally, CyberGrasp might only be feasible for some sizes and shapes of hands; instead, Sense Glove offers more customisation options [139].

Baik et al.' [140] employed a notable haptic glove for their research by developing one that can provide force and cutaneous feedback to a user's index finger and thumb using a tendon-driven mechanism. The kinesthetic feedback of the haptic glove is implemented by applying force on two joints of a finger. Also, a contact plate at the fingertip delivers cutaneous feedback by pressing the user's skin and pulling the tendon. Their results indicated an increase in realism and in the perceived understanding of contact force. Their system's main advantage is the index finger's two-motion DoF. Furthermore, adding cutaneous feedback can improve a sense of presence rather than just applying force feedback. However, when comparing it to SenseGlove DK1 and Nova (Section 2.4.5), the Baik at al. haptic gloves offered fewer DoF. SenseGlove's haptic gloves, in contrast, provide an impressive 11 degrees of freedom for each hand. Furthermore, force feedback is applied to all of the fingers and thumb in SenseGlove's haptic device, whereas Baik et al.'s system can only be used on the index finger and thumb.

Several haptic gloves are commercially available, such as Dexmo (Dexta Robotics, Shenzhen, China), HaptX (Seattle, US) [140] [138]. Nonetheless, to the best of my knowledge, these haptic devices have never been employed in scientific research. Therefore, for the scope of the current study, these haptic gloves will not be discussed or compared with the ones used in this study.

2.4.5 SenseGlove Nova

In the current study, a vibrotactile and force feedback haptic glove, ***SenseGlove Nova***, was used to provide haptic feedback to the user in a virtual simulation (Figure 2.3). SenseGlove Nova offers an innovative solution for IVR experiences. As illustrated by Shor et al. [133], the first version of this unique tool tracks the user's movements and provides precise haptic feedback when interacting with virtual objects and environments. SenseGlove Nova has been primarily designed to help train technical professionals, such as aircraft mechanics and assembly line workers [139]. Its interface delivers two distinct types of haptic feedback: force and vibrotactile feedback [133]. Aligning with Yi et al. [129] literature three principles, Sense Glove's design emphasises realism, performance, and comfort.

Whenever a user grasps an object in VR, the actuators of brakes are more applicable to each finger, apply force and prevent each finger from closing further [131]. By using resistance through its magnetic friction brakes, SenseGlove Nova emulates the feeling of size and stiffness. The Nova model incorporates four brakes committed to each finger and the thumb; the brakes go from the index to the ring finger, plus the thumb [139]. Each brake furnishes up to 20N of force, comparable to the weight of a 2 kg brick on each finger, making for outstanding force feedback [139]. The different force levels transferred to the fingertips via mechanical wires enable SenseGlove Nova to enrich training simulations involving various objects in VR,

Figure 2.3: The SenseGlove Nova, Source: SenseGlove Nova [122]

including items that go from rugged machinery to rubber duck items.

In addition to the force feedback implementation, SenseGlove Nova has embedded advanced actuator technology to render the feeling of realistic button clicks, vibrations and impact simulations [139]. The vibrotactile actuator is both on the thumb and index finger, while the voice coil actuator is situated in the hub of the glove [139]. Finally, SenseGlove Nova incorporated sensor-based finger tracking. There are four sensors to catch the flexion and extension of three fingers: the middle, the index and the ring fingers, and one sensor to grasp the abduction and adduction of the thumb. These movements are captured by assessing the extension of the cables on the glove [139].

The SenseGlove has a place among the new controller generation and interaction design [138]. Unlike the older input devices, interaction devices rely on advancing computing power to deliver a more intuitive control experience. Before VR, users had to translate their desires into a list of computer-generated actions [139]. Now, in VE, this change comes to the forefront [139]. Training, learning, and collaboration tasks come together seamlessly within VE. By using traditional controllers, a user was forced to filter their desires through a series of actions, for instance, that require button pushes and trigger pulls. Instead of focusing on the training session, the user's attention must be divided between learning the environment and the material.

Interaction tools such as SenseGlove Nova enable the user to perform tasks in the VE that can be transferred back to real-life interactions. The kinesthetic feedback causes the user to adopt similar behaviours and gestures required by the everyday world, while the tactile feedback adds immersion and realism to the interaction process. VR decreases the time spent on learning a specific task, but more importantly, it reduces the number of errors made on the exercise trained in VR. Haptic feedback commonly concentrates on tactile or force feedback, but rarely both; SenseGlove Nova has broken this circle by implementing kinesthetic and tactile feedback. [27].

2.5 CAMIL model

As it has been raised multiple times in previous research, finding whether and how an immersive virtual environment can enhance learning is complex. In this regard, Makransky et al. [21] created a theoretical framework called the ***Cognitive Affective Model of Immersive Learning*** (***CAMIL***) by summarising the existing findings on IVR in education and training. In general, the model framework points out that instructional methods based on evidence from research with less immersive media can be generalised to learning in IVR. Figure 2.4 displays the constructs included in CAMIL and the connections between these constructs.

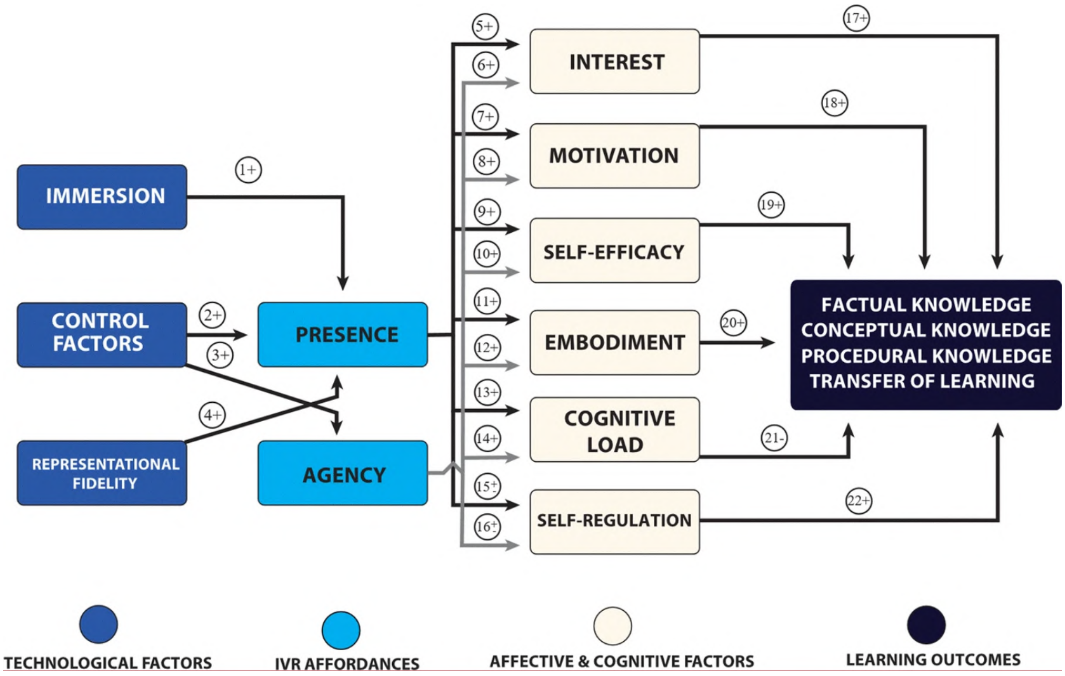

Figure 2.4: Overview of the CAMIL model, The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality [21]

The CAMIL recognises presence and agency as the prevalent psychological affordances of learning in IVR and illustrates how immersion, control factors, and representational fidelity ease these affordances [21]. The model depicts six affective and cognitive features that can lead to IVR-based learning outcomes: interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation. Finally, the said model also describes how these factors lead to factual, conceptual, and procedural knowledge acquisition and knowledge transfer.

2.5.1 The Perspective of CAMIL

The CAMIL theory suggests that the effectiveness of learning in IVR is determined by the technology and the instructional methods used within IVR training. These methods must align with the unique capabilities and advantages of the IVR medium. Stated it is not just about using VR; it is about using it to leverage its specific strengths to enhance the learning experience [21]. This idea aligns with the current study that acknowledged immersion as being amplified by integrating VR with haptic feedback. Thus, interaction and immersion are presented to traditional learning methods but are more significant within IVR or other future immersive technologies. Therefore, presence and agency, both psychological constructs that arise from immersion and interaction, will be higher in immersive media. As a result, instructional methods that enrich learning through higher presence and agency will increase specifically learning through immersive technology.

Regarding instructional methods, it is also possible that the capabilities of a medium enable an instructional methodology, such as the embodied principle, a type of instructional methodology based on the theory of embodied cognition (Section 2.2), suggesting that physical actions and sensory experiences play a significant role in learning [21]. The said theory aligns with applying haptic feedback in a VE to increase learning. Haptics allow learners to feel the VR environment and interact by physically touching virtual objects. CAMIL predicts that this embodied principle would be more effective when learning through an IVR lesson than a traditional medium (e.g. video), as learners generally will have a higher sense of presence in IVR. In addition to that, CAMIL also predicts the said principle causes learning in an IVR, supporting the method perspective.

The current research used the CAMIL model as a guideline to justify and demonstrate how the interaction between haptic feedback and VR can achieve procedural and factual knowledge. However, the focus was only on achieving learning outcomes through immersion and interaction instead of considering "control factors" and "representational fidelity" as CAMIL model frames; those other two features were not varied in the study and were outside the scope of the study.

Control factors. Control factors are variables or elements manipulated or controlled during an instructional experiment or study, such as how much control a person has during the experiment. By saying that it will not be varied within the study, these factors are intentionally kept constant or unchanged throughout the study.

Representational fidelity. Representational fidelity refers to how accurately a VE or simulation reproduces or represents the real world or a specific context. It contains factors like the realism of visual and auditory cues, the accuracy of object representations, and how closely the VE resembles its real-world replica. High representational fidelity means that the virtual environment closely simulates reality regarding appearance and behaviour. In other words, representational fidelity relates to the accuracy of the virtual representation.

Immersion. On the other hand, immersion is a broader concept containing various factors contributing to a user's feeling of being "immersed" in a VE. It is not limited to visual or auditory fidelity but includes the overall engagement and sensory experience. Immersion can be affected by sensory feedback (including haptic feedback), interactivity, the user's sense of presence within the environment, and their ability to interact with and influence the virtual world. Immersion is a more holistic measure of the user's overall experience in the VE.

The same discussion can be made for excluding the sense of agency, which was not the scope of the present research: the said research considered only presence enhanced by haptic feedback in VR as the only single affordance of learning. Additionally, as the focus was only on achieving learning outcomes through immersion and interaction, as the CAMIL model illustrated in Figure 2.4, immersion does not directly influence the sense of agency. Based on previous studies, force and vibrotactile feedback can influence the sense of presence in VTE [26] [33] [34] [35] [71].

Likewise, four out of six factors described in Makransky et al.'s model [21] positively correlate with haptic feedback. As a result, this research focuses on interest [36] [37], motivation [38], embodiment [40], and self-efficacy [42] [43]. Regardless of being previously studied with positive results, this research examined them for the first time, aiming to explore procedural and factual knowledge over time. The studies focused on a possible positive correlation between haptics and cognitive load and self-regulation showed, in the end, a negative correlation [141] [142]; therefore, this study did not consider cognitive load and self-regulation when exploring possible factors that lead to an increase in learning outcomes.

2.5.2 Immersion and Presence in Virtual Environments

Presence and immersion are predominant parts of the learning process in VEs [21]. The definitions of immersion and presence have become essential in the literature of VEs, but there might be some overlaps in their meaning [14].

Regarding ***immersion***, Morelot et al.'s literature [14] described it as a technology that also explains how computer displays can provide a vivid illusion of reality to the user's senses.

In particular, immersion is entirely defined by the bodily properties of the VE: the extent and quality of tracking of user movements, the range and fidelity of perceptual feedback, and the interaction between them [71]. Immersion and realistic multisensory channels are positive elements in the learning process, as demonstrated in several studies [24] [11]. In the context of the CAMIL model, using VR and haptic feedback in tandem can contribute to incrementing immersion in VE. Immersion in VR involves feeling fully absorbed and engaged in virtual simulation, and haptic feedback can enhance the said sense of immersion.

If the level of immersion relies on the technology employed, the sense of ***presence*** is a subjective factor linked to the sensitive and cognitive experience of the user [14]. Presence is commonly understood as a sense of "being there" in VE [143]. VR technology comes between users and their natural environment; it involves their perceptual apparatus, so people engage with the VR-generated VE. Then, the people's perceptual apparatus tells them they are in the virtual rather than the natural world. This argument is the essence of presence. To this understanding, as long as VR provides users with an environment they can make sense of as they interact, they should expect to feel some sense of presence [71].

The CAMIL model regards immersion, control factors, and representational fidelity as the main factors encouraging a sense of presence in VEs. As mentioned in the previous sections, only immersion will be considered the primary element affecting presence (Section 2.5.1) in the current study. Therefore, based on the model, the extent of sensory information presented can influence and increase the sense of presence in a VE [21]. This construct concerns the degree of immersion offered by the system in question. Furthermore, the CAMIL model differentiates between three components of presence: physical, social, and self-presence [144].

Using Lee et al.'s definitions [144], physical presence can be seen as a psychological condition in which virtual physical objects are experienced as actual physical objects in either sensory or non-sensory ways. The second type is portrayed as a psychological state in which virtual social players are experienced as real social players in either sensory or non-sensory ways [144]. Finally, self-presence is depicted as a psychological state where the virtual self is experienced as the actual self in either sensory or non-sensory ways [144]. The current research used physical presence when considering the specific type of presence studied.

2.5.3 Haptic Feedback and Presence

Defining presence concerning haptic feedback is a complex subject for which several approaches have been published. As mentioned in Section 2.4.2, different kind of haptic feedback has consistently shown their potential not only to enhance task performance but also to elevate the user's sense of presence [33] [145]. This assertion underlines the connection between presence, practical task completion, and haptic feedback features.

In the context of VR, the embodied theory (Section 2.2) suggests that active interaction within VR environments, significantly enhanced by haptic feedback, intensifies the sense of presence in the virtual world. As the current research focused on implementing haptic feedback in a VR training simulation to enhance procedural and factual knowledge, it is clear that the close relationship between embodiment, interaction, and haptic feedback has a fundamental role in achieving the research goal.

Rose et al. [146] studied the result regarding haptic feedback on both extremity upper and lower kinematics and performance and concluded that haptic feedback improved interaction, spatial guidance and learning outcomes in VR environments. Furthermore, Cooper et al. [147] underlined that substitute multimodal sensory feedback could enhance general task performance and the user's perceived sense of presence.

In the view of the CAMIL model, interaction and presence are enhanced by integrating haptic feedback into VR, thereby emphasising the efficacy of the instructional method that used the implementation of haptics in a VR training simulation [21]. CAMIL focused on interaction and immersion in VR as actors of learning outcomes, which perfectly joins the current research approach (Section 3). The said research aligns with the CAMIL model, which states that it is not the VR medium per se but rather the instructional methodology within VR training that effectively holds the unique affordances of the medium [21].

2.5.4 How Do Presence Influence Situational Interest, Intrinsic Motivation, Self-Efficacy and Embodiment

This section will illustrate the four factors based on the CAMIL model influencing the different learning outcomes. As explained in 2.5.1, only four out of six will be considered and investigated regarding their role in enhancing procedural and factual knowledge in IVR. The central hypothesis is that improving these four factors through haptic device interaction will increase learning performance and memory retention in a short and long time.

2.5.5 Situational Interest

Interest is a psychological construct that embodies a relationship between a person and a specific topic or content domain and is characterised by both cognitive elements [21]. Its meaning and importance in the learning process have been severely studied over the decades [148], and the researchers have recognised two types of interest: situational and personal [149].

Situational interest [150] is a temporary and context-specific interest that arises when a person becomes engaged or curious about something in a specific situation or environment. It's often triggered by external factors or the novelty of a situation. The circumstances or the immediate environment typically drive situational interest. For example, a student might develop a situational interest in a science experiment conducted in class, even if they do not generally have a deep interest in science. Personal interest [150] is a long-term and intrinsic interest in a particular subject, hobby, or domain. It reflects an individual's durable passion for or curiosity about a specific area of knowledge or activity. For instance, someone who loves astronomy and stargazing has a personal interest in the cosmos that extends beyond any specific situation.

In this study, only situational interest was considered and defined as the focused attention and effective reaction activated in a specific moment by certain stimuli. It is spontaneous and increases learning when a task or to-be-learned notion is new [148]; it can also be increased when wanting to know more about specific information. Researchers have noted interest experienced by a learner during training or a lesson as a critical driver of long-term engagement with learning [37].

Based on the CAMIL model, one factor that can enhance interest is presence, supported by several empirical articles investigating the outcomes of educational interventions in IVR [21] [52]. IVR environments can promote generative processing by providing a more realistic experience, resulting in a higher sense of presence [71]. Therefore, it causes the learner to put more effort and actively engage in cognitive processing to form a coherent mental representation of the knowledge and experience, leading to learning outcomes. IVR creates a stronger sense of presence, which leads to higher engagement, interest and motivation and, finally, a more profound cognitive processing in the learning process [52]. In other words, an increased presence in a realistic VE may constitute a new and intense experience, triggering one's interest in the moment.

In Shen et al.'s study [141], they discussed and measured the impact of VR intervention on students' laboratory skills, cognitive load and learning motivation. For their study, they divided participants into four groups: a gesture interaction group, a controller manipulation, a haptic training group, and finally, a flat display control group. The tests result in an increase in cognitive load due to the additional perceptual channels. However, unlike the cognitive load, the haptic implementation improves participants' learning interest.

2.5.6 Intrinsic Motivation

Intrinsic motivation refers to the internal conditions that result in pursuing specific goals [151]. Autonomy, competence and relatedness are essential needs that should be achieved to develop intrinsic motivation [21]. Bowen et al. [151] reported that VR provides content-specific, fascinating, authentic learning experiences that can affect academic achievement and motivation. One factor that can lead to an increase in motivation is presence. In Makransky et al.'s literature [21], it was stated that higher presence was associated with a higher cause, resulting from an increase in the learning outcomes.

In addition to presence, employing haptic feedback in an IVR environment can support motivation. The haptic modality was found to have a more substantial motivating effect than the mere visual or auditory modalities [152]. MA et al.'s study [39] developed an educational application with a haptic device to investigate the effects of force feedback on self-learning. Participants in the experimental group used a designed application to study friction using force feedback, whereas participants in the control group examined the same knowledge without force feedback. Their findings showed that force feedback was beneficial within an education context, and using a haptic device can improve the user's motivation.

2.5.7 Self-Efficacy

Based on the CAMIL model, the subjective measure of ***self-efficacy*** is one of the cognitive affordances that impact the learning outcome. It can be defined as people's personal belief about their ability to fulfil a specific task [153]. More and more self-efficacy has gained attention within the scientific community, as it has been positively connected to the IVR modality and learning outcomes [153]. Thus, it is crucial to investigate this subjective perception in different training modalities to investigate their relationship with training effectiveness.

Radhakrishnan et al. [153] found through their study that participants in the VR condition noted increased self-efficacy and immersion. The goal's study was to investigate the effectiveness of IVR for training participants in the so-called "buzz-wire" fine motor skill task compared to physical training. Yovanoff et al. [154] tried to understand how dynamic haptic training could be used to design surgical skills in a training environment. Their principal findings showed how medical students had boosted trust in their ability to perform the skills necessary to operate. They suggested that students can be trained on the Central Venous Catheter (CVC) using haptic simulators as powerful as static simulators.

Not only do VR and haptic tools lead to a better self-efficacy perception of oneself, but the presence factor is also seen as one of the leading agents to increase self-efficacy. Makransky et al. [21] described how a high sense of presence can lead learners to experience activities in a virtual lesson as performance accomplishments because they perceive the virtual experience as "real", translating into a positive relation between presence and self-efficacy. This discussion is further supported by previous literature, including a meta-analysis by Gegenfurtner et al. [155], which concluded that higher levels of interaction and user control result in higher self-efficacy assessments.

2.5.8 Embodiment

Embodiment in VR can be summed up as the perception that emerges when a body's property is possessed and processed as if it were the property of one's biological body [21] [156]. In the case of the CAMIL model, increased levels of embodiment experienced by learners in IVR are associated with the sense of presence [21]. This conclusion results from implementing the self into the virtual world, which enhances the general sense of presence, making the users feel inside the VE rather than merely observing it. Therefore, the relationship between presence and embodiment is amplified in IVR, resulting in a more profound knowledge acquisition.

Embodiment is often studied through visuomotor and visuotactile integration. It is a central part of embodied cognition theory (Section 2.2), suggesting that how we think and make sense of the world depends on our sensorimotor system and bodily interactions with the environment. Given the theory, haptic feedback can be seen as a terrific way to improve learning by complementing the visual channel with a new sensory one [40]. Furthermore, Richard et al.'s literature [156] showed several studies supporting haptic feedback in VR to enhance presence and embodiment. Their study explored which haptic cue had more influence over virtual embodiment. They conducted a within-subject experiment with twenty-four participants and compared self-reported embodiment over a humanoid avatar during a colouring assignment under three conditions: force feedback, vibrotactile feedback, and no haptic feedback. Their findings showed significant superiority of force feedback over no haptic condition regarding embodiment.

2.6 The Current Study

In response to the research gaps and questions raised by the CAMIL model and the existing literature, the role of VR and haptic feedback in increasing presence and the four factors illustrated in the CAMIL model (Section 2.5) was investigated within the present study. Furthermore, building upon the understanding of the embodied cognition theory (Section 2.2), this research examines how the conjunction of different sensory channels (visual, audio and tactile) influences different learning outcomes. Finally, this study examines whether the interaction between VR and haptics can enhance procedural and factual knowledge retention (Section 2.1, Section 2.1.1) over short and long periods. In Chapter 4, a comprehensive analysis of the hypotheses will be conducted, searching into a detailed examination of the collected data. However, to provide a concise overview of these hypotheses, they are introduced in Section 2.7 more broadly.

As Renganayagalu et al. [93] reported in their review, the safety and emergency domain has undergone several investigations; however, there still is a notable research gap in haptic feedback for procedural VR training. Moreover, the implementation of haptic feedback in the virtual simulation has gotten minimal attention from the researchers within the literature. These gaps underline the area still to be explored, where VR and haptic feedback could enhance knowledge acquisition regarding fire extinguishers. Therefore, the present study employed a fire virtual training simulation, where several fire extinguishers were needed in different contexts.

As an illustrative example, Lovreglio et al.'s study [157] was considered, which compared training in VR on how to use a fire extinguisher to traditional video-based training. One drawback of the study was the lack of haptic implementation while shedding light on the advantages of adopting a VR training simulation. Another study by Seo et al. [158] showed a promising use of haptic in VR regarding using a fire extinguisher. However, its lack of data collection raised questions about the reliability and validity of the study.

2.7 Research Question and Hypothesis

This study aims to shed light on the potential benefits of haptic feedback in VTEs and its impact on learning outcomes over time. Thus, the central research question to be addressed is:

"Does the implementation of force and vibrotactile feedback in a virtual training environment (VTE) lead to enhanced procedural and factual knowledge acquisition after one week, compared to a VTE without haptic feedback?"

Consequently, the hypothesis that follows aims to answer the said main research question:

(H): Implementing force and vibrotactile feedback in a virtual training environment (VTE) enhances procedural and factual knowledge acquisition after one week, compared to a VTE without haptic feedback.

To address this goal, the current study tested several sub-research questions and their hypotheses, as reported below. The study tests whether the force and vibrotactile feedback increase the perceived virtual sense of presence, interest, motivation, embodiment and self-efficacy, procedural and factual knowledge. Additionally, the present research investigates whether a positive correlation exists within the experimental group between presence and the four factors mentioned above, the said factors and procedural knowledge and factual knowledge, and finally, presence and the stated learning outcome.

2.8 Sub-Research Questions and Sub-Hypotheses

To answer the main research question reported above, the CAMIL model was used in this study to explain how procedural and factual knowledge are achieved through the interaction between VR and haptic feedback. Consequently, it became compulsory to present sub-questions and their hypotheses as follows:

SQ1: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation result in a higher presence score than the virtual fire safety training simulation without haptic feedback (NHF)?

H1: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher presence score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ2: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation result in a higher interest score than the virtual fire safety training simulation without haptic feedback (NHF)?

H2: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher interest score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ3: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation result in a higher motivation score than the virtual fire safety training simulation without haptic feedback (NHF)?

H3: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher motivation score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ4: Does implementing force and vibrotactile feedback (HF) in a virtual fire training simulation result in a higher embodiment score than the virtual fire safety training simulation without haptic feedback (NHF)?

H4: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher embodiment score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ5: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation result in a higher self-efficacy score than the virtual fire safety training simulation without haptic feedback (NHF)?

H5: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher self-efficacy score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ6: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation lead to a higher procedural knowledge (post-training) than the virtual fire safety training simulation without haptic feedback (NHF)?
H6: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ7: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation lead to a higher procedural knowledge (one week after training) than the virtual fire safety training simulation without haptic feedback (NHF)?
H7: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ8: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation lead to higher factual knowledge (post-training) than the virtual fire safety training simulation without haptic feedback (NHF)?
H8: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ9: Does implementing force and vibrotactile feedback (HF) in a virtual fire safety training simulation lead to a higher factual knowledge (one week after training) than the virtual fire safety training simulation without haptic feedback (NHF)?
H9: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ10: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and haptic in the virtual fire safety training simulation?
H10: A positive ($0 \leq \rho \leq 1$) correlation exists between the sense of presence and haptic feedback in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ11: Is there a positive correlation ($0 \leq \rho \leq 1$) between the sense of presence and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H11: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and interest in haptic

feedback (HF) conditions compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ11.1: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H11.1: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and motivation in haptic feedback (HF) conditions compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ11.2: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H11.2: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and embodiment in haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ11.3: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H11.3: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ12: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and procedural knowledge (increase = post - pre) and a negative ($-1 \leq \rho \leq 0$) correlation with procedural knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H12: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and procedural knowledge (increase = post - pre) and a negative ($-1 \leq \rho \leq 0$) correlation exists between the sense of presence and procedural knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ12.1: Is there a positive ($0 \leq \rho \leq 1$) correlation between the sense of presence and factual knowledge (increase = post - pre) and a negative ($-1 \leq \rho \leq 0$) correlation with factual knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?

H12.1: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and factual knowledge (increase = post - pre), and there is a negative ($-1 \leq \rho \leq 0$) correlation with factual knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ13: Is there a positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and interest and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H13: A positive($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and interest and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ13.1: Is there a positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and motivation and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H13.1: A positive($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and motivation and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ13.2: Is there a positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and embodiment and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H13.2: A positive($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and embodiment and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

SQ13.3: Is there a positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and self-efficacy and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback

(HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?
H13.3: A positive($0 \leq \rho \leq 1$) *correlation exists between procedural knowledge (increase = post - pre) and self-efficacy and a negative* ($-1 \leq \rho \leq 0$) *correlation between procedural knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).*

SQ14: Is there a positive ($0 \leq \rho \leq 1$) **correlation between factual knowledge (increase = post - pre) and interest, and a negative** ($-1 \leq \rho \leq 0$) **correlation between factual knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?**
H14: A positive ($0 \leq \rho \leq 1$) *correlation exists between factual knowledge (increase = post - pre) and interest and a negative correlation* ($-1 \leq \rho \leq 0$) *between factual knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).*

SQ14.1: Is there a positive ($0 \leq \rho \leq 1$) **correlation between factual knowledge (increase = post - pre) and motivation and a negative** ($-1 \leq \rho \leq 0$) **correlation between factual knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?**
H14.1: A positive ($0 \leq \rho \leq 1$) *correlation exists between factual knowledge (increase = post - pre) and motivation and a negative correlation* ($-1 \leq \rho \leq 0$) *between factual knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).*

SQ14.2: Is there a positive ($0 \leq \rho \leq 1$) **correlation between factual knowledge (increase = post - pre) and embodiment and a negative** ($-1 \leq \rho \leq 0$) **correlation between factual knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?**
H14.2: A positive ($0 \leq \rho \leq 1$) *correlation exists between factual knowledge (increase = post - pre) and embodiment and a negative correlation* ($-1 \leq \rho \leq 0$) *between factual knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).*

SQ14.3: Is there a positive ($0 \leq \rho \leq 1$) **correlation between factual knowledge (increase**

= post - pre) and self-efficacy and a negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)?

H14.3: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (increase = post - pre) and self-efficacy and a negative correlation ($-1 \leq \rho \leq 0$) between factual knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

3. Method

The experiment investigated the influence of implementing force and vibrotactile feedback in a virtual training simulation designed to train participants using different fire extinguishers. In addition, the study explored how haptic feedback impacted participants' sense of presence, interest, motivation, embodiment, and self-efficacy, besides investigating whether haptic feedback enhanced procedural and factual knowledge over time.

In line with the CAMIL model (Section 2.5), the current research sought the correlations between:
1) ***Haptic feedback and sense of presence.***
2) ***Haptic feedback and the four factors mentioned before***.
3) ***Haptic feedback and procedural and factual knowledge***.
The same simulation and training were also conducted with a group in which force and vibrotactile feedback were intentionally deactivated to measure haptic feedback's importance in the learning process.

This chapter first illustrated the experimental study, including the different conditions, experiment tasks and implementation. Second, a brief overview of the target sample of this study description was presented, followed by the design procedure shown in the third section. What follows is the data collection method used in the current research; this fourth part explains the different questionnaires and questions employed to investigate the presence, the four factors involved in the CAMIL process, procedural knowledge and memory. The fifth section describes ethical considerations concerning the research, concluding with the sixth part on the study's limitations.

3.1 Research Design

The experiment was set up as a between-subject study. The participants were randomly divided into two groups, each testing one condition. The nature of the experimental conditions moved the choice of selecting a between-subject study design. The main scope of the current study was investigating the impact of haptic feedback on learning outcomes within a virtual training simulation. Because of that, the study concerned only two conditions - one with haptic feedback (HF), vibrotactile and force feedback, enabled and the second one with no haptic feedback (NHF).

The main concern was the consistency of the training simulation itself: the content, the tasks, and the general training were the same experienced in both conditions, with the only different factor represented by the presence or lack of haptic feedback. The choice of a between-subjects design was encouraged by the primary concern that if participants experienced both conditions in sequence, for instance, by presenting first the haptic situation and secondly the same simulation without any haptic input, the two training sessions (identical), might have altered the researcher ability to detect any significant difference in the learning acquisition.

Therefore, assigning participants to one of the two conditions was found logical, ensuring they experienced a distinct training experience. This approach allowed to focus on measuring the impact of haptic feedback on learning outcomes and minimising potential confounding variables that could happen after exposing the participants to similar tasks.

To test the hypotheses empirically, a quantitative approach was chosen. This decision was driven mainly by the time required for the experiments, particularly concerning the pre-and post-test assessment of procedural and factual knowledge retention. Regarding the assessment after the training, one week was chosen as the optimal and most advantageous time to check whether the knowledge acquisition lasted. This preference was supported by the literature [159] that reported that humans typically forget about 75% of the knowledge they have learned after one week. Thus, another evaluation test was conducted one week after the first training session to study how well the participants retained the knowledge they learned under different training conditions.

It goes without saying that assessing procedural and factual knowledge by conducting two rounds of testing (right after the simulation and after one week from the training) requires time and effort from both participants and the researcher to accurately capture the changes over time. As a result, choosing a quantitative data collection was a pragmatic choice that allowed the study's feasibility and time execution.

3.1.1 Implementation and Apparatus

In the current study, a vibrotactile and force feedback haptic glove, SenseGlove Nova, was used to provide haptic feedback to the user in a virtual simulation. How this type of haptic glove technical features was already illustrated in Section 2.4.5. During the experiment, two pairs of size gloves were used, small and medium, as the participants had different sizes of hands. Before wearing them, the device needed to be turned on by briefly pressing the power button until the LED light was turned on.

Once on, the Nova could be worn. It was important to tighten and attach the straps on the palm to comfortably and firmly secure the hub. Furthermore, the finger tabs on the thimbles needed to be positioned correctly on the finger beds, and the force feedback cables were not obstructed or interfered with in any way. The Softglove could be detached from the rest of the hardware by gently sliding the thimbles and cable guides back and forth (Figure 3.1). The same applies to the Softglove's attachment to the Nova's hub, which can be detached by pulling the Softglove away from the hub. Once detached, the glove could be replaced. This process happened each time the glove's size was changed based on the hands' users. Finally, to attach the Softglove, the process just explained was reversed.

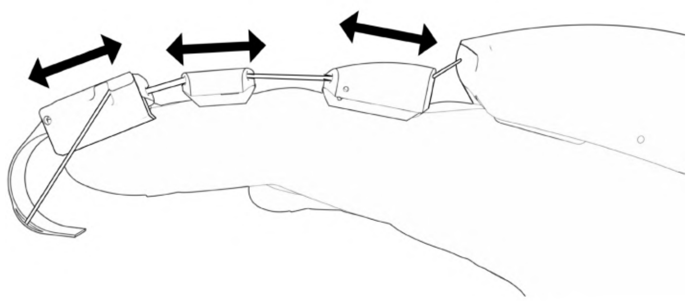

Figure 3.1: Attaching the Softglove, Getting Started Guide SenseGlove Nova, Article SenseGlove [160]

Once the user had worn the glove, they had to be connected to the SenseCom program (Figure 3.2). While this program was active, the user could interface with their gloves from any number of programs. A build for standalone headsets manages the glove connections internally; however, it was possible to use SenseCom to verify the gloves connections on devices such as the Oculus Quest.

SenseGlove Nova is wireless and compatible with standalone headsets like Meta Quest Pro, used in the current study. Meta Quest Pro is a VR headset with an integrated eye tracker released in October 2022 [161]. The system utilises the Snapdragon XR2 processor; the important specifics are within the two displays – one for each eye. Meta Quest Pro has a resolution of 1832*1920 pixels per eye and a claimed field of view of 106° (horizontal) × 96° (vertical) [161]. Both screens also offer a 90Hz refresh rate, decreasing motion sickness issues [162].

Meta Quest Pro was linked to the PC during the experiment through the USB-dedicated cable for safety and procedural reasons. The Oculus Link, a software that Oculus integrated

Figure 3.2: SenseCom interface, Getting Started Guide SenseGlove Nova, Article SenseGlove [160]

with the Oculus Quest, can connect the Meta Quest Pro to a PC. The connection served a precise purpose within the study's setup. The researcher could offer users real-time assistance while navigating the virtual training simulation by linking the Meta Quest Pro to a PC. The researcher could provide guidance or clarification if participants experienced challenges or felt disoriented during the simulation. As a result, this ability ensured that participants could maximise their learning experience and receive immediate assistance.

Finally, the fire safety training simulation designed for this study was developed using the Unity game engine, a versatile platform known for its ability to create immersive and interactive virtual environments. In this simulation, participants were placed in various fire emergency scenarios, such as a hotel hallway and a kitchen. They were tasked with using different fire extinguishers to extinguish the different types of fires. The Unity engine allowed for a realistic rendering of the fire, smoke, and environment, creating a realistic training experience.

3.2 Participants

The total sample consists of 70 participants. The target chosen for the current study focuses on university students. The convenience of access and availability drove the decision to recruit university students as targets for my research. In addition, considering the nature of the fire safety training simulation (Section 2.6), which aimed to teach how and when to use different fire extinguishers, selecting participants who could benefit from learning these skills was compulsory. As a result, choosing university students was a convenient and appropriate choice. Two participants were excluded from the final sample as they did not complete the learning assessment questionnaire after one week. Hence, the final sample includes **68 participants** (*M*=24.5 *y*, *SD* = 3.9 *y*, male = 27, female = 40, non-binary = 1).

3.3 Procedure

This study was conducted over May and June, specifically from the 19th of May to the 25th of June, and it was impossible to experiment online. The experiment took place at the "Eye Tracking Lab" in Science Park at Utrecht University, as it offered a suitable and quiet space to test the gear and the training simulation. As mentioned in the previous sections, participants were divided into the experimental (haptic feedback activated, HF) and the control group (haptic feedback disabled, NHF). The participants were divided randomly in either of the two groups as soon as they arrived at the laboratory. The goal was to have two groups with the same amount of people, so the researcher tried to divide them equally each time.

Once the participants arrived at the Eye Tracking Lab, they were welcomed and explained how the experiment was designed. They were also clarified about the data collection, privacy concerns and the possibility to stop the simulation whenever they feel discomfort. After they read the experiments' instructions through the laptop provided by the researcher and agreed, given their consensus, to collect their data, they were asked to fill in a questionnaire containing demographic questions, previous experience in haptics, VR and fire training questions, and questions aiming to assess existing procedural and factual knowledge on fire extinguishers. Finally, they were asked to leave their email address. This information was requested to facilitate the email sending of the questionnaire to assess the participants' retention of the knowledge acquired during the experiment one week after the study's conclusion. After that, they were ready to start. An overview of the experiment procedure can be seen in Figure 3.3.

3.3.1 Calibrating the SenseGlove Nova

The first thing they were asked to do was to calibrate the pair of SenseGlove Nova within Meta Quest Pro. By doing that, the gloves fitted with their hands' movements and were ready to be tracked by the HMD. Participants were asked to move their fingers until the orange virtual hands began to move (Figure 3.4). Once it did, participants could confirm the calibration by giving a "thumbs up" gesture (Figure 3.4). Once the Nova Gloves were calibrated, the participant could proceed to the next scene.

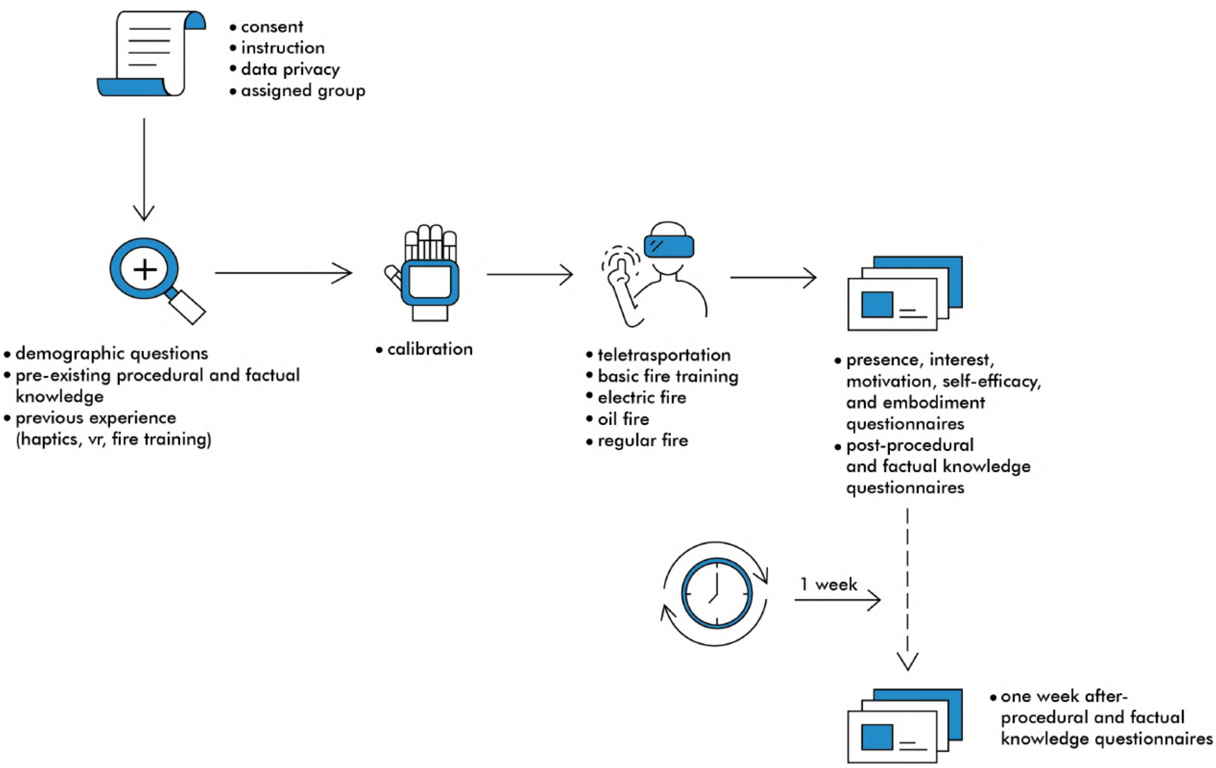

Figure 3.3: Overview experiment procedure,

3.3.2 Teleportation Tutorial

As soon as the participants entered the simulation, they were presented with a tutorial to teach them how to teleport in the simulation (Figure 3.5). Due to the cable linking the headset to the PC, the participants could reach only a certain point in the space, more precisely to 2 metres. Therefore, it was necessary to let them get objects or go to places within the simulation that they otherwise could not have reached. When using Nova Gloves, users can teleport by pointing their hands at the ground, extending only the index finger. Once the participants teleported, they would continue to the Main Menu.

3.3.3 The Main Menu

The Main Menu was where users could select the training. They could interact with the menu by hovering over the various buttons (Figure 3.6).
Basic Fire Training will run the user through a whole training scenario of all classes of fire.
Electrical Fire will have the user deal with an electrical fire in a hotel lobby.
Oil Fire will have the participant deal with a fire in a deep fryer in a kitchen.
Regular Fire will have the user deal with a small fire inside a hotel room.
Reset Training will bring the user back to the calibration scene.
Exit Training will shut down the training program.

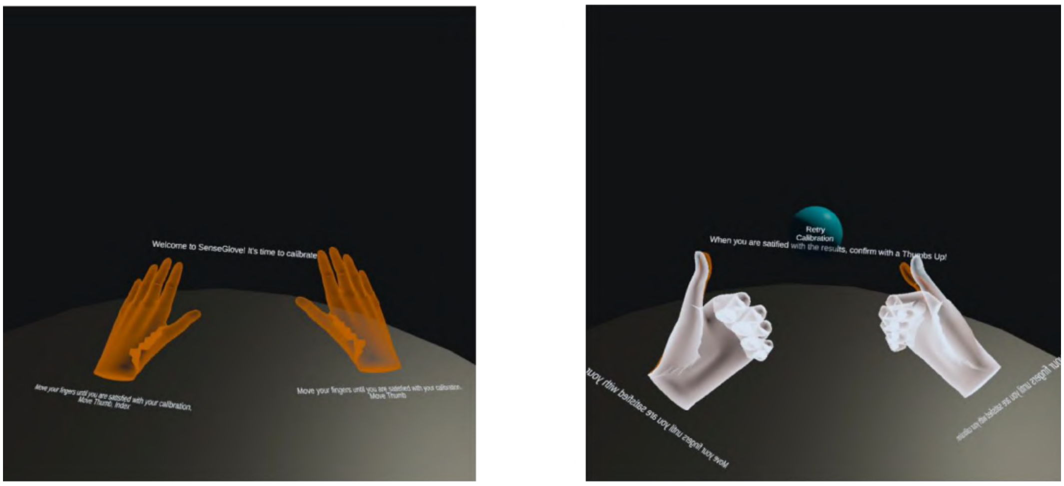

Figure 3.4: Calibrating process. On the left side, participants moved their fingers until the orange virtual hands began to move. On the right side, participants confirm the calibration by giving a "thumbs up" gesture.

3.3.4 Basic Fire Safety Training

As soon as the participants entered the simulation, they were presented with a menu through which they had to choose between the training session and the other three training simulations. They were asked to select the Basic Fire Training simulation first to get familiar with the gear and the VR setting. This training taught the user how to operate a fire extinguisher and which extinguishers are suited for which fire. It ran the participant through Class A, B, C, D and F Fires (Figure 3.7). For each case, green arrows above the extinguisher indicate which one(s) suits the current fire.

Class A – Solid Material Fire
- Can be extinguished by any extinguisher, except for the CO2 type.

Class B – Liquid Material Fire
- Liquid Fires can only be extinguished with a Foam or Wet Chemical type.
- The entirety of the liquid must be covered in foam for it to work.

Class C – Gas Fire
- Can be extinguished by cutting off the gas supply with the lever on the left.

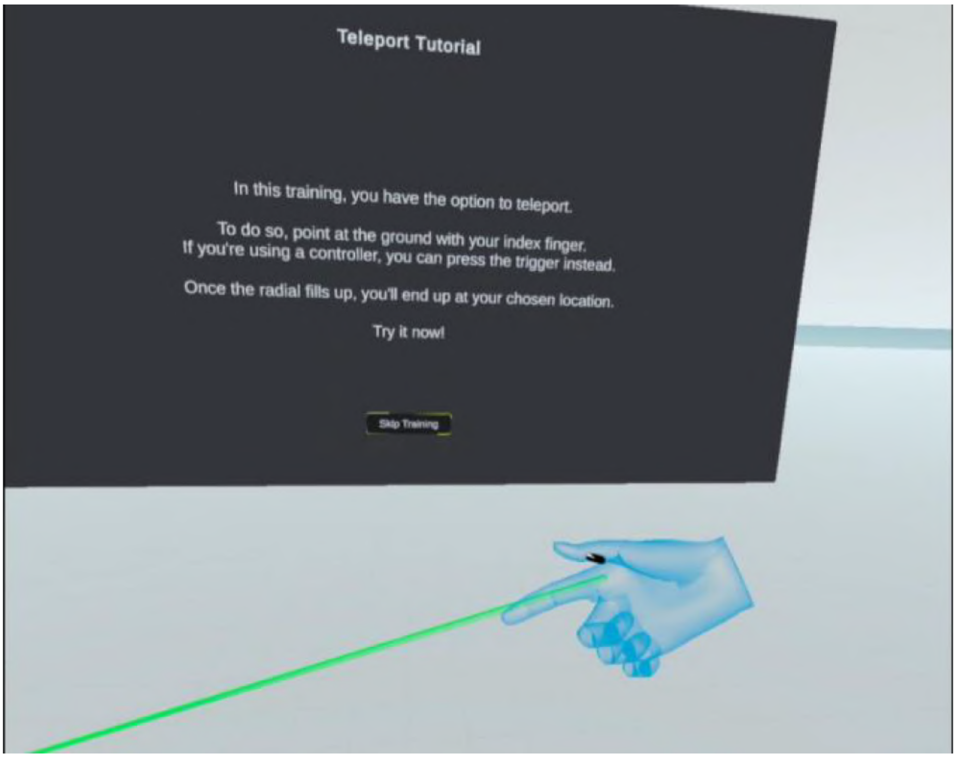

Figure 3.5: Participants had to teleport around the 3D environment to reach certain places in this demo. This tutorial taught them how to do so.

Class D – Electrical Fire

- The scooter's flames must be extinguished with a CO2 extinguisher and then immersed into the fountain. If the scooter is on fire while being dunked, remove it and place it back.

Class F – Oil Fire

- Oil fires can only be extinguished by a Wet Chemical type.

The tasks presented in the training session were four, each requiring extinguishing a different type of fire. It is possible to see the various training simulation tasks in Figure 3.8. These fires included those for which the simulation presented five distinct fire extinguishers: water, foam spray, ABC powder, carbon dioxide and wet chemicals (Figure 3.9). In case of an error, the audio guidance warned the users about their mistake and explained why their choice was wrong, encouraging them to try again. Likewise, in case of the correct selection of fire extinguishers, the audio congratulated the users and underlined the type of fire requiring the right fire extinguishers.

3.3.5 Extinguisher Basics

The user needed to grab the red handle at the top to pick up an extinguisher. A green highlight will appear so the user will know where to place their hand (Figure 3.10). Next, the user had to

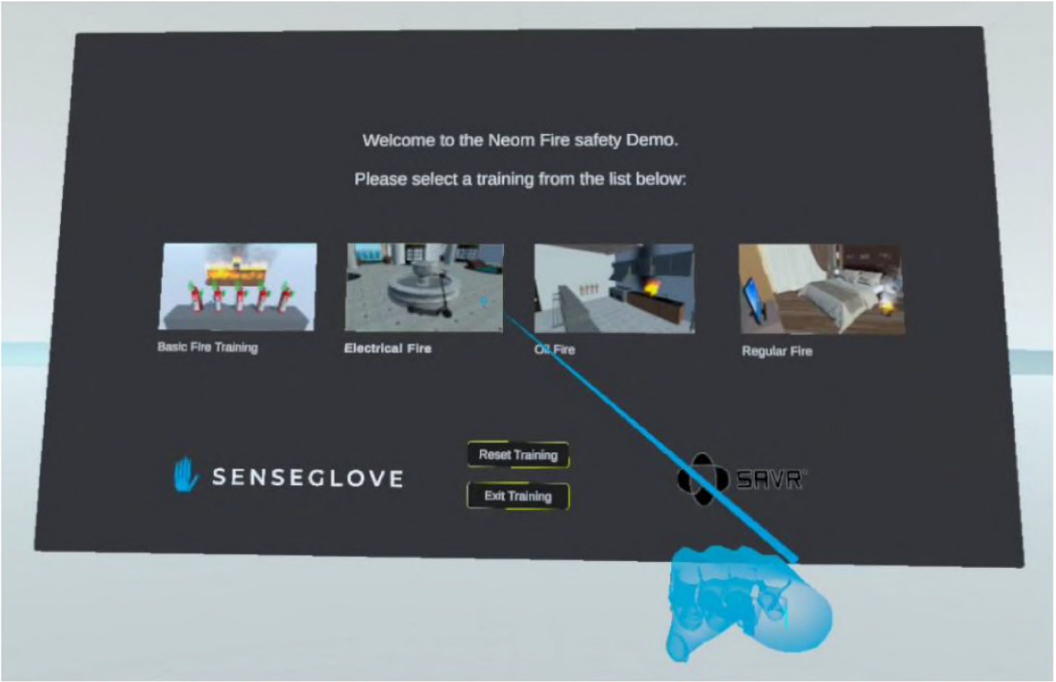

Figure 3.6: An example of selecting the electrical fire safety training.

remove the safety pin from the extinguisher with their other hand by grabbing it (Figure 3.11). The pin will be highlighted in green. Unfortunately, due to the limits of this simulation, the user could not put their finger through the ring and pull the pin out that way. Once the users have pulled out the pin, they can grab the nozzle. Once again, a green highlight will show them how to do that (Figure 3.12). To release a fire extinguisher, the user must lower it to the ground and open their hand (Figure 3.13). They could teleport while holding an extinguisher by pointing at the ground with the hand not holding on to the main extinguisher body.

When the training session concluded, the participants were asked to return to the menu and select one of the three simulations. The sequence of the training trial influenced this decision: the final task of the training involved dealing with a kitchen fire, which was also the focus of one of the last testing simulations within the Basic Fire Training environment. Thus, to decrease the chance of potential biases and memory-related issues, the simulation regarding dealing with regular fire was chosen as the first to be tested, the electric fire simulation training as the second, and finally, the third one was the one destined to train an oil fire extinguisher.

3.3.6 Electrical Fire Training

In this training, the user dealt with an electric scooter on fire (Figure 3.14, Figure 3.15). The user had to extinguish the flames on the scooter using the CO_2 extinguisher on the wall behind, then

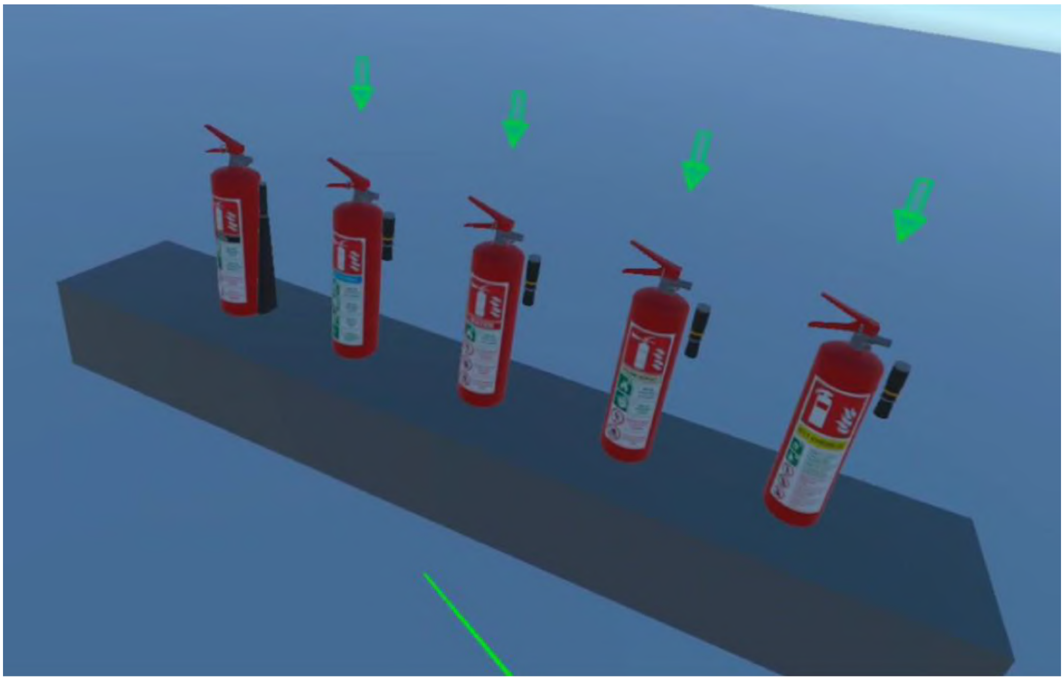

Figure 3.7: Basic Fire Training. The arrows indicate which fire extinguisher(s) is the correct choice for a specific type of fire.

dip the scooter into the nearby fountain to keep the flame from re-igniting (Figure 3.16).

3.3.7 Oil Fire Training

In this training, the participants were in a kitchen where an oil fire had started in a deep fryer (Figure 3.17). They had to select the correct fire extinguisher from the wall behind them (Figure 3.18).

3.3.8 Regular Fire Training

In this training, participants started outside a hotel room door, where a fire had broken out (Figure 3.19). They were asked to check the door frame for heat before opening it; they had to place both hands above the middle of the door to do so (Figure 3.20 A). Afterwards, they spread their arms outwards so that their hands touched the corners of the door frame, then moved down along the frame (Figure 3.20 B). They were prompted to extinguish the fire by moving through the entire door (Figure 3.20 C). They needed to select the correct fire extinguisher to put out the flames. Once they had extinguished the flames, they received one final explanation and a button to return to the main menu.

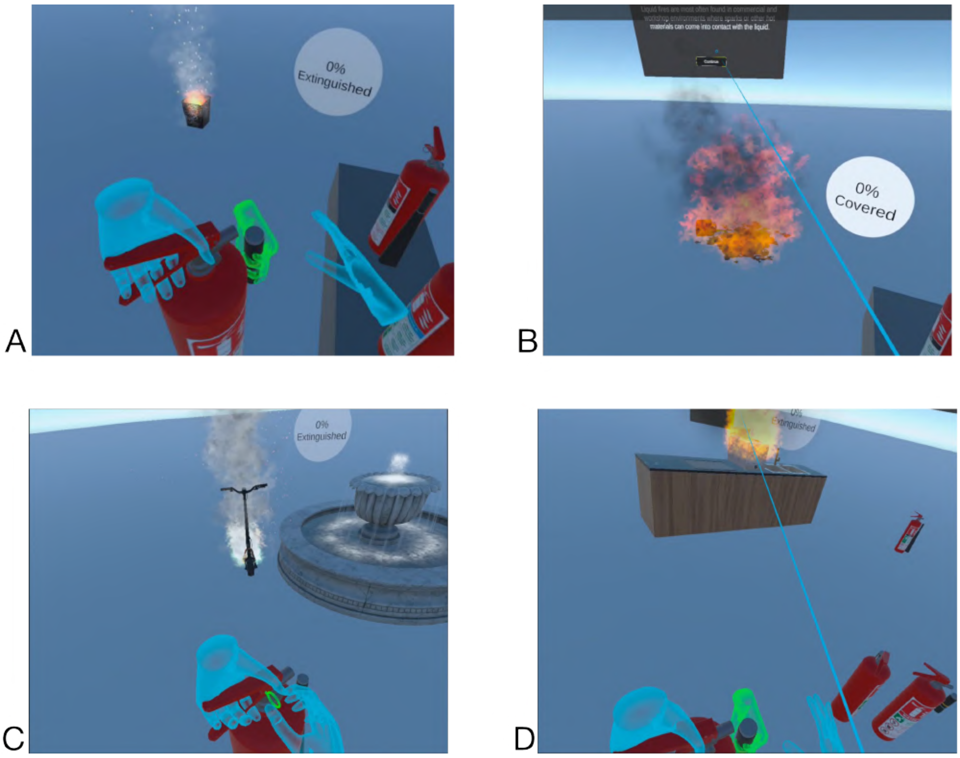

Figure 3.8: Image A illustrates the first training task the user came across extinguishing the paper fire. **Image B** pictures the second simulation within the training: extinguishing oil fire. In **Image C**, the user was required to extinguish an electrical fire by using the appropriate fire extinguisher and dunking the electric scooter into the fountain. Finally, in **Image D**, the user had to extinguish a fire in a kitchen.

3.3.9 Experiment Final Part

Once the training session and simulation trials were completed, the participants were asked to complete a final questionnaire that included surveys about presence, interest, motivation, embodiment and self-efficacy. In addition, the same questions on procedural and factual knowledge asked in the first questionnaire were asked again. Finally, after one week of the training, a third questionnaire was sent to the participants, asking them to answer the same procedural and factual knowledge questions. The study required between 30 and 40 minutes to finish, including questionnaires after the training simulations.

3.4 Data Collection Method

In the current study, the virtual training simulation represents the context in which the participants interact, and the haptic feedback within the simulation constitutes the independent variable. In accordance with our hypotheses, seven dependent variables were used: presence, interest, motivation, embodiment, self-efficacy, procedural and factual knowledge. Participants in the present study had to answer a questionnaire after the training and final testing simula-

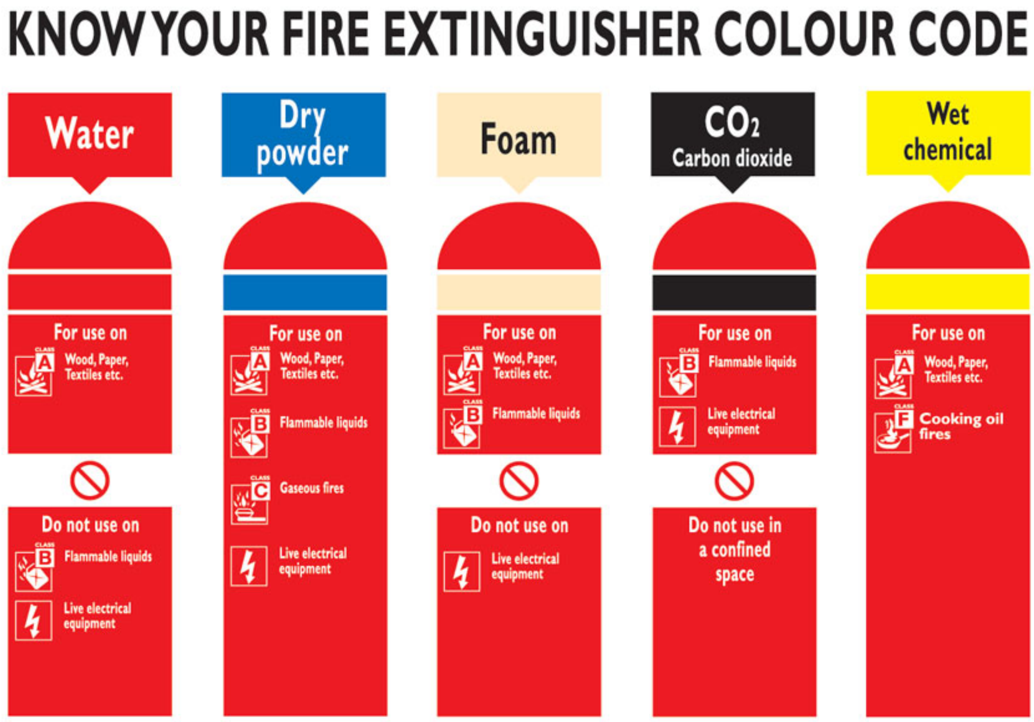

Figure 3.9: Fire Extinguishers Types, Source FIRE EXTINGUISHER TYPES AND USES CHART, Website Northantsfire [163]

tions ended. This questionnaire asked questions related to the variables of interest, and the order in which these questions were presented to each participant was randomised (Appendix B). These variables are further illustrated in this section.

3.4.1 Independent Variables

The independent variable in the study was the presence or absence of force and vibrotactile feedback. In the test condition, including haptic feedback, the participants received force and vibrotactile feedback whenever interacting with the virtual objects (fire extinguishers). Once they grabbed the fire extinguisher's handle, they felt a resistance that did not allow them to close their hands thoroughly, giving them the perception of holding a real object. The latter feedback came into play whenever they had to press the level to use the fire extinguisher and put off the fire properly. The participants did not receive any haptic force feedback in the condition without haptic feedback.

3.4.2 Dependent Variables: (1) Presence

After completing the training and final test simulations, the participants had to answer the presence questionnaire with five items. It was taken from a validated instrument previously

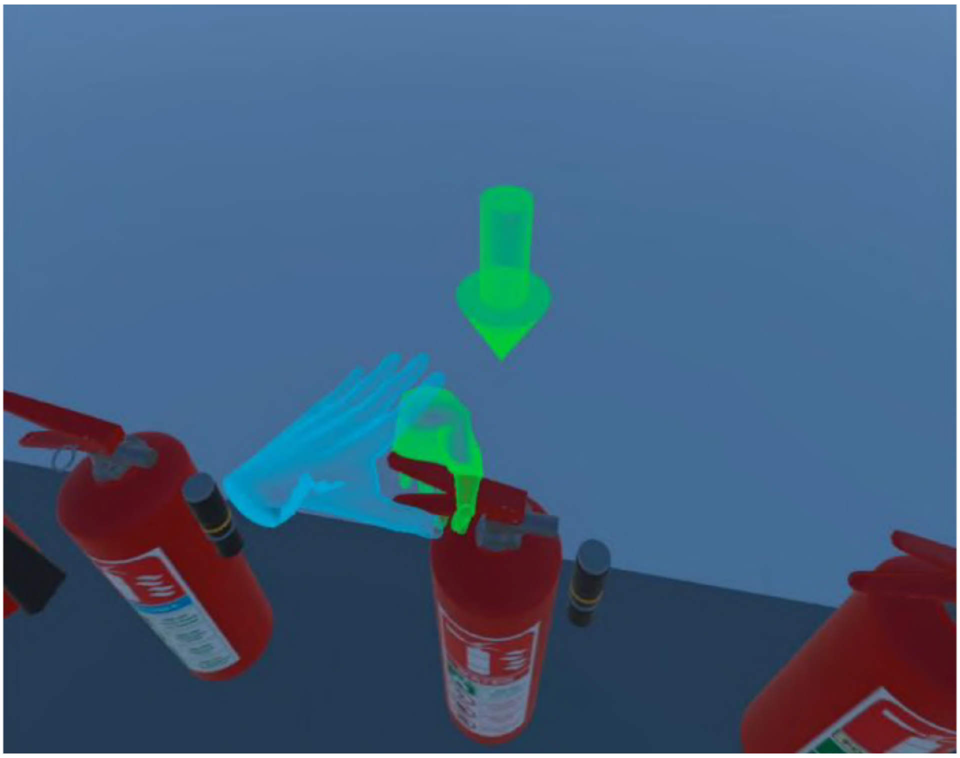

Figure 3.10: Picking up an extinguisher

used in similar research [164]. The original questionnaire was initially developed and validated by Jennett et al. [165] and only after was taken by Qian et al. [164] to be adapted for their study. Qian et al.'s study presented a 9-point Likert scale. This scale was modified to a 5-point Likert scale, as the literature suggested that a 5-point scale appears to be less confusing and to improve response rate [166]. The 5-point Likert scale was utilised for each of the dependent variables.

3.4.3 Dependent Variables: (2) Interest

The interest factor influenced through the virtual simulation was tested using the User Engagement Scale short form (UES - SF) [167]. This short form of the scale consists of twelve items with a 5-point Linkert scale.

3.4.4 Dependent Variables: (3) Motivation

Motivation was tested using the short form of the Intrinsic Motivation Inventory (IMI) [168]. In their study [168], Cuddihy et al. demonstrated that their short version of IMI gave similar results for all the twenty items from the original and longer IMI. Their short version presents eight items using a 7-point Linkert scale. In the current study, the scale was changed to a 5-point scale, and the items decreased to 7; as in Cuddihy et al.'s short IMI form, two questions related to the sub-scale of "pressure/tension" were very similar. Therefore, the participants

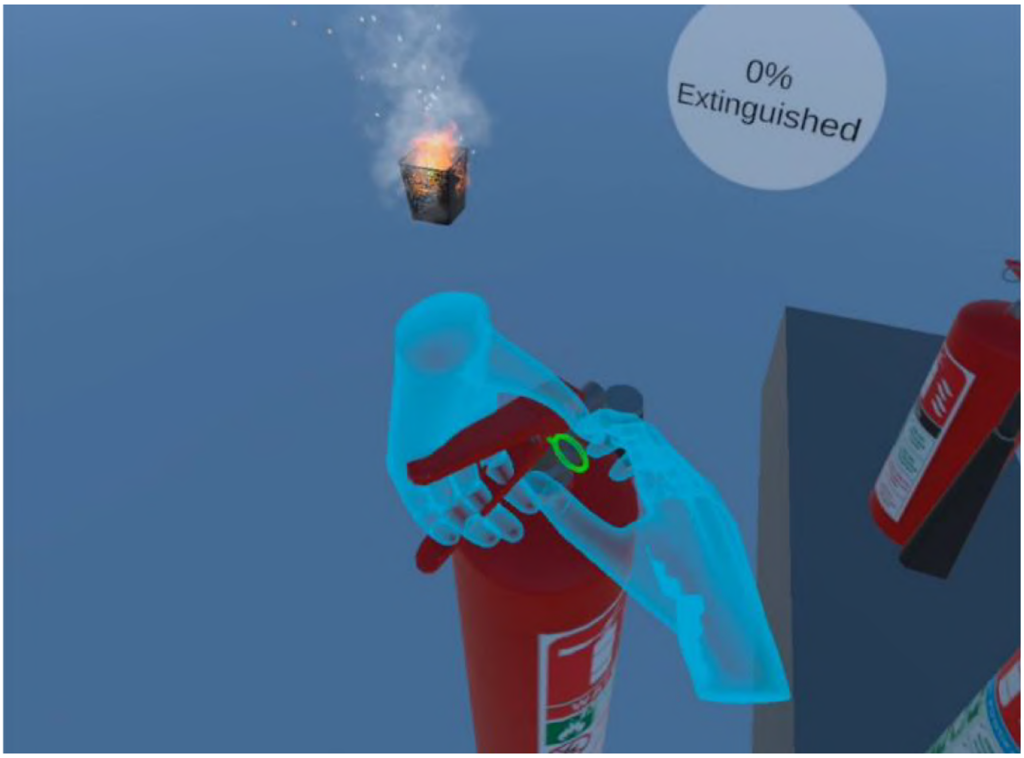

Figure 3.11: An example of how to remove the safety pin from the extinguisher

would have answered the same questions.

3.4.5 Dependent Variables: (4) Embodiment

Longo et al. developed and tested a questionnaire scale to assess embodiment with the items [169]. The questionnaire was used to measure the embodiment psychometrically and consists of three scales: ownership, location and agency. In Fröhner et al.'s study [170], they used this questionnaire as a 7-point Likert scale; as already explained previously, in the current study, it was changed to a 5-point scale.

3.4.6 Dependent Variables: (4) Self-efficacy

The perceived self-efficacy was measured through the questionnaire designed by Lischer-Katz et al. [171]. It contains twelve items, and in the present study, it was used based on a 5-point Likert scale.

3.4.7 Dependent Variables: (5) Procedural Knowledge and Factual Knowledge

As already discussed in Section 2.1.6 and Section 2.1.5, different domains require different instructional methodologies; it has become clear that each scenario within the virtual training simulation needs different questions to assess the participant's understanding of the material

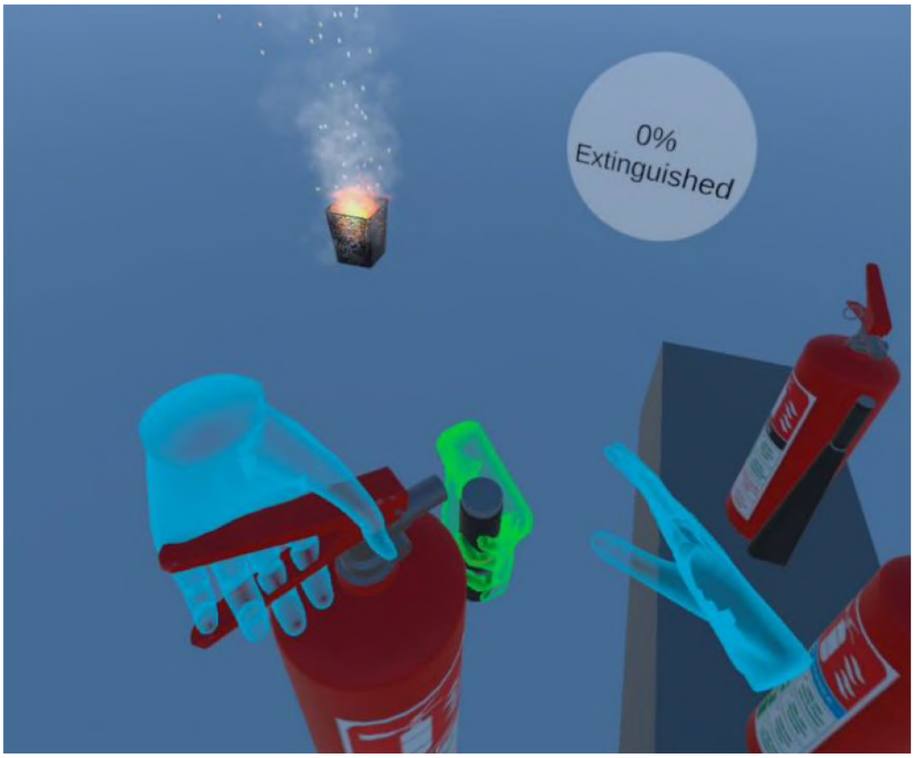

Figure 3.12: How to grab the nozzle from the extinguisher

effectively. As a result, in the current study, a tailored questionnaire was developed precisely to evaluate these two learning outcomes. Four multiple-choice questions were made regarding memory retention, and two open-questions and one multiple-choice question were thought to assess procedural knowledge.

These two learning outcomes were assessed by presenting the same questions before testing the training simulation sessions within the questionnaire, where demographic questions were also presented. The goal was to get an overview of each participant's knowledge about fire extinguishers and emergency training before being trained. After completing the experiment, the same set of questions was again proposed in a randomised order. Once again, the purpose was to gather enough data to conclude a possible increase in the learning process. One week after each participant's test was completed, the researcher sent a final questionnaire to assess procedural and knowledge factual knowledge to investigate whether participants could remember what they had learned after one week. The length of the final questionnaire was between 5 and 8 minutes. Comparing participants' post-test scores to pre-test scores enables the researcher to verify whether the training successfully increased participants' knowledge of the training content.

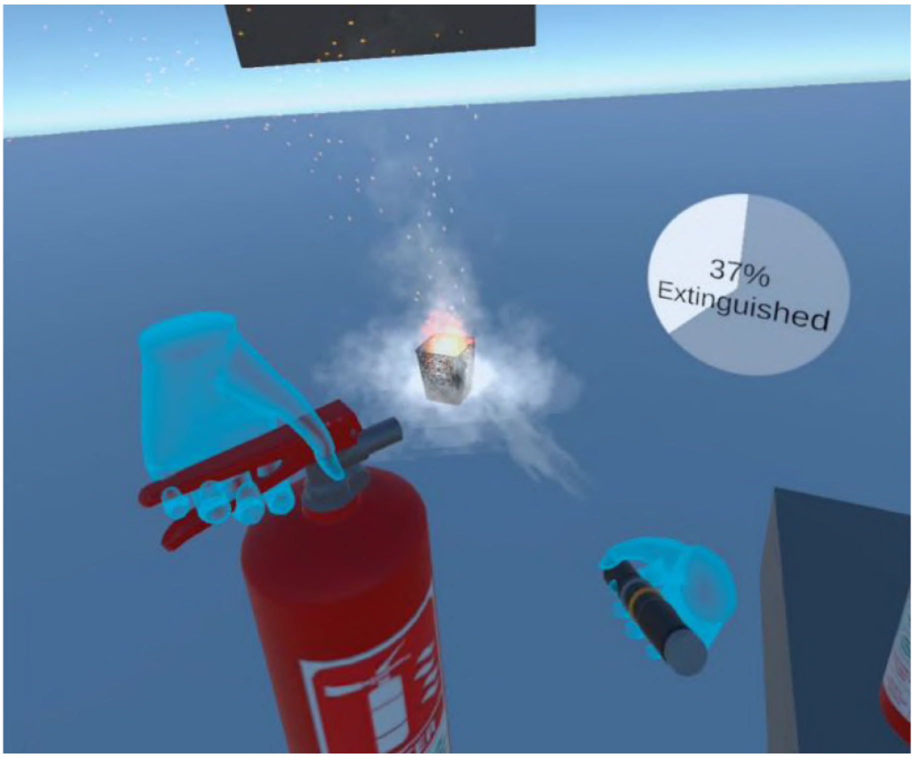

Figure 3.13: To release a fire extinguisher, the user lowers it to the ground and opens their hand to extinguish the fire.

3.5 Data Analysis Methods

The statistical methods used in the current research will be briefly explained before describing and explaining the analysis of the data collected through the measurements reported previously and discussing the results.

3.5.1 Data distribution

The data collected for the present research did not follow a normal distribution. Moreover, it is important to notice that said data are ordinal, as they refer to subjective evaluation through the Likert scale assessment already explained in Section 3.4. Given the data's nature and non-normal distribution, non-parametric tests were considered the most appropriate. Regarding the procedural and factual knowledge assessment, non-parametric tests were also conducted. These data types are ordinal, as the scores can only take on specific values (1 in case of correct answer, -0.25 if partially correct and 0 in case of wrong one).

Figure 3.14: In the frame, the user has just selected the second training about electric fire.

3.5.2 Mann-Whitney U test

Consequently, the Mann-Whitney U test was employed to evaluate the potential difference between the experimental and control groups. This test is suited to confront two independent groups of ordinal data or non-normally distributed. Mann-Whitney U test can be used on small (5-20) and large samples (n > 20); its power increases with the sample size [172]. Regarding the size of the sample chosen for the current study, as reported by Zhu et al. [173], among the five methods investigated in their study on the most appropriate size calculation methods for Mann- Whitney U test, Shieh's method has the best performance. As a result, 68 participants were found in line with Shieh's conclusions for this study.

3.5.3 Wilcoxon signed-rank test

Additionally to the Mann-Whitney U test, the Wilcoxon signed-rank test [174] was employed to evaluate the difference between pre and post-tests related to procedural and factual knowledge before the training, right after it and after one week from the experiment conclusion, as it is the most suitable for comparing matched samples. This test is fitted to assess differences between participants in different moments, and it works well with ordinal and non-normally distributed data.

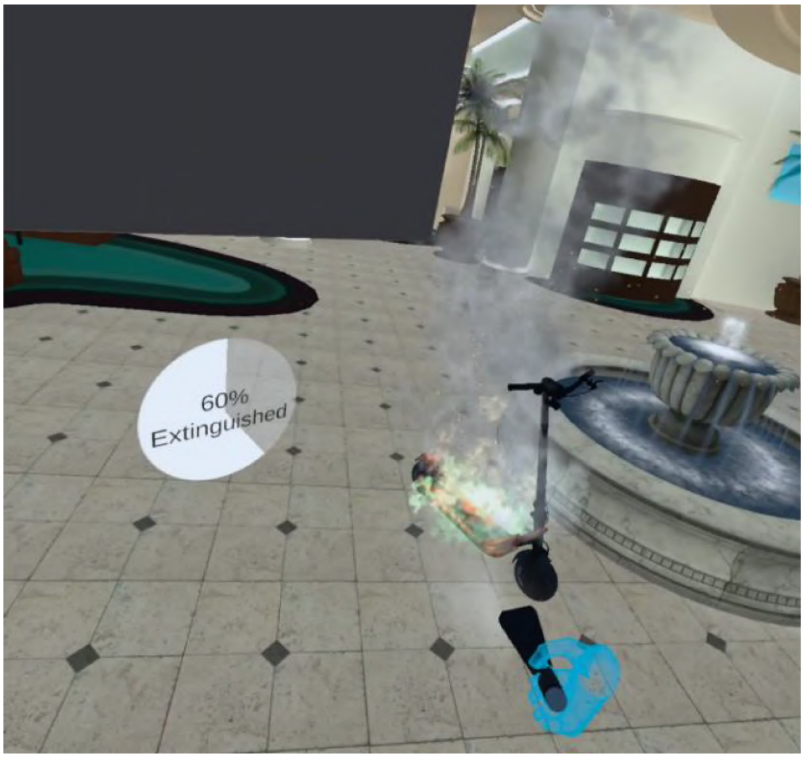

Figure 3.15: In the frame, the user has chosen the proper extinguisher and started using it.

3.5.4 Spearman's rank-order correlation

Finally, Spearman's rank-order correlation, the non-parametric version of the Pearson correlation coefficient, was used. Spearman's correlation coefficient calculates the strength and direction of a relationship between two ranked variables [175]. Simply put, it measures whether one variable increases or decreases with another, even when their relationship is not linear. This non-parametric correlation coefficient is a good measure of the relationship between two variables when outliners, non-normality and non-linearity may exist between the two variables being investigated [175]. For all these reasons, it seemed appropriate to employ Spearman's coefficient correlation in the current study, as one of the goals of the said study was to investigate whether possible correlations between the dependent variables (3.4.7) could be correlated to an increase of procedural and factual knowledge when haptic feedback was employed.

3.6 Ethical Considerations

Before starting the experiment, participants needed to agree to participate and give their data, which will be kept safe in the Qualtrics environment. Furthermore, all the data collection was anonymous. They were free to withdraw themselves from the experiment at any time, but once done, finishing another time was not possible. By giving their consent, they also agreed to fill

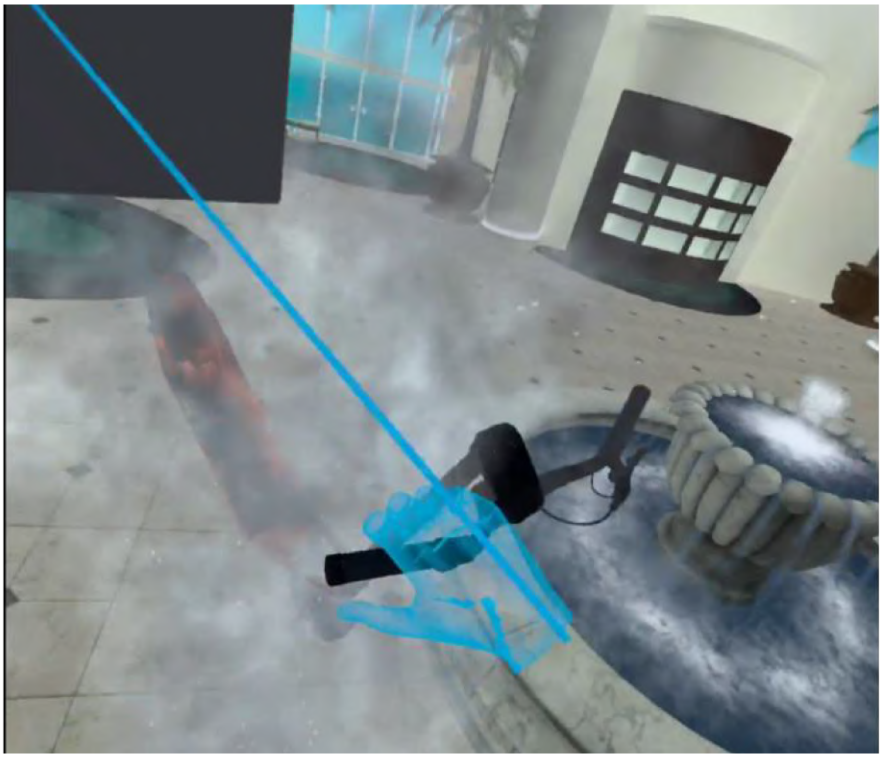

Figure 3.16: The participant has finished the extinguishing part and grabs the electric scooter to dip into the water to keep the flame from re-igniting.

in a second survey they got one week after the first experiment. The second questionnaire was sent via email through the email address each participant decided to give to the researcher.

Instead of using participant names or complete email addresses, the researcher assigned unique codes to each participant. These codes matched the follow-up survey responses with the initial data. Moreover, any personally identifiable information (PII) was removed from the dataset before analysing the data. In this way, participants' anonymity was ensured.

Regarding ethical concerns during the experiment, participants had to move in a limited space due to cable linked to the Meta Quest Pro and the PC. The reasons for this choice are explained in Section 3.1.1. Consequently, the researcher ensured user safety during the experiment. The experiment location was cleaned before beginning, and every possible obstacle hurting the participants was moved. However, the desk where the PC was located stayed relatively close as the 2-metre cable could only reach a certain distance.

Figure 3.17: The user enters the oil fire simulation in the frame.

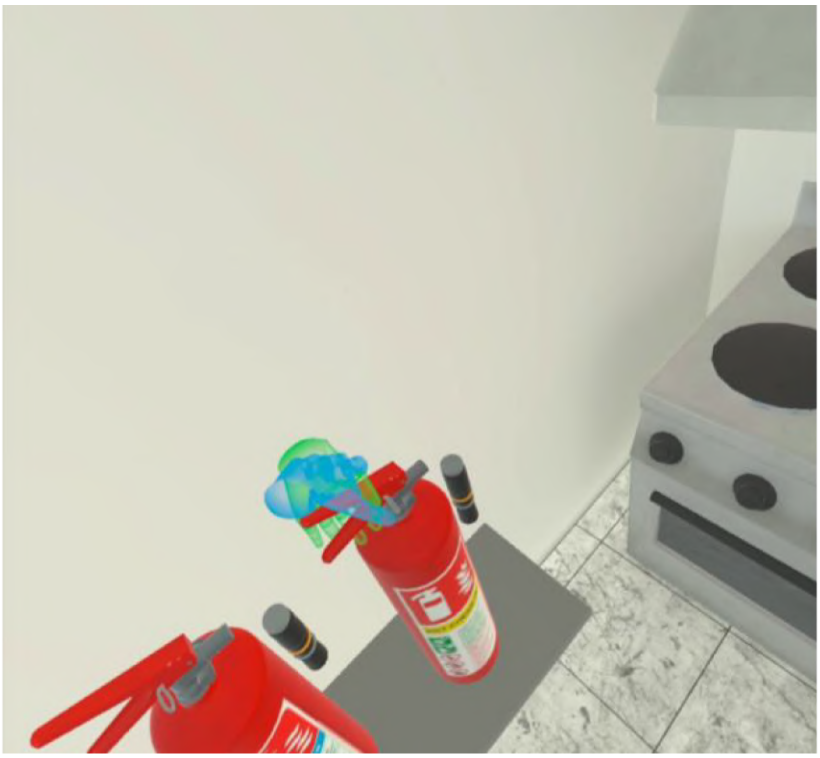

Figure 3.18: The user is choosing the correct fire extinguisher.

Figure 3.19: The user has entered the Regular Fire training simulation. The environment resembles a hall of a hotel.

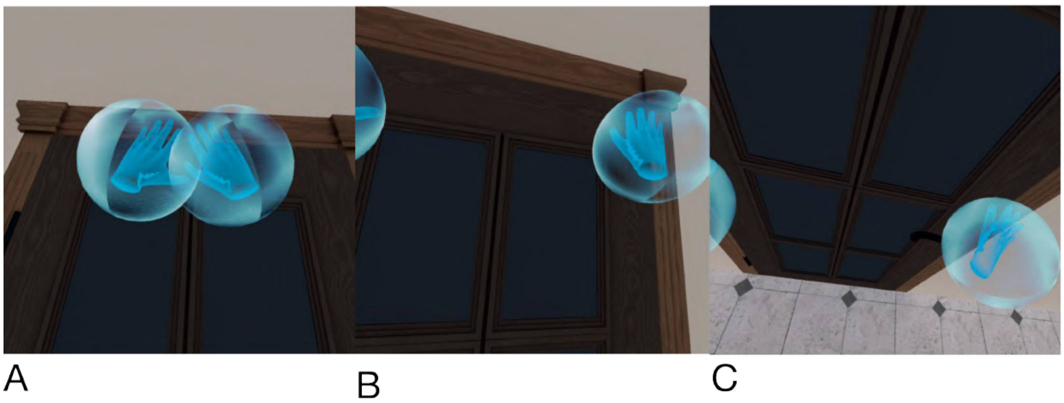

Figure 3.20: Picture A shows how to place both hands above the middle of the door to check whether the door is cold. **Picture B**: the user keeps checking for heat by moving the hands around the door's frame. **Picture C** shows how to check the door's handle with the backside of the hand to check further any sign of fire.

4. Results

4.1 Descriptive Data

A short overview, Table 4.1, of the descriptive statistics of all the collected variables is provided.

Presence. In HF, presence has a higher mean (M = 3.64, SD = 0.62) than in NHF (M = 3.49, SD = .77).

Interest. The HF group reported a slightly higher mean interest score (M = 4.1, SD = .34) than the NHF group (M = 3.93, SD = .61).

Motivation. Motivation's mean in HF (M = 4.1, SD =0.44) was assessed higher than the NHF (M = 3.96, SD = .62) group.

Embodiment. Embodiment differed highly between HF (M = 3.93, SD = .47) and NHF (M = 3.30, SD = .62).

Self-efficacy. Self-efficacy's mean value was higher in HF (M = 3.58, SD = .53) than in NF (M = 3.43, SD = .58).

Factual Knowledge. For both groups, participants scored higher after the training simulation compared to the notion demonstrated before the training. HF questions' average score regarding information held before the training (M = 1.17, SD = .48) increased after the training simulation (M = 1.34, SD = .45); the same happened in NHF, with a lower score in already existing information (M = 1.27, SD = .46) before the training, with an increase after it (M = 1.61, SD = .50). Even though both increased factual knowledge after the training, both groups had a decrement of memory after one week, with HF (M = 1.28, SD = .40) and NHF (M = 1.58, SD = .51).

Procedural Knowledge. Regarding procedural knowledge, both groups tended to increase and maintain what they learned. This outcome happened in particular in the case of procedural knowledge before the training session in HF (M = 1.12, SD = .74), with a later average increase in the mean score (M = 2.62, SD = .90). After one week from the training, HF (M = 2.46, SD = .90) showed a decrease. The same happened in the NHF condition, with a pre-training situation (M = 1.29, SD = .61) that significantly increased after it (M = 2.92, SD = .69) and decreased after one week from the training simulation (M = 2.49, SD = .61).

Experimental Group Haptic Feedback (HF)

	Presence	Interest	Motivation	Embodiment	Self-efficacy	Factual Knowledge pre-training	Factual Knowledge post-training	Factual Knowledge after one week training	Procedural Knowledge pre-training	Procedural Knowledge post-training	Procedural Knowledge after one week training
N	34	34	34	34	34	34	34	34	34	34	34
Mean	3.64	4.1	4.1	3.93	3.58	1.17	1.34	1.28	1.12	2.62	2.46
Median	3.80	4.15	4.30	3.90	3.60	1.17	1.34	1.15	1.30	2.60	2.30
Mode	3.80	3.80	4.40	3.90	3.80	.56	.94	.90	.00	2.60	3.00
Std.Deviation	.62	.34	.44	.47	.53	.48	.45	.40	.74	.90	.90
Minumum	2.40	3.60	3.30	2.90	2.30	.31	.60	.70	.00	.00	.70
Maximum	4.80	4.80	4.90	4.90	4.50	2.06	2.56	2.30	2.60	5.00	4.00
Percentiles 25	3.20	3.80	3.67	3.47	3.27	.80	.94	.90	.52	2.22	1.70
50	3.80	4.15	4.30	3.90	3.60	1.17	1.34	1.15	1.30	2.60	2.30
75	4.00	4.50	4.40	4.22	4.02	1.59	1.64	1.52	1.60	3.30	3.00

Control Group NO Haptic Feedback) (NHF)

	Presence	Interest	Motivation	Embodiment	Self-efficacy	Factual Knowledge pre-training	Factual Knowledge post-training	Factual Knowledge after one week training	Procedural Knowledge pre-training	Procedural Knowledge post-training	Procedural Knowledge after one week training
N	34	34	34	34	34	34	34	34	34	34	34
Mean	3.49	3.93	3.96	3.30	3.43	1.27	1.61	1.54	1.29	2.92	2.49
Median	3.60	3.95	4.00	3.30	3.45	1.19	1.65	1.60	1.30	3.00	2.60
Mode	3.20	4.30	3.70	3.30	3.10	.90	1.00	1.30	1.00	2.30	2 .00
Std.Deviation	.77	.61	.62	.70	.58	.46	.50	.51	.61	.69	.61
Minumum	1.60	2.80	3.00	1.30	2.30	.56	.56	.60	.00	2.00	1.30
Maximum	4.80	5.00	5.00	4.90	4.70	2.50	2.62	2.50	2.30	4.60	4.00
Percentiles 25	3.00	3.37	3.40	2.90	3.07	.90	1.27	1.27	.92	2.30	2.00
50	3.60	3.95	4.00	3.30	3.45	1.19	1.65	1.60	1.30	3.00	2.6 0
75	4.00	4.50	4.60	3.80	3.80	1.51	2.06	1.82	1.77	3.30	2.77

Table 4.1: Overview of the descriptive statistics for each of the dependent variables divided by groups: HF and NHF.

4.2 Comparison of Presence, Interest, Motivation, Embodiment, Self-efficacy, Procedural and Factual Knowledge

To determine whether the force and vibrotactile feedback enhance students in the HF group's sense of presence, interest, motivation, embodiment and self-efficacy, in addition to procedural and factual knowledge, this study will examine whether there is a statistically significant distinction in the levels of the just mentioned variables between the HF group (n = 34) and the NHF group (n = 34). As already reported in Section 3.5.1, the data (ordinal) does not follow a normal distribution; therefore, Mann-Whitney U tests (Section 3.5.2) were computed. A general overview of the differences between the examined variables can be found in Table 4.2, and a comparison of presence and the four cognitive factors is illustrated in Figure 4.3.

				Mann-Whitney U test HF and NHF			
Categories	Group	N	Mean Rank	Rank Sum	U	Z	p
Presence	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	32.46 36.54	1103.50 1242.50	508.50	-.85	.392
Interest	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	31.53 37.47	1072.00 1274.00	477.00	-1.24	.242
Motivation	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	32.47 36.53	1104.00 1242.00	509.00	-.85	.395
Embodiment	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	26.24 42.76	892.00 1454.00	297.00	-3.45	<.001
Self-efficacy	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	31.40 37.60	1067.50 1278.50	472.50	-1.29	.195
Factual knowledge (pre - training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	36.07 32.93	1226.50 1119.50	524.50	-.65	.051
Factual knowledge (post - training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	39.99 29.01	1359.50 986.50	391.50	-2.28	.022
Factual knowledge (one week after training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	39.82 29.18	1354.00 992.00	397.00	-2.23	.026
Procedural knowledge (pre -training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	36.59 32.41	1244.00 1102.00	507.00	-.879	.379
Procedural knowledge(post - training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	37.43 31.57	1272.50 1073.50	478.50	-1.23	.217
Procedural knowledge(one week after training)	No Haptic Feedback (NHF) Haptic Feedback (HF)	34 34	35.44 33.56	1250.00 1141.00	546.00	-.395	.693

Table 4.2: Mann-Whitney U tests comparing presence, interest, motivation, embodiment, self-efficacy, procedural knowledge (pre, post and one week after training), factual knowledge (pre, post and one week after training) in HF and NHF

4.2.1 Comparison of Presence Regarding Haptic Feedback

The hypothesis presented below is formulated to test whether *presence* increases by using haptic feedback. The presence score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the user's sense of presence.

H1: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher presence score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H1.0: There is no positive (presence HF > presence NHF) difference in presence score between condition HF and NHF.

H1a: There is a positive (presence HF > presence NHF) difference in presence score between conditions HF and NHF.

Mann Whitney-U test revealed that there was not a statistically significant difference in presence score between HF and NHF (U = 508.50, Z = -.85, p =.392), which means that participants in HF (M = 3.64, SD = .62), do not perceive to being more present in the virtual simulation than the ones in NHF (M = 3.49, SD = .77). Even if HF presented a higher mean score, the difference between the two groups is not significant. Therefore, H1.0 can not be rejected.

4.2.2 Comparison of Interest Regarding Haptic Feedback

The hypothesis presented below is formulated to test whether interest increases by using haptic feedback. The interest score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the user's interest.

H2: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher interest score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H2.0: There is no positive (interest HF > interest NHF) difference in interest score between condition HF and NHF.

H2a: There is a positive (interest HF > interest NHF) difference in interest score between conditions HF and NHF.

Mann Whitney-U test revealed that there was not a statistically significant difference in interest score between HF and NHF (U = 477.00, Z = -1.24, p = .242), which means that participants in HF (M = 4.1, SD = .34), does not perceive to be more interested in the virtual simulation than the ones in NHF (M = 3.93, SD = .61). Even if HF presented a higher mean score, the difference between the two groups is not significant, and therefore, H2.0 can not be rejected.

4.2.3 Comparison of Motivation Regarding Haptic Feedback

The hypothesis presented below is formulated to test whether motivation increases by using haptic feedback. The motivation score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the user's motivation.

H3: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher motivation score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H3.0: There is no positive (motivation HF > motivation NHF) difference in motivation score between conditions HF and NHF.

H3a: There is a positive (motivation HF > motivation NHF) difference in motivation score between conditions HF and NHF.

Mann Whitney-U test revealed that there was not a statistically significant difference in motivation score between HF and NHF (U = 509.00, Z = -.85, p = .395), which means that participants in HF (M = 4.1, SD = .44), do not perceive to be more motivated in the virtual simulation than the ones in NHF (M = 3.96, SD = .62). Even if HF presented a higher mean score, the difference between the two groups is not significant. Therefore, H3.0 can not be rejected.

4.2.4 Comparison of Embodiment Regarding Haptic Feedback

The hypothesis presented below is formulated to test whether embodiment increases by using haptic feedback. The embodiment score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the user's embodiment.

H4: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher embodiment score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H4.0: There is no positive (embodiment HF > embodiment NHF) difference in embodiment score between conditions HF and NHF.
H4a: There is a positive (embodiment HF > embodiment NHF) difference in embodiment score between conditions HF and NHF.

Mann Whitney-U test revealed a statistically significant difference in embodiment score between HF and NHF (U = 297.00, Z = -3.45, p = < .001), confirming the H4a hypothesis. It shows that participants in the HF group (M = 3.93, SD = .47) perceived embodiment higher than in the NHF group (M = 3.30, SD = .62). In addition to the statistical significance found, practical significance, denoted by the effect size $r = \frac{z}{\sqrt{N}}$ [176], was also conducted. Effect size reveals how meaningful the relationship between variables or the difference between groups is. It indicates the practical significance of a research result. As a result, the difference in embodiment score between HF and NHF was significant (p < .001) and meaningful (r = .42), which indicates a moderate positive effect. The value of this effect is considered moderate, implying a noticeable difference between the two groups, even though not extremely large.

4.2.5 Comparison of Self-efficacy Regarding Haptic Feedback

The hypothesis presented below is formulated to test whether self-efficacy increases by using haptic feedback. The self-efficacy score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the user's self-efficacy.

H5: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher self-efficacy score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H5.0: There is no positive (self-efficacy HF > self-efficacy NHF) difference in self-efficacy score between conditions HF and NHF.
H5a: There is a positive (self-efficacy HF > self-efficacy NHF) difference in self-efficacy score between conditions HF and NHF.

The Mann Whitney-U test revealed no meaningful difference in self-efficacy score between HF and NHF (U = 472.50, Z = -1.29, p = .195). As a result, participants in HF (M = 3.58, SD = .53) do not perceive more self-efficacy in the virtual simulation than the ones in NHF (M = 3.43, SD = .58). Therefore, H5.0 cannot be rejected.

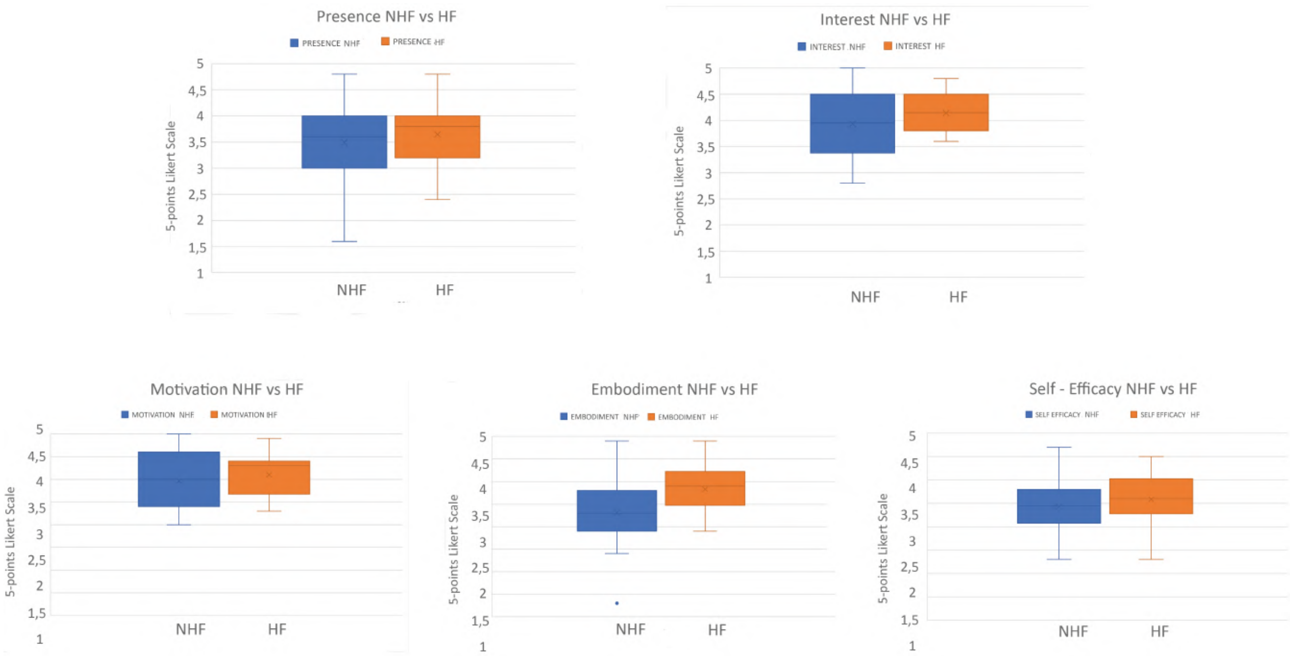

Table 4.3: Mann-Whitney U tests comparing presence, interest, motivation, embodiment, self-efficacy, procedural knowledge (pre, post and one week after training), factual knowledge (pre, post and one week after training) in HF and NHF

4.2.6 Comparison of Procedural Knowledge (Pre and Post Training) Regarding Haptic Feedback

Procedural Knowledge (pre-post training): The hypothesis presented below aims to assess whether haptic feedback affects procedural knowledge scores before and after the training session. The procedural knowledge (post-training) score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the participant's procedural Knowledge. Figure 4.1 illustrates the comparison regarding procedural knowledge for both pre and post-training.

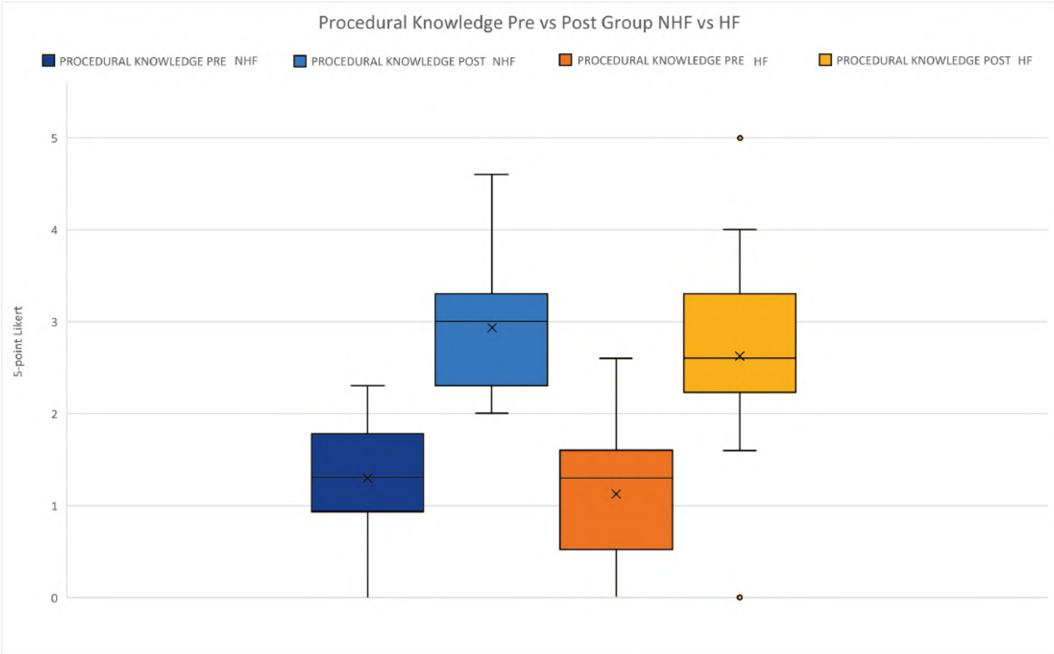

Figure 4.1: Comparison of Procedural Knowledge pre and post-training between haptic feedback condition (HF) and the condition not employing any feedback (NHF)

H6: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H6.0: There is no positive (procedural knowledge HF > procedural knowledge NHF) significant difference in procedural knowledge scores between the HF and NHF conditions, both before (pre-training) and after (post-training) the training.
H6a: There is a positive (procedural knowledge HF > procedural knowledge NHF) significant difference in procedural knowledge scores between the HF and NHF conditions, both before (pre-training) and after (post-training) the training.

Mann Whitney-U test revealed that there was not a statistically significant difference in procedural knowledge assessed before the training (pre-training) between HF and NHF (U = 507.00, Z = -.87, p = .375), which means that participants in HF (M = 1.12, SD = .74), and those NHF (M = 1.29, SD = .61), began to a similar knowledge level before going through the virtual training. Similarly, there was not a meaningful difference in procedural knowledge (post-training) between HF and NHF (U = 478.50, Z = -1.23, p = .217), which means that participants in HF (M = 2.62, SD = .90) did not acquire more procedural knowledge in the virtual simulation than the ones in NHF (M = 2.92, SD = .69). No significant difference was also found regarding the difference in the increase of procedural knowledge from pre-training to post-training retention between HF and NHF (U = 549.50, Z = -.35, p = .726).

Having examined the baseline procedural knowledge levels in the HF and NHF conditions, the investigation now focuses on haptic feedback's impact on post-training procedural knowledge. The Wilcoxon Signed-Rank Test indicated that the procedural knowledge post-test (Md = 2.60, SD = .90) in HF was statistically significantly higher than the procedural knowledge pre-test (Md = 1.30, SD = .74), (Z = 4.85, p = .001), with a large effect size (r = .76) Figure 4.2; likewise, in group NHF, the same test indicated that the procedural knowledge post-test (Md = 3.00, SD = .69) was statistically significantly higher than the procedural knowledge pre-test (Md = 1.30, SD = .61), (Z = 5.09, p = .001) with a large effect size (r = .87) Figure 4.2.

While there was no significant difference between the HF and NHF groups regarding procedural knowledge scores, it is important to underline that both groups showed a significant increase in procedural knowledge after the training (post-training) compared to before (pre-training). Consequently, H6.0 cannot be rejected, as significant gains in procedural knowledge were observed in both groups, regardless of haptic feedback.

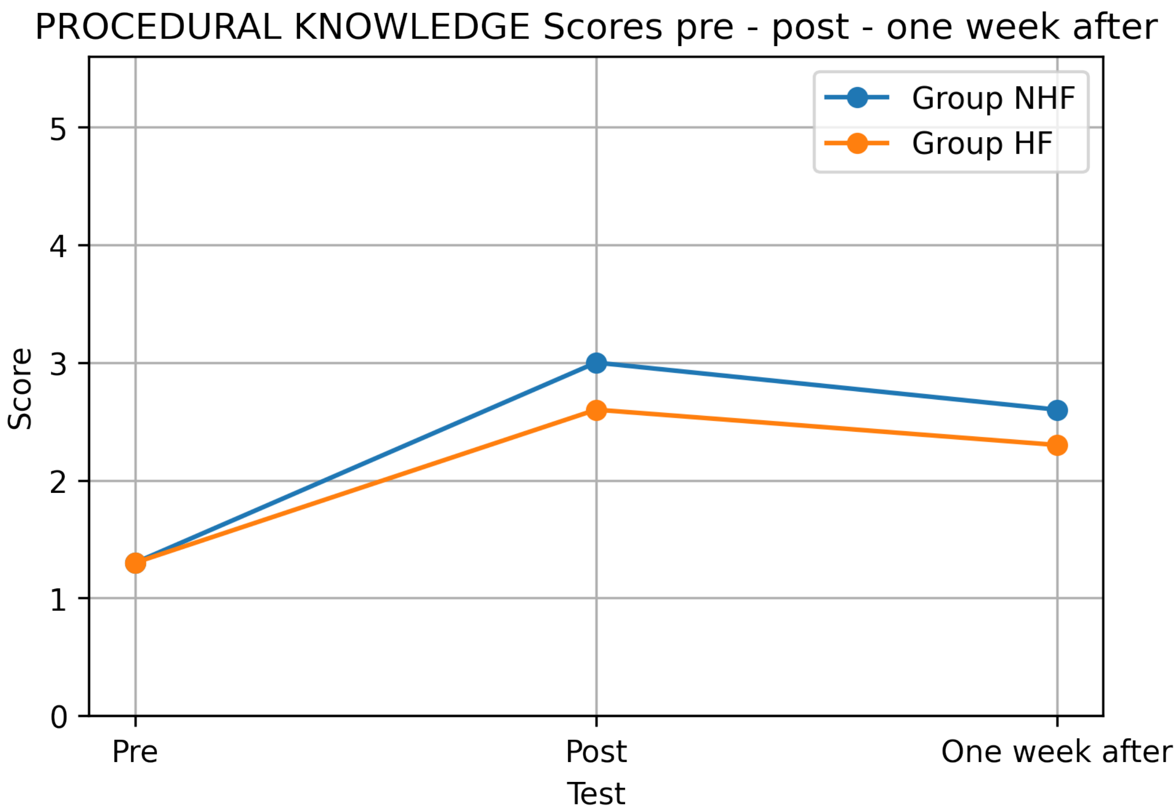

Figure 4.2: Pre-Post-One week after Training Procedural Knowledge

4.2.7 Comparison of Procedural Knowledge (One Week After Training) Regarding Haptic Feedback

Procedural Knowledge (one week after training): The hypothesis presented below is formulated to test whether procedural knowledge assessed after one week from the training session increases using haptic feedback. The procedural Knowledge (one week after training) score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE helped to retain more of the participant's procedural Knowledge. Figure 4.3 compares HF and NHF regarding procedural knowledge one week after the training.

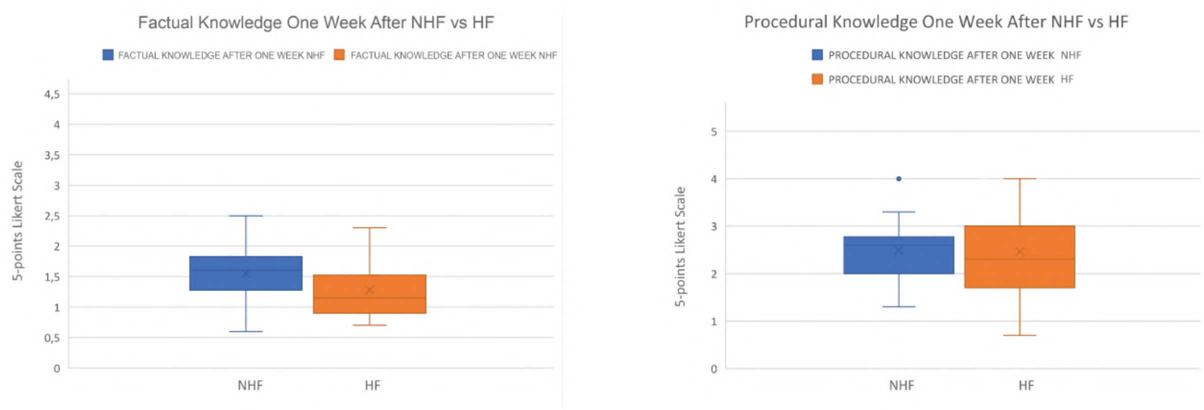

Figure 4.3: Comparison of Factual Knowledge (left) and Procedural Knowledge (right) one week after training between haptic feedback condition (HF) and the condition not employing any feedback (NHF)

H7: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H7.0: There is no positive (procedural knowledge HF > procedural knowledge NHF) significant difference in procedural knowledge one week after training between the group using haptic feedback (HF) in the virtual fire safety training simulation and the group without haptic feedback (NHF).

H7a: There is a positive (procedural knowledge HF > procedural knowledge NHF) significant difference in procedural knowledge one week after training, with the group using haptic feedback (HF) in the virtual fire safety training simulation having higher scores compared to the group without haptic feedback (NHF).

Mann Whitney-U test revealed that there was not a statistically significant difference in procedural knowledge (one week after training) between HF and NHF (U = 546.00, Z = -.39, p

= .693), which means that participants in HF (M = 2.46, SD = .90), did not perceive to lose more procedural knowledge information in the virtual simulation than the ones in NHF (M = 2.49, SD = .61). No significant difference was also found regarding the difference in the decrease of procedural knowledge from post-training and one week after retention between HF and NHF (U = 471.00, Z = -.18, p = .185).

Additionally, when comparing the procedural knowledge scores one week after training with both the pre-training scores and post-training scores within each group, the Wilcoxon Signed-Rank Test demonstrated that the procedural knowledge post-test (Md = 2.60, SD = .90) in HF was not statistically significantly higher than the procedural knowledge test after one week (Md =2.30, SD = .90), (Z = 1.21, p = .224) Figure 4.2. In the NHF group, the Wilcoxon Signed-Rank Test indicated that there was a statistically significant difference between the procedural knowledge test after one week (Md = 2.60, SD = .61) and the procedural knowledge post-test (Md = 3.00, Sd = 0.69), (Z = 3.31, p = .001) Figure 4.2.

A further investigation focused on assessing participants' procedural knowledge scores one week after the training, considering their pre-training knowledge levels. Therefore, the Wilcoxon Signed-Rank Test was used and showed for HF that the procedural knowledge test after one week (Md = 2.30, SD = .90) was statistically significantly higher than the procedural knowledge pre-test (Md = 1.30, Sd = .74), (Z = 4.88, p = .001). Regarding the NHF group, the same happened for the said group: the procedural knowledge test after one week (Md = 2.60, SD = .61) was statistically significantly higher than the procedural knowledge pre-test (Md = 1.30, SD = .61), (Z = 4.95, p = .001).

The analysis showed no statistically significant variation in procedural knowledge scores one week after training between the HF and NHF groups, indicating that adding haptic feedback did not result in a significant difference in retained knowledge. These results suggest that H7.0 cannot be rejected. Furthermore, when comparing the procedural knowledge scores one week after training with the pre-training and post-training scores within each group, it was found that participants in both the HF and NHF groups showed changes in their procedural knowledge levels over time.

4.2.8 Comparison of Factual Knowledge (Before and After Training) Regarding Haptic Feedback

Factual Knowledge (pre-post training). The hypothesis presented below aims to assess whether haptic feedback affects factual knowledge scores before and after the training session. The factual Knowledge (post-training) score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the participant's procedural Knowledge. Figure 4.4 illustrates the comparison regarding factual knowledge for both pre and post-training.

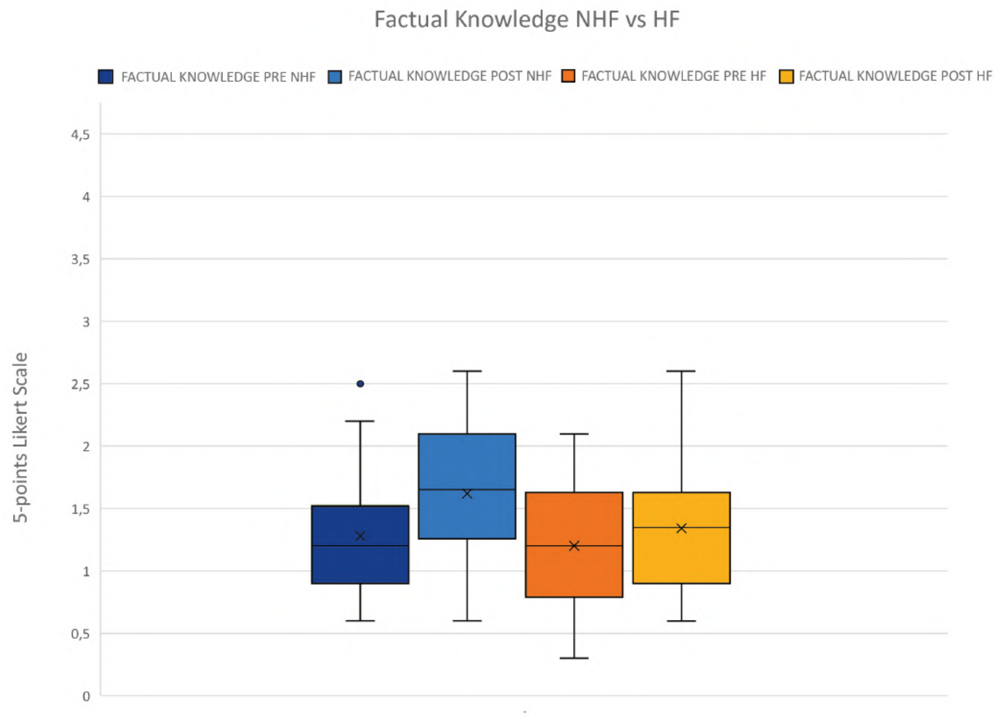

Figure 4.4: Comparison of factual knowledge pre and post-training between haptic feedback condition (HF) and the condition not employing any feedback (NHF)

H8: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H8.0: There is no positive (factual knowledge HF > factual knowledge NHF) significant difference in factual knowledge scores between the HF and NHF conditions, both before (pre-training) and after (post-training) the training.

H8a: There is a positive (factual knowledge HF > factual knowledge NHF) significant difference in factual knowledge scores between the HF and NHF conditions, both before (pre-training) and after (post-training) the training.

Mann Whitney-U test revealed that there was not a statistically significant difference in factual knowledge (pre-training) between HF and NHF ($U = 524.50$, $Z = -.65$, $p = .051$), which means that participants in HF ($M = 1.17$, $SD = .48$), and those in NHF ($M = 1.27$, $SD = .46$), began to a similar knowledge level before going through the virtual training. On the other hand, the Mann Whitney-U test revealed a statistically significant difference in factual knowledge post-training score between HF and NHF (U = 391.50, Z = -2.28, p = .022); however, this difference shows that participants in the HF group (M = 1.34, SD = .45) acquire less information than in the NHF group (M = 1.61, SD = .50). Finally, no significant difference was found regarding the increase in factual knowledge from pre-training to post-training between HF and NHF (U = 448.50, Z = -1.58, p = .112).

In addition to the statistical significance found, the effect size $r = \frac{z}{\sqrt{N}}$ [176] was also conducted. As a result, the difference in factual knowledge (post-training) score between HF and NHF was significant (p = .022), with a small meaningful negative effect (r = -.28). The small effect size suggests that while statistically significant, the actual impact of haptic feedback in factual knowledge may be relatively modest in practical terms. This effect underlines that as the presence of haptic feedback (HF) increases, factual knowledge decreases slightly.

Having examined the baseline factual knowledge levels in the HF and NHF conditions, the investigation now concentrates on haptic feedback's impact on post-training factual knowledge using the Wilcoxon Signed-Rank Test. It indicated that the factual knowledge post-test (Md = 1.34, SD = .45) in HF was not significantly higher than the factual knowledge pre-test (Md = 1.17. SD = .48), (Z = 1.79, p = .72) Figure 4.5; on the contrary, in group NHF, the same test indicated that factual knowledge post-test (Md = 1.65, SD = .50) was statistically significantly higher than the factual knowledge pre-test (Md = 1.90, SD = .46) (Z = 3.39, p = .001) Figure 4.5.

Based on these findings, H8.0 cannot be rejected. The data suggests no significant difference in factual knowledge between the HF and NHF conditions before and after the training.

4.2.9 Comparison of Factual Knowledge (One Week After Training) Regarding Haptic Feedback

Factual Knowledge (one week after training). The hypothesis presented below is formulated to test whether factual knowledge assessed after one week from the training session increases using haptic feedback. The factual knowledge (one week after training) score is expected to be higher for HF than NHF because the literature review showed that using haptic feedback within a VE could stimulate the participant's memory. Figure 4.3 compares HF and NHF regarding the factual knowledge one week after the training.

H9: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

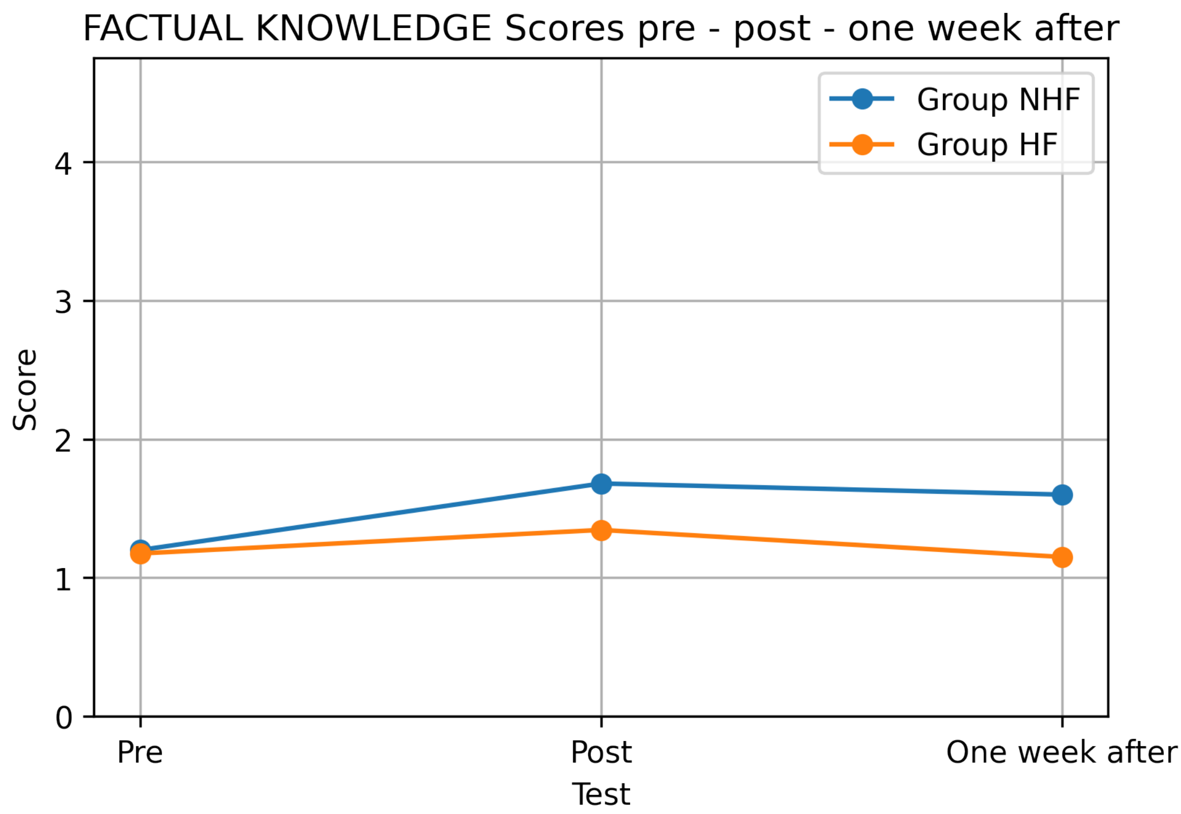

Figure 4.5: Pre-Post-One week after Factual Knowledge

H9.0: There is no positive (factual knowledge HF > factual knowledge NHF) significant difference in factual knowledge one week after training between the group using haptic feedback (HF) in the virtual fire safety training simulation and the group without haptic feedback (NHF).
H9a: There is a positive (factual knowledge HF > factual knowledge NHF) significant difference in factual knowledge one week after training, with the group using haptic feedback (HF) in the virtual fire safety training simulation having higher scores compared to the group without haptic feedback (NHF).

Mann Whitney-U test revealed that there was a statistically significant difference in factual knowledge (one week after training) score between HF and NHF (U = 397.00, Z = -.39, p = .693); however, this difference shows that participants in HF (M = 1.28, SD = .40) demonstrated to retain less information in the virtual simulation than the ones in NHF (M = 1.58, SD = .51). In addition to the statistical significance found, the effect size $r = \frac{z}{\sqrt{N}}$ was also conducted. As a result, the difference in the factual knowledge (one week after) between HF and NHF was significant (p = .022), with a small meaningful effect (r = .23). The small effect size suggests that while statistically significant, the actual impact of haptic feedback in factual knowledge may be relatively modest in practical terms. This effect underlines that as the presence of haptic feedback increases, factual knowledge decreases slightly. Finally, no significant difference was found regarding the decrease in factual knowledge from post-training to one week after the training between HF and NHF (U = 554.50, Z = -.28, p = .773).

Additionally, when comparing factual knowledge scores one week after training with both the pre-training scores and post-training scores within each group, the Wilcoxon Signed-Rank Test revealed that the factual knowledge after one week (Md = 1.15, SD = .40) in HF was not statistically significantly lower than the factual knowledge post-test (Md = 1.34, SD = .45), (Z = 1.21 p = .217) Figure 4.5. NHF group, where the Wilcoxon Signed-Rank Test indicated that the factual knowledge assessed after one week (Md = 1.60, SD = .51) was also not significantly lower than the factual knowledge post-test (Md = 1.65, SD = .50), (Z = 1.06, p = .285) Figure 4.5.

A further investigation was conducted to calculate participants' factual knowledge levels one week after the training, considering their pre-training memory levels. Therefore, the Wilcoxon Signed-Rank Test was used and showed for HF that the factual knowledge performance after one week (Md = 1.15, SD = .48) was not significantly higher than the factual knowledge pre-test (Md = 1.30, SD = .74), (Z = .66, p = .507). In contrast, in the NHF group, factual knowledge evaluation after one week (Md = 1.60, SD = .51) was statistically significantly higher than in the pre-test (Md = 1.19, SD = .46), (Z = 2.91, p = .004).

Based on the data and statistical analyses, H9.0 cannot be rejected. It suggested no significant difference in factual knowledge between the HF and NHF conditions one week after training and no significant difference over time within each group.

4.3 Correlation Analysis

Table A.1 and Table A.1 in Appendix A offer an overview of the correlation matrix using Spearman's rank-order correlation coefficient rho (ρ). At the same time, in the present section, it is possible to see Figure 4.6 and Figure 4.7, where HF and NHF correlation heatmaps are illustrated.

4.3.1 Correlations between Presence in Haptic Feedback Group and Presence No Haptic Feedback

Presence HF and Presence NHF correlation. The hypothesis presented below is formulated to test whether the factor of presence has a significant and positive relationship with haptic feedback. Presence is expected to correlate significantly with haptic feedback. The literature review showed that using haptic feedback within a VE could increase presence by employing force and vibrotactile feedback.

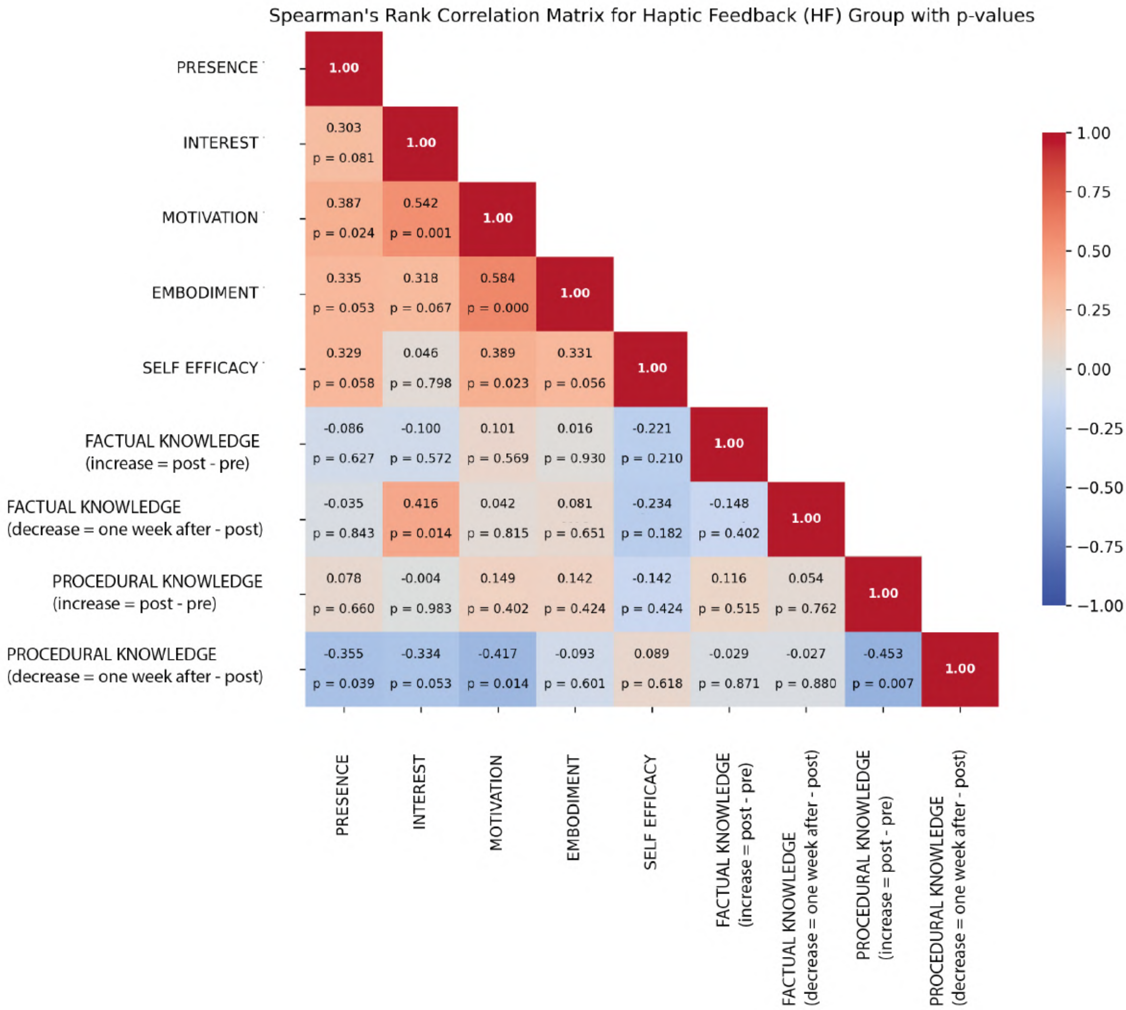

Figure 4.6: Overview of the correlation heatmap HF condition

H10: A postive ($0 \leq \rho \leq 1$) correlation exists between the sense of presence haptic feedback

H10.0: There is no significant and positve ($0 \leq \rho \leq 1$) correlation between presence and haptic feedback

H10a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between presence and haptic feedback

No statistically significant correlation exists in HF between presence and haptic feedback ($\rho = .116, p = .512$). Therefore, H10.0 cannot be rejected.

4.3.2 Correlations between Presence and Interest

Presence and Interest correlation. The hypothesis presented below is formulated to test whether the factor of presence has a significant and positive relationship with interest. Presence is expected to correlate significantly with interest for HF than NHF because the literature review

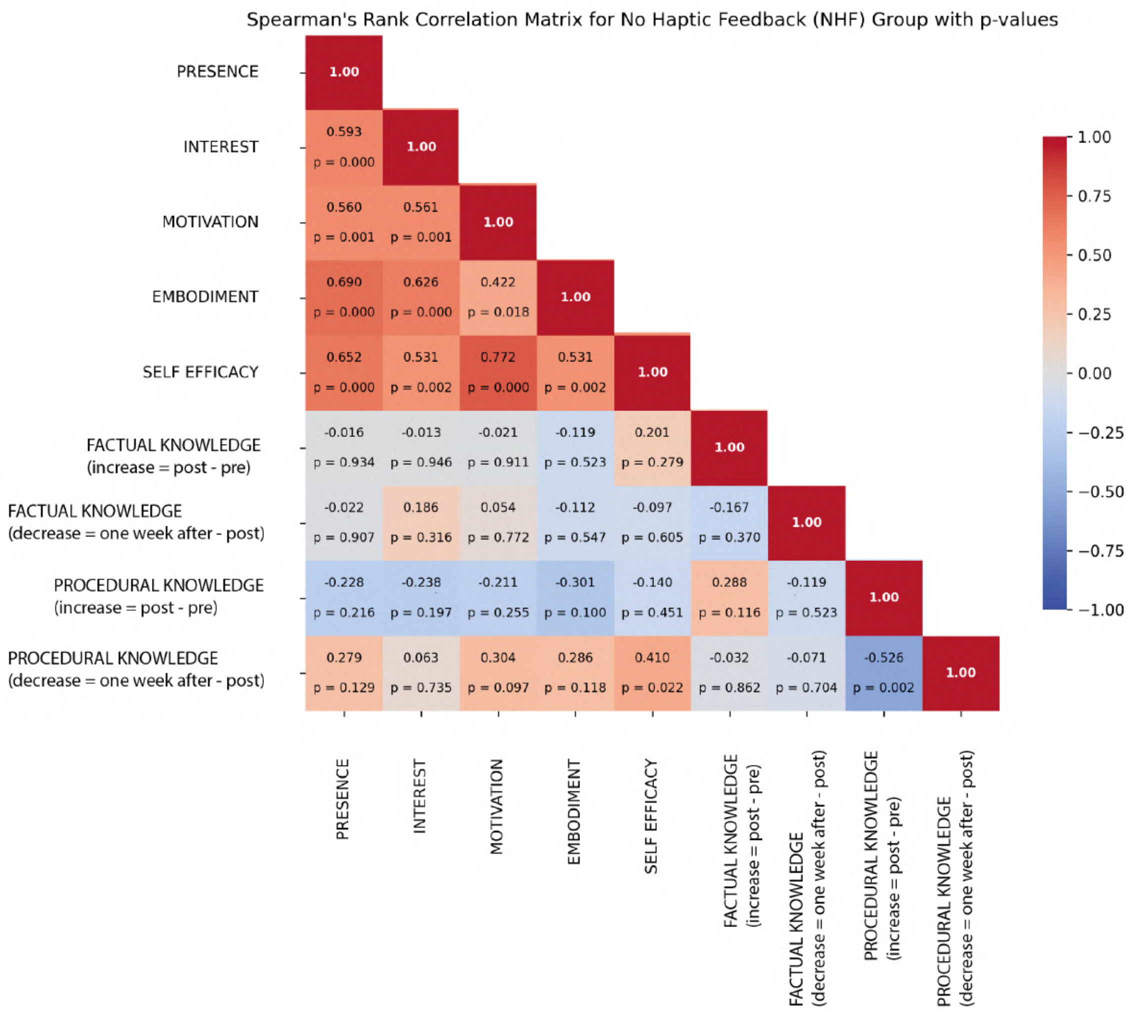

Figure 4.7: Overview of the correlation heatmap NHF condition

showed that using haptic feedback within a VE could increase interest by enhancing the participant's sense of presence.

H11: A positive ($0 \leq \rho \leq 1$) correlation exists between the sense of presence and interest in haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H11.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between presence and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H11a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between presence and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

No statistically significant correlation exists in HF between presence and interest ($\rho = .303, p = 0.081$). While in the NHF group, interest was positively correlated with presence

($\rho = .693, p = .001$). Therefore, H11.0 cannot be rejected.

4.3.3 Correlations between Presence and Motivation

Presence and Motivation correlation. The hypothesis presented below is proposed to test whether the factor of presence has a significant and positive relationship with motivation. Presence is expected to correlate significantly with motivation for HF than NHF because the literature review showed that using haptic feedback within a VE could increase motivation by enhancing the participant's sense of presence.

H11.1: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and motivation in haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H11.1.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between presence and motivation in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
H11.1a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between presence and motivation in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

A positive statistically significant correlation exists in HF between presence and motivation ($\rho = .387, p = .024$). Likewise, presence significantly correlated with motivation ($\rho = .532, p = .001$) in NHF. As a result, because presence has a positive and significant relationship with motivation in both conditions, H11.1a can be only partially correlated.

4.3.4 Correlations between Presence and Embodiment

Presence and Embodiment correlation. The hypothesis presented below is proposed to test whether the factor of presence has a significant and positive relationship with embodiment. Presence is expected to correlate significantly with embodiment for HF than NHF because the literature review showed that using haptic feedback within a VE could increase embodiment by enhancing the participant's sense of presence.

H11.2: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and embodiment in haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H11.2.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between presence and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
H11.2a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between presence and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
Regarding presence and embodiment, their correlation is marginally significant ($\rho = .335, p =$

.053); however, as the p-value to be considered significant, it needs to be less than 0.05; it is impossible to consider this cognitive factor to have a meaningful correlation with presence. In the NHF condition, on the contrary, embodiment found a positive and significant correlation with presence ($\rho = .303, p = .001$). Due to these findings, H11.2.0 cannot be rejected.

4.3.5 Correlations between Presence and Self-Efficacy

Presence and Self-efficacy correlation. The hypothesis presented below is proposed to test whether the factor of presence has a significant and positive relationship with self-efficacy. Presence is expected to correlate significantly with self-efficacy for HF than NHF because the literature review showed that using haptic feedback within a VE could increase self-efficacy by enhancing the participant's sense of presence.

H11.3: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H11.3.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between presence and self-efficacy in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
H11.3a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between presence and self-efficacy in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

Self-efficacy correlates only marginally significantly with presence ($\rho = .329, p = .058$) in HF. However, for embodiment, the p-value to be considered significant must be less than 0.05; it is impossible to consider these two cognitive factors to have a meaningful correlation with presence. In group NHF, however, self-efficacy is significantly correlated with presence ($\rho = .599, p = .001$). Because of these findings, H11.3.0 cannot be rejected.

4.3.6 Correlations between Presence and Procedural Knowledge

Presence and Procedural Knowledge correlation. Below, the hypothesis proposes to test whether the factor of presence has a significant positive and negative relationship with procedural knowledge. Presence is expected to correlate positively and significantly with increased post-training procedural knowledge in HF than NHF. Likewise, presence is expected to correlate negatively and significantly with the decrease of one week after training procedural knowledge in HF than NHF. The literature review showed that using haptic feedback within a VE could increase procedural memory retention by enhancing the participant's presence.

H12: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and procedural knowledge (increase = post - pre) and a negative ($-1 \leq \rho \leq 0$) correlation exists between the

sense of presence and procedural knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H12.0: There is no significant and positive ($0 \leq \rho \leq 1$) *correlation between the presence and procedural knowledge (increase = post - pre) and no significant and negative* ($-1 \leq \rho \leq 0$) *correlation between the presence and procedural knowledge (decrease = one week after - post) in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.*

H12a: There is a significant and positive ($0 \leq \rho \leq 1$) *correlation between the presence and procedural knowledge (increase = post - pre) and a negative* ($-1 \leq \rho \leq 0$) *significant correlation between presence and procedural knowledge (decrease = one week after - post) in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.*

In HF, procedural knowledge (increase = post - pre) does not correlate significantly and positively with presence ($\rho = .078, p = .660$). On the other hand, after one week, procedural knowledge (decrease = one week after - post) is significantly and negatively correlated with presence ($\rho = -.355, p = .039$). The lack of significant relationship between presence and procedural knowledge (increase = post -pre) ($\rho = -.228, p = .216$) and after one week (decrease = one week after - post) ($\rho = .279, p = .129$) was found in NHF condition. Therefore, H12a can be partially accepted.

4.3.7 Correlations between Presence and Factual Knowledge

Presence and Factual Knowledge correlation. Below, the hypothesis reported tests whether the factor of presence has a significant positive and negative relationship with factual knowledge. Presence is expected to correlate positively and significantly with increased post-training factual knowledge in HF than in NHF. Likewise, presence is expected to correlate negatively and significantly with the decrease in one week after training of factual knowledge in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase memory retention by enhancing the participant's presence.

H12.1: A positive ($0 \leq \rho \leq 1$**) correlation exists between a sense of presence and the factual knowledge (increase = post - pre) and a negative (**$-1 \leq \rho \leq 0$**) correlation exists between the sense of presence and factual knowledge (decrease = one week after - post) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).**

H12.1.0: There is no significant and positive ($0 \leq \rho \leq 1$) *correlation between the presence and factual knowledge (increase = post - pre-training) and no significant negative correlation* ($-1 \leq \rho \leq 0$) *between presence and factual knowledge (decrease = one week after and post-training) in the haptic feedback (HF)*

condition, compared to no haptic feedback (NHF) group.
H12.1a: There is a significant and positive ($0 \leq \rho \leq 1$) *correlation between sense of presence and factual knowledge (increase = post - pre) and a significant and negative correlation* ($-1 \leq \rho \leq 0$) *between sense of presence and factual knowledge (decrease = one week after - post) in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.*

In HF, factual knowledge (increase = post - pre) does not correlate significantly and positively with presence ($\rho = -.009, p = .627$). Likewise, after one week, factual knowledge (decrease = one week after - post) is still not significantly correlated with presence ($\rho = -.004, p = .843$). The same lack of significant relationship between presence and factual knowledge, post-training (increase = post -pre) ($\rho = -.002, p = .934$) and after one week (decrease = one week after - post) ($\rho = -.002, p = .907$) was found in NHF condition. Therefore, H12.1.0 cannot be rejected.

4.3.8 Correlations between Procedural Knowledge and Interest

Procedural Knowledge and Interest Correlation. Below, the hypothesis reported tests whether procedural knowledge has a significant positive and negative relationship with interest. The increase in procedural knowledge is expected to correlate positively and significantly with interest in HF than in NHF. Likewise, the decrease of one week after training procedural knowledge is expected to correlate negatively and significantly with interest in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase procedural memory by enhancing the participant's interest.

H13: A positive ($0 \leq \rho \leq 1$**) correlation exists between procedural knowledge (increase = post - pre) and interest, and a significant and negative (**$-1 \leq \rho \leq 0$**) correlation exists between procedural knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).**
H13.0: There is no significant and positive ($0 \leq \rho \leq 1$) *correlation between procedural knowledge (increase = post - pre) and interest, and no significant and negative* ($-1 \leq \rho \leq 0$) *correlation between procedural knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.*
H13a: There is a significant and positive ($0 \leq \rho \leq 1$) *correlation between procedural knowledge (increase = post - pre) and interest, and no significant and negative* ($-1 \leq \rho \leq 0$) *correlation between procedural knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.*

In HF, procedural knowledge (increase = post - pre) does not correlate significantly with interest ($\rho = -.004, p = .983$). Likewise, procedural knowledge is still not significantly and positively correlated with interest ($\rho = -.334 p = .053$) after one week (decrease = one week after - post). The same lack of significant relationship between interest and procedural knowledge, post-training (increase = post - pre) $\rho = -.238, p = .197$ and after one week (decrease = one week after - post) ($\rho = .063, p = .735$) was found in NHF condition. Therefore, H13.0 cannot be rejected.

4.3.9 Correlations between Procedural Knowledge and Motivation

Procedural Knowledge and Motivation Correlation. Below, the hypothesis reported tests whether procedural knowledge has a significant positive and negative relationship with motivation. The increase in procedural knowledge is expected to correlate positively and significantly with motivation in HF than in NHF. Likewise, the decrease of one week after training procedural knowledge is expected to correlate negatively and significantly with motivation in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase procedural memory by enhancing the participant's motivation.

H13.1: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and motivation, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H13.1.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge and motivation (increase = post - pre) and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H13.1a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and motivation, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, procedural knowledge (increase = post - pre) does not correlate significantly with motivation ($\rho = .149, p = .402$). On the other hand, procedural knowledge is significantly and negatively correlated with motivation ($\rho = -.417, p = .014$) after one week (decrease = one week after - post). The lack of significant relationship between motivation and procedural knowledge, post-training (increase = post - pre) ($\rho = -.211, p = .255$) after one week (decrease = one week after - post) ($\rho = .304, p = .097$) was found in NHF condition. Therefore, H13.1a can be partially retained.

4.3.10 Correlations between Procedural Knowledge and Embodiment

Procedural Knowledge and Embodiment Correlation. Below, the hypothesis reported tests whether procedural knowledge has a significant positive and negative relationship with embodiment. The increase in procedural knowledge is expected to correlate positively and significantly with embodiment in HF than in NHF. Likewise, the decrease of one week after training procedural knowledge is expected to correlate negatively and significantly with embodiment in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase procedural memory by enhancing the participant's embodiment.

H13.2: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H13.2.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H13.2a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, procedural knowledge (increase = post - pre) does not correlate significantly with embodiment ($\rho = .142, p = .424$). Likewise, procedural knowledge is still not significantly correlated with embodiment ($\rho = -.093 p = .618$) after one week (decrease = one week after - post). The same lack of significant relationship between interest and procedural knowledge, post-training (increase = post - pre) ($\rho = -.301 p = .100$) and after one week (decrease = one week after - post) ($\rho = .286, p = .118$) was found in NHF condition. Therefore, H13.2.0 cannot be rejected.

4.3.11 Correlations between Procedural Knowledge and Self-Efficacy

Procedural Knowledge and Self-Efficacy Correlation. Below, the hypothesis reported tests whether procedural knowledge has a significant positive and negative relationship with self-efficacy.

The increase in procedural knowledge is expected to correlate positively and significantly with self-efficacy in HF than in NHF. Likewise, the decrease of one week after training procedural knowledge is expected to correlate negatively and significantly with self-efficacy in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase procedural memory by enhancing the participant's self-efficacy.

H13.3: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (increase = post - pre) and self-efficacy, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge(decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H13.3.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and self-efficacy, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H13.3a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between procedural knowledge (increase = post - pre) and self-efficacy, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, procedural knowledge (increase = post - pre) does not correlate significantly with self-efficacy ($\rho = -.142, p = .424$). Likewise, after one week (decrease = one week after - post), procedural knowledge is still not significantly correlated with self-efficacy $\rho = .089, p = .618$. The same lack of significant relationship between self-efficacy and procedural knowledge, post-training (increase = post - pre) ($\rho = -.140, p = .451$); on the other hand, after one week (decrease = one week after - post) ($\rho = .410p = .022$) was found positively significant correlated in NHF condition. Therefore, H13.3.0 cannot be rejected.

4.3.12 Correlations between Factual Knowledge and Interest

Factual Knowledge and Interest Correlation. Below, the hypothesis reported tests whether factual knowledge has a significant positive and negative relationship with interest. The increase in factual knowledge is expected to correlate positively and significantly with interest in HF than in NHF. Likewise, the decrease of one week after training factual knowledge is expected to correlate negatively and significantly with interest in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase memory by enhancing the participant's interest.

H14: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (increase = post - pre) and interest, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H14.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and interest, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H14a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and interest, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and interest in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, factual knowledge (increase = post - pre) does not correlate significantly with interest ($\rho = -.100, p = .572$). After one week (decrease = one week after - post), factual knowledge is significantly but positively correlated with interest ($\rho = .416, p = .014$). The same lack of significant relationship between interest and factual knowledge, post-training (increase = post - pre) ($\rho = -.042, p = .814$) and after one week (decrease = one week after - post) ($\rho = .221, p = .210$) was found in NHF condition. Therefore, H14a cannot be accepted.

4.3.13 Correlations between Factual Knowledge and Motivation

Factual Knowledge and Motivation Correlation. Below, the hypothesis reported tests whether factual knowledge has a significant positive and negative relationship with motivation. The increase in factual knowledge is expected to correlate positively and significantly with motivation in HF than in NHF. Likewise, the decrease of one week after training factual knowledge is expected to correlate negatively and significantly with motivation in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase memory by enhancing the participant's motivation.

H14.1: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (increase = post - pre) and motivation, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H14.1.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and motivation, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between

factual knowledge (decrease = one week after - post) and motivation in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
H14.1a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge and motivation (decrease = one week after - post) in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, factual knowledge (increase = post - pre) does not correlate significantly with motivation ($\rho = .101, p = .569$). Likewise, after one week (decrease = one week after - post), factual knowledge is still not significantly correlated with motivation ($\rho = .042, p = .815$). The same lack of significant relationship between motivation and factual knowledge, post-training (increase = post - pre) ($\rho = .021, p = .911$) and after one week (decrease = one week after - post) ($\rho = .054, p = .772$) was found in NHF condition. Therefore, H14.1.0 cannot be rejected.

4.3.14 Correlations between Factual Knowledge and Embodiment

Factual Knowledge and Embodiment Correlation. Below, the hypothesis reported tests whether factual knowledge has a significant positive and negative relationship with embodiment. The increase in factual knowledge is expected to correlate positively and significantly with embodiment in HF than in NHF. Likewise, the decrease of one week after training factual knowledge is expected to correlate negatively and significantly with embodiment in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase memory by enhancing the participant's embodiment.

H14.2: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).
H14.2.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.
H14.2a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and embodiment, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and embodiment in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, factual knowledge (increase = post - pre) does not correlate significantly with embodiment ($\rho = .016, p = .930$). Likewise, after one week (decrease = one week after - post), factual knowledge is still not significantly correlated with embodiment ($\rho = .081, p = .651$). The same lack of significant relationship between embodiment and factual knowledge (increase = post - pre) $\rho = -.119, p = .547$ and after one week (decrease = one week after - post) ($\rho = -.112, p = .547$) was found in NHF condition. Therefore, H14.2.0 cannot be rejected.

4.3.15 Correlations between Factual Knowledge and Self-Efficacy

Factual Knowledge and Correlation. Below, the hypothesis reported tests whether factual knowledge has a significant positive and negative relationship with self-efficacy. The increase in factual knowledge is expected to correlate positively and significantly with self-efficacy in HF than in NHF. Likewise, the decrease of one week after training factual knowledge is expected to correlate negatively and significantly with self-efficacy in HF than in NHF. The literature review showed that using haptic feedback within a VE could increase memory by enhancing the participant's self-efficacy.

H14.3: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (increase = post - pre) and self-efficacy, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).

H14.3.0: There is no significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge (increase = post - pre) and self-efficacy, and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge (decrease = one week after - post) and self-efficacy in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

H14.3a: There is a significant and positive ($0 \leq \rho \leq 1$) correlation between factual knowledge and self-efficacy (increase = post - pre) and a significant and negative ($-1 \leq \rho \leq 0$) correlation between factual knowledge and interest (decrease = one week after - post) in the haptic feedback (HF) condition, compared to no haptic feedback (NHF) group.

In HF, factual knowledge (increase = post - pre) does not correlate significantly with self-efficacy ($\rho = -.221, p = .210$). Likewise, after one week (decrease = one week after - post), factual knowledge is still not significantly correlated with self-efficacy ($\rho = -.234, p = .182$). The same lack of significant relationship between self-efficacy and factual knowledge, post-training (increase = post - pre) ($\rho = .201, p = .279$) and after one week (decrease = one week after - post) ($\rho = -.097, p = .605$) was found in NHF condition. Therefore, H14.3.0 cannot be rejected.

4.4 Exploratory Analysis of the Impact of Previous Experience on Learning Outcomes

4.4.1 Haptic Feedback Previous Experience

Because of the limited sample sizes in the Intermediate (N = 3) and Advanced (N = 5) ratings regarding previous experience in using haptic feedback, the primary focus of the exploratory analysis was the Beginner category (N = 60), considering the total sample. This decision was made to ensure statistical robustness and the ability to draw meaningful insights.

In the analysis of factual knowledge post-training, when filtered for participants categorized as Beginner in previous haptic experience, a statistically significant difference was observed between the HF and NHF groups (U = 561.00, Z = .80, p = .013). However, the NHF group showed higher factual knowledge scores than the HF group. A significant difference in factual knowledge was found one week after the training, filtered for participants categorized as Beginner in terms of previous haptic experience (U = 535.99, z = .84, p = .039). Again, the NHF group showed higher factual knowledge scores after one week than the HF group. No other significant relations with factual and procedural knowledge filtered by previous haptic experiences were found.

4.4.2 Virtual Reality Previous Experience

Because of the limited sample sizes in the Intermediate (N = 9) and Advanced (N = 5) ratings regarding previous experience with VR, the primary focus of the exploratory analysis was the Beginner category (N = 54), considering the total sample. This decision was made to ensure statistical robustness and the ability to draw meaningful insights.

Factual knowledge post-training filtered for previous virtual reality experience considered at the beginner level; a statistically significant difference was found between the HF and NHF groups (U = 432.00, Z = .84, p = .042). However, the NHF group showed higher factual knowledge scores than the HF group. No other significant relations with factual and procedural knowledge filtered by previous virtual reality experience were found.

4.4.3 Fire Training Previous Experience

After a week of training, factual knowledge showed a significant difference between HF and NHF when filtered by participants' prior experience in any fire safety training lesson (U = 86.00, Z = .71, p = .030) Figure 4.8. However, based on the results, participants with prior fire safety training experience performed better in the NHF group than the HF group, suggesting that for individuals with previous fire safety training experience, haptic feedback may not contribute significantly to the retention of knowledge.

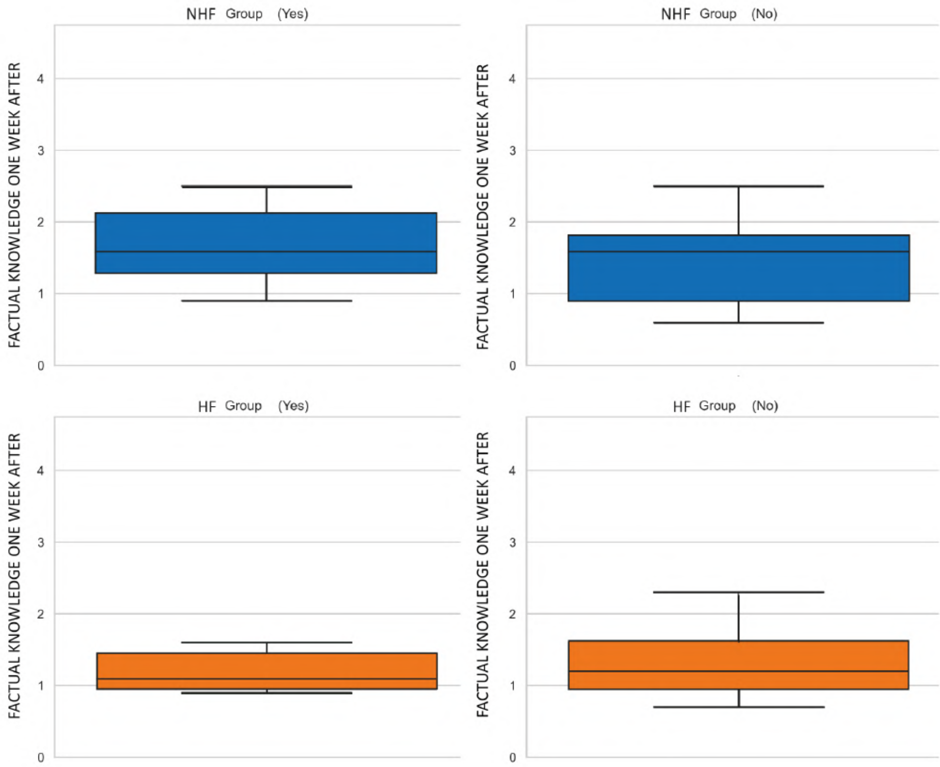

Figure 4.8: Group HF (orange) and NHF (blue): One week after-training regarding factual knowledge filtered for previous experience (yes or no) in fire safety training

4.4.4 Hypotheses Summary

This Section summarises all hypotheses presented previously, indicating the ones accepted (in green) and the ones that have been rejected (in red).

HYPOTHESIS	ACCEPTED (green = yes, red = no)
H1: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher presence score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H2: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher interest score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H3: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher motivation score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H4: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher embodiment score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	yes
H5: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher self-efficacy score than in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H6: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H7: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher procedural knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)	no
H8: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (post-training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF)	no
H9: Using haptic feedback (HF) in a virtual fire safety training simulation leads to a higher factual knowledge (one week after training) score compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no

Table 4.4: Overview of the hypotheses: from H1 to H9.

HYPOTHESIS	ACCEPTED (yes / no)
H10: A positive ($0 \leq \rho \leq 1$) correlation exists between the sense of presence and haptic feedback in the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H11: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and interest in haptic feedback (HF) conditions compared to the virtual fire safety training simulation where haptic feedback is not implemented NHF) .	no
H11.1: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and motivation in haptic feedback (HF) conditions compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	yes/no
H11.2: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and embodiment in haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H11.3: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H12: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and procedural knowledge (post - pre-training) and a negative ($-1 \leq \rho \leq 0$) correlation exists between the sense of presence and procedural knowledge (one week after and post-training) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	yes/no
H12.1: A positive ($0 \leq \rho \leq 1$) correlation exists between a sense of presence and the factual knowledge (post-training), and there is a negative ($-1 \leq \rho \leq 0$) correlation with factual knowledge (one week after) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H13: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (post-training) and interest and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (after one week) and interest in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H13.1: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (post-training) and motivation and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (after one week) and motivation in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	yes/no
H13.2: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (post-training) and embodiment and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (after one week) and embodiment in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H13.3: A positive ($0 \leq \rho \leq 1$) correlation exists between procedural knowledge (post-training) and self-efficacy and a negative ($-1 \leq \rho \leq 0$) correlation between procedural knowledge (after one week) and self-efficacy in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H14: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (post-training) and interest and a negative correlation ($-1 \leq \rho \leq 0$) between factual knowledge and interest (after one week) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H14.1: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (post-training) and motivation and a negative correlation ($-1 \leq \rho \leq 0$) between factual knowledge and motivation (after one week) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H14.2: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (post-training) and embodiment and a negative correlation ($-1 \leq \rho \leq 0$) between factual knowledge and embodiment (after one week) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no
H14.3: A positive ($0 \leq \rho \leq 1$) correlation exists between factual knowledge (post-training) and self-efficacy and a negative correlation ($-1 \leq \rho \leq 0$) between factual knowledge and self-efficacy (after one week) in the haptic feedback (HF) condition compared to the virtual fire safety training simulation where haptic feedback is not implemented (NHF).	no

Table 4.5: Overview of the hypotheses: from H10 to H14.3.

5. Discussion

This thesis explores the impact of haptic feedback in virtual training simulations on two learning outcomes: procedural and factual knowledge over one week. While VR training simulations hold promise for learning, it needs to be clarified how haptic feedback affects this process. The present research aims to clarify this relationship. This study uses the CAMIL model and Embodied Cognition theory as guidelines. Figure 5.1 shows the findings summarised.

CAMIL suggests that haptic feedback in VR can enhance cognitive factors like presence, interest, motivation, embodiment, and self-efficacy, ultimately improving procedural and factual knowledge retention. The final purpose is to determine whether haptic feedback significantly enhances procedural and factual knowledge in VR training simulation over time.

Therefore, an experiment was designed with two conditions and carried out on university students in the Netherlands, where participants had to interact with a fire safety training simulation. Surprisingly, haptic feedback did not significantly increase presence, interest, motivation and self-efficacy. On the other hand, embodiment differed significantly when force and vibrotactile feedback were employed.

No significant difference between the two conditions was found in assessing procedural knowledge pre-, post-, and after one week from the training. Furthermore, the effect of haptic feedback on procedural knowledge could be considered as high as the lack of that feedback since, in both groups, a significant increase was found from the pre-training-score to the post-training-score. The haptic feedback group showed no significant decrease in procedural information after one week, while it happened to the no haptic feedback group. The overall increase in procedural knowledge from pre-training to one week after was significant in both groups. Within the haptic feedback group, procedural knowledge retention after one week decreased less than in the group without haptic feedback.

No significant difference was found in assessing factual knowledge pre-training scores. On the other hand, a statistically significant difference in post-training scores was seen. This difference, however, showed the haptic feedback condition retained less factual knowledge than the no-haptic condition. The increase in factual knowledge from the pre-and post-training was not significant in the haptic feedback group. Also, no significant decrease was found in factual knowledge from post-training to one-week after-training retention. A statistically significant difference was found between the two conditions regarding one week after training score, showing better retention in the no haptics group. Finally, no significant increase was found before the training assessment to one week after the training in the haptic feedback group. In comparison, the control condition showed a statistical increase in factual knowledge from the pre-training score to one week after.

Lastly, it was examined whether presence positively correlates with interest, motivation, embodiment and self-efficacy. In addition, it was also investigated whether these factors positively (increase = post - pre) and negatively (decrease = one week - post) correlated with procedural and factual knowledge. The finding showed that presence does correlate with only motivation and shares a negative relation with procedural knowledge retention after one week of the training, and the same was true for the motivation factor. This result shows that increasing presence will also increase motivation, and the decay of procedural knowledge after one week will decrease. This finding partly helps to answer the main research question of the current research.

Although the previous relation between presence, motivation and procedural knowledge (decrease = one week after - post) was found, further significant results were not discovered. The following section will discuss the possible reasons and implications of these findings.

5.1 Influence of Haptic Feedback on Presence, Interest, Motivation, Embodiment and Self-Efficacy

Overall, there were no significant differences in assessing presence, interest, motivation, and self-efficacy. As a result, rejecting H1.0, H2.0, H3.0, and H5.0 is impossible; these findings do not demonstrate that haptic feedback leads to increased presence and the said three cognitive factors in a VTE. Even if these differences were not significant, HF presented a mean score higher for each of the variables considered, which, in turn, shows encouraging findings on how using haptic feedback can still (1) make the user feel more present in the simulation, (2) make the virtual training more compelling, (3) help the user to be more motivated in learning the material, and finally (4) strengthens the users self-believes in their abilities, as pointed out in the literature [21].

Furthermore, presence, interest, and motivation differ in standard deviation results; in the HF group, the standard deviation for the mentioned factors was lower than in the NHF group. These findings suggest that participants in this group had more consistent scores related to presence, interest, and motivation. In other words, participants' experiences in the HF group were relatively uniform. The lower standard deviation in the HF group might suggest that haptic feedback contributes to a more consistent sense of presence, interest, and motivation among participants. However, it is essential to state that while haptic feedback can influence uniformity regarding the presence and the mentioned two cognitive factors, the current study did not find statistically significant differences. As a result, while these tendencies are intriguing, further research is required to establish whether haptic feedback leads to more consistent cognitive experiences.

On the other hand, a significant difference was observed between the HF and NHF conditions for one cognitive factor. The embodiment's difference emerged statistically significant and showed a moderate effect size, confirming the H4a hypothesis. This finding demonstrated that force and vibrotactile feedback effectively increase embodiment in a VTE. These two haptic feedbacks enable the users to connect with and understand better the VE by making them feel like the properties of their virtual body were so accurate that they perceived them as if they were part of their real, physical body. This result aligns with previous research that showed that haptic feedback enhances embodiment in a VE [40] [156].

5.2 Influence of Haptic Feedback on Procedural Knowledge and Factual Knowledge

Procedural Knowledge. H6a was not supported by the research, indicating that there is no difference between procedural knowledge before the training between the condition experiencing haptic feedback and the one without it. This means HF and NHF participants started the training from similar knowledge levels before the virtual training. Likewise, there was no significant difference in procedural knowledge (post-training), which means that HF participants did not acquire more procedural knowledge in the virtual simulation than in NHF. After one week, the two conditions had no statistically significant difference; therefore, H7a was also not supported by this research. Nevertheless, when it was examined the difference between the mean scores one week after the training and the scores immediately after post-training in both groups, it became evident that the HF condition showed a smaller decrease in procedural knowledge from post-assessment to one week after. In other words, while the overall difference was not significant, HF resulted in better procedural knowledge retention compared to the NHF group after one week.

These findings contrast with embodied cognition theory (Section 2.2) and Crandall et al.'s paper [63], which reported and discussed how haptic feedback increases learning outcomes in different fields. One possible reason could be a flaw in the training simulation's tasks: enabling haptic feedback within the interaction with fire extinguishers did not significantly increase the acquisition of new notions of procedural knowledge. If the training material was simple enough, participants from both groups might have quickly learned the same amount of new procedural knowledge.

Second, participants might have employed similar learning strategies despite the presence or absence of haptic feedback. The training might have allowed them to learn effectively through visual or auditory cues, and consequently, the additional haptic feedback might not have significantly impacted procedural knowledge acquisition [54]. Moreover, instead of clear procedures that are usually possible for factual and conceptual knowledge learning, regarding procedural knowledge, it is necessary to simultaneously consider different perspectives, such as social factors, problem-solving skills, and institutional characteristics [72], which the current research did not consider as part of the research question. Finally, participants might have focused more on the aesthetic aspects of the simulation rather than on the tasks required. Therefore, this shift in attention might have affected the participants' focus.

Remarkably, even if there was no significant difference in using haptic feedback or not to enhance procedural knowledge, there was a considerable increase and retention of procedural knowledge after one week compared to pre-training levels, which offers valuable insights; further explanations will be given in Section 5.4

Factual Knowledge. The study did not support H8a; therefore, there was no difference between the factual knowledge assessed before the training between the condition experiencing haptic feedback and the one without it. This means HF and NHF participants started the training from similar knowledge levels before the virtual training. On the other hand, there was a negative significant difference in factual knowledge retention straight after the post-assessment between the two groups, which had a small effect. The said effect suggests that while statistically significant, the impact of haptic feedback on factual knowledge may be relatively modest in practical terms. This effect suggests that factual knowledge decreases slightly as haptic feedback (HF) increases. Because of this difference, NHF was the group that retained more of the new material learnt by undergoing the training simulation. This result showed that, with the same level of information, haptic feedback did not contribute to retaining more factual knowledge.

The difference in the factual knowledge one week after the training between HF and NHF was significant. However, this difference shows that participants in HF retained less factual knowledge in the virtual simulation than in NHF. As a result, the small effect size suggests that while statistically significant, the impact of haptic feedback on factual knowledge may be relatively modest in practical terms. This effect underlines that as haptic feedback (HF) increases, factual knowledge decreases slightly. Therefore, H9a was also not supported by this research. Haptic feedback condition did not show a higher factual knowledge after one week of the virtual training simulation.

One possible cause of these results can be seen in the Cognitive Load Theory (CLT) [75]. It might be that force and vibrotactile feedback, instead of giving more sensory information to help the user improve their memory of the virtual material (as seen in Section 2.2), increase the amount of information the participants have to understand and process. Consequently, this increases extraneous cognitive load, leading to an impossibility of remembering new information after both short (immediately after the training simulation) and long (one week after the training) time.

5.3 A comparison: Before and After Training Regarding Procedural Knowledge

H6a and H7a cannot be accepted; however, it remains interesting that there is a remarkable increase in procedural knowledge after the training compared to the previous assessment before the training. This increase was found to be significant and have a large effect. Likewise, in the group without haptic feedback experience, the post-assessed procedural knowledge significantly differed from the pre-training one, with a large effect size. In line with previous studies [59] [61] [62], adding haptic feedback in a virtual simulation indeed increases procedural knowledge. However, it is impossible to conclude that it is only because of this implementation that participants show a higher post-training score than the one assessed before the simulation. Indeed, without any feedback, the control group training scored higher after the training session than the evaluation of the pre-training situation, showing that several other factors must explain these findings.

It is possible that the training, despite the presence or absence of haptic feedback, was highly influential in enhancing procedural knowledge. The content and design of the training simulation were well-structured and instructive, and participants in both groups significantly improved their knowledge acquisition. Another possible reason behind these results was also raised in Section 5.2: the training material might have been simple enough, enabling the participants from both groups to learn the same amount of new procedural knowledge quickly. Finally, the participants had similar levels of prior knowledge, which could explain the similar improvements.

No significant decrease was found in haptic condition between one week after the training and post-training score on procedural knowledge. In contrast, a significant decrease was found in the group without haptic feedback employed. This result indicates that with haptic feedback, participants' retention of procedural knowledge was slightly more effective over time.

Overall, with a positive significant increase from pre-training to after one week, procedural knowledge was remembered effectively in the HF group over one week. The same also happened in the NHF condition, where the findings showed a generally higher procedural knowledge acquisition retained after one week from the one assessed before the simulation. Based on what was discussed in Section 2.4.2, one of the gaps found in the literature regarding the implementation of haptic feedback in VR was the lack of studies regarding user performance enhanced over time by the said implementation. The present research shows encouraging results in using haptic feedback to improve procedural knowledge over time. Nevertheless, this result can only be established partially, as no positive difference was found compared to the control group (NHF), also confirming the previous findings of past studies that carried mixed and inconclusive results [31] [11].

One possible explanation for these conclusions might be that participants could try the training only once. Repeating several times the learning process could lead to more excellent procedural knowledge acquisition and be directly retrieved from Long Term Memory [177]. Secondly, the discussion raised in the previous Section 5.2 leads to considering that participants might have adopted similar learning approaches or strategies during the training, limiting the impact of haptic feedback. Lastly, the study's sample size might have needed to be larger to detect statistically significant differences in procedural knowledge between the HF and NHF groups [173].

5.4 A comparison: Before and After Training Factual Knowledge

H8a and H9a cannot be accepted; in HF, there was no significant increase in factual knowledge, neither between the increase from the pre-test and post-test nor between the pre-test and after the one-week assessment. In contrast, the NHF group showed a positive and significant difference in assessing factual knowledge post-training compared to the before-training situation. Therefore, drawing meaningful conclusions about whether haptic feedback in a VTE might increase factual knowledge acquired and remembered was impossible. This result confirms the difficulty in assessing and investigating memory retention within the interaction between VR and haptic feedback [23].

Haptic feedback concerns the physical interaction of users with the VE. This interaction allows individuals to actively engage with and understand the virtual world, thereby making sense of their surroundings. (Section 2.2, Section 2.4. Factual knowledge, which involves remembering information and specific details, might not have been acquired within the haptic feedback condition because not involving physical interaction. The feedback did not help the user memorise details and information about fire safety training extinguishers.

One possible cause of these conclusions might be that memory retention can differ widely among individuals, and the effects of haptic feedback may be more evident in some participants than in others [48]. The study might have yet to capture these individual differences. As the study focused on retaining specific information related to fire safety training extinguishers, haptic feedback might be more effective for specific memory tasks but less so for others. Another problem is, as discussed in Section 5.2, that participants in both groups had similar baseline memory levels, decreasing the potential impact of haptic feedback. Finally, the Cognitive Load Theory (CLT) [75], might suggest that force and vibrotactile feedback, instead of giving more sensory information to help the user improve their memory of the virtual material (Section 2.2), it contributed to increasing the amount of information the participants have to understand and process.

Both conditions showed no significant decrease in factual knowledge from post-training to after a week. However, a further investigation showed a significant overall increase in factual knowledge from pre-training to one week later in the NHF group. In contrast, the HF showed no significant overall increase. Given the lack of positive empirical results from the literature [178] and based on the current results, haptic feedback might have been a distraction. Participants might have focused more on the haptic output than the information to learn. Based also on the exploratory analysis made (Section 4.4.1), the majority of the sample experienced haptic feedback was new to this kind of output, which might indicate that their attention was shifted from the learning material to the new haptic feeling they experienced.

5.5 The Relationship Between Presence and The Four Cognitive Factors

There were no positive relationships between the sense of presence and the use of haptic feedback. This result might be due to the participants' varied sensory perceptions and preferences. Some learners might be more sensitive to haptic feedback, while others may not feel the feedback as intensely. Singular differences in sensory understanding can influence the efficacy of haptic feedback [53] [54].

There were no positive relationships between presence and interest, embodiment and self-efficacy in the group experiencing haptic feedback. Nevertheless, the last two cognitive factors showed marginal significant evidence, but their p-values were greater than .05; H11.0, H11.1.0 and H11.3.0 could not be rejected. On the other hand, in NHF, all three cognitive factors mentioned above positively correlated with presence, which means that by increasing presence, interest, self-efficacy, and embodiment also increase. Regarding a positive relation with motivation, condition HF showed a significant and positive correlation with this factor, as for NHF. The strength of this correlation was the same between the two groups. The main research question of this study is investigating whether a positive and significant correlation happens between the sense of presence and the four cognitive factors in the HF condition, especially in comparison to a scenario where haptic feedback was not employed.

An explanation for the positive correlation found with motivation in HF is that haptic feedback makes the interaction within the VE engaging, as the possibility to feel the virtual objects and consequently complete the tasks leads to a higher sense of achievement. As a result, high engagement and achievement lead to great motivation [151]. This result aligns with previous MA et al.'s research [39], which underlines how force feedback benefits education and how a haptic device can improve the user's motivation. Nevertheless, NHF was also shown to correlate positively with presence and motivation. This similarity might be because participants experience a sense of engagement and immersion within the VTE despite using haptic feedback. The design of the training simulation alone might be the reason for this same positive relation.

Although interest, embodiment and self-efficacy were higher in haptic feedback conditions, the three measures do not correlate with presence, going against previous research findings which showed that VR could create a stronger sense of presence, leading to higher interest [71], self-efficacy [153] and embodiment [156] through the employment of haptic feedback. While interest, embodiment, and self-efficacy are important cognitive factors contributing to the overall virtual training experience, their relationship with presence might be more complex.

The sense of presence can be influenced by various elements above these cognitive factors, such as the quality of the VE, the realism of interactions, or personal differences in how users engage with the VR (Section 2.5.1). This assumption shows that it is crucial to consider the complex relationships between variables, which can be affected by several factors. In the present research context, even if specific changes happen in the variables, these changes might not predict changes in others.

5.6 The Relationship Between Presence and Procedural Knowledge and Factual Knowledge

H12.1.0 and H12.0 could not be rejected, meaning that procedural knowledge (increase = post - pre) and factual knowledge both increase (increase = post - pre) and decrease (decrease = one-week knowledge - post) were not associated with presence, which differs from previous research investigating the relationship between presence and learning performance [179]. This lack of correlation happened in both conditions (HF and NHF).

However, H12a can be partially accepted, as a negative and significant relation was found between the presence and the retention of procedural information after one week (decrease = one-week knowledge - post). This result aligns with Makransky et al. [21] theory, where presence is the central psychological affordance influencing different learning outcomes over time in an IVR environment. Moreover, this correlation further proves how haptics can affect the sense of presence, influencing the retaining of procedural information [33].

Regarding the lack of other correlations mentioned above, it is impossible to conclude that the presence or absence of haptic feedback can positively and negatively affect, in order, the increase and decrease of two considered learning outcomes. The lack of significant correlations suggests that a sense of presence and haptic feedback may not be the only determining elements affecting this association.

Participants might feel so deeply in the VR fire safety training simulation that they forget to pay attention to learning from the tasks presented. Also, as the majority of the sample size considered beginners both to haptic feedback and VR experience (Section 4.4), they might be more concentrated in the fire safety training simulation itself rather than the assignments within the said simulation.

5.7 The Relationship Between Procedural Knowledge and Factual Knowledge and The Four Cognitive Factors

It can be concluded that interest, embodiment and self-efficacy do not impact one's procedural knowledge (increase = post - pre, decrease = one week after - post) and factual knowledge (increase = post - pre, decrease = one week after - post). It could be that the three cognitive factor levels stay the same throughout the learning process in both conditions. This assumption would mean the said three factors are not influencing the acquisition and retention of the new material regarding fire safety training.

In contrast, motivation was negatively correlated with the decrease in procedural knowledge (decrease = one week after - post), which makes H13.1a partially retained. By increasing motivation, the decay of retention of procedural knowledge (decrease = one week after - post) decreases. This result agrees with the CAMIL model [21], which believes that motivation can enhance procedural knowledge and maintain it over time. Moreover, this contributes to a first step in understanding the relationships that enhance procedural knowledge over time in VTE (Section2.1.6).

Regarding the lack of relations between the learning outcomes and the rest of the four cognitive factors, one reason might be seen in the study's instructional design that might have been effective enough in transferring the training information to participants, regardless of their initial cognitive factors [73]. In such a case, the influence of personal differences in interest, motivation, embodiment, and self-efficacy might have been minimised. Furthermore, learning is a complex process influenced by multiple emotional, cognitive and contextual variables. The relationship between these factors is intricate, making it challenging to detect and isolate the impact of any single element.

5.8 Previous Experience: Haptic Feedback, Virtual Reality and Fire Safety Training

Lastly, it was investigated how previous experience in using haptic feedback, experiencing VR and any fire safety training is related to procedural knowledge and factual knowledge (pre-, post and one week after training). As stated in Section 4.4.1, almost the totality of the overall sample was categorised as beginners for previous haptic and VR experience. Nevertheless, some intriguing findings can be discussed. This investigation about the previous experience was conducted to examine whether previous experience might have affected the learning process.

Firstly, considering previous haptic feedback experience, most participants fell into the Beginner category. For this group, using haptic feedback in both the post and one week after training simulation did not offer a significant advantage in retaining learned material compared to the lack of haptic feedback. When exposed to haptic feedback, novice users may become more absorbed in the sensory experiences rather than focusing on memorising training information. This could explain why those in the group without haptic feedback performed better, as fewer sensory stimuli might be less overwhelming for those new to VR and haptic experience. For someone new to this technology, these vibrotactile and force feelings can be intense and unknown, building a sensory overload.

Moving on to previous VR experience, there was a significant difference between the HF and NHF groups regarding post-training factual knowledge among Beginners. Those new to VR training simulation, without the additional stimuli given by haptic feedback, retained more information than those who experienced both. This conclusion suggests that IVR training without additional sensory information is a more effective way to learn for beginners. The absence of haptic feedback could help them concentrate better on the training content, avoiding cognitive overload [75].

Lastly, we explored the influence of previous fire safety training experience. A significant difference appeared in post-training factual knowledge between those who answered "yes" and "no." This finding indicates that users with previous fire safety training experience might already know what to do and act more quickly without adding sensory cues, as shown in the no haptic feedback group.

It is not possible to draw any meaningful conclusion from the exploratory analysis. As previously stated, the lack of data for the other two subcategories made it impossible to conclude that previous experience in haptics, VR or fire safety training impacted the user's learning process.

5.9 Limitations

Several limitations to this research have possibly impacted the results of this study.

Problems Within The Simulation. During the virtual training simulation, participants in both groups, seven in the haptic feedback condition and three in the one without, experienced their virtual hands floating away from their sight. The number of users that experienced this issue cannot be ignored, as in the haptic feedback group, this number represents 20% of the sample. Consequently, the attention and learning process of those who encountered this problem are believed to be negatively affected. The final results need to be considered also because of this limitation.

Sample Size. The sample size used in this experiment needs to be expanded. Even if the sample size chosen was in line with what was said in the literature [173], the present research would have benefited from more participants. The study would have had a higher statistical power with a larger sample size, increasing the probability of detecting smaller, potentially significant effects or correlations and enhancing the generalisability of the current study's findings to a broader population. Moreover, a bigger sample could have allowed for more robust exploratory analyses: it could have eased a deeper analysis into whether participants (filtered by the categories of Beginner, Intermediate and Advanced) with previous experience in haptic feedback and VR have different learning outcomes than those without such background.

Tests and Assessment. The present research did not conduct a qualitative study due to the length of the experiment and questionnaires. It would have benefited from a qualitative study using interviews or open-ended surveys, highlighting significant aspects of the training in both conditions, such as participants' opinions, emotional factors, and challenges.

Lack of Repeatability In The Training Sessions. Due to the length of the experiment (around 40 minutes) and the participant's availability, repeating the training simulation over time was impossible. This lack of repeatability decreased the success of learning and retaining more information. As the literature stated [82] [177], repeating multiple times the learning process could lead to more excellent procedural knowledge acquisition and be directly retrieved from Long Term Memory.

5.10 Future Research

Future research was formerly addressed (Chapter 1). However, some factors should be further investigated to optimise a VTE's learning process. First, future research may consider investigating the role of other features influencing procedural knowledge, such as different learning and problem-solving strategies [60]. To draw significant conclusions, these factors need to be considered and investigated when it comes to procedural knowledge, as learning is a complex process influenced by multiple factors [72]. Examining these factors in the context of procedural knowledge can provide a more exhaustive understanding of learning dynamics.

Furthermore, the task virtual training simulation's difficulty should be increased. As speculated in Section 5.3, the training material might have been simple enough, enabling the participants from both groups to learn the same amount of new procedural knowledge quickly, with the consequence of not detecting any significant different over the two conditions. Therefore, challenging users may lead to more effort, engagement and attention towards the tasks presented, increasing the chance of recalling and learning procedural information. Being more involved and attentive to the learning task has been demonstrated to increase learning acquisition [84].

As explained in the limitation part (Section 5.9), repeating the training simulation over time was impossible. Therefore, conducting longitudinal studies would be an effective solution, considering the chance to repeat it five to seven times, as reported in the literature [82]. By doing so, the skills gained in VTE are expected to be retained, with increased performance over time. The same longitudinal studies could further investigate the relationship between force and vibrotactile feedback between presence, interest, embodiment and self-efficacy.

The study's results showed that participants who felt positively present in the VTE did not consistently or significantly report higher levels of interest, embodiment, or self-efficacy in the haptic feedback condition. Their relationship, then, might be more complex and not linear. Longitudinal studies assess the learning curve related to the employment of haptic feedback in VR. Participants may start with limited knowledge or skills related to haptic feedback, but this little understanding could improve with training. Tracking this learning curve can help determine critical points at which participants' knowledge and cognitive responses change.

5.11 Conclusion

This research focused on whether implementing haptic feedback in a virtual training environment enhances the final learning outcome. To tackle this query, an investigation of virtual training reality, procedural and factual knowledge, haptic feedback and different cognitive theories were investigated to find substantial proof that haptic feedback could do so. While guided by the theoretical framework of the CAMIL model, which asserts that enhancing presence and four cognitive factors can lead to different learning outcomes in the interaction of VR and haptic feedback, this study attempted to put this theory into practice within a virtual fire safety training simulation.

Addressing the main research question: "*Does the implementation of force and vibrotactile feedback in a virtual training environment (VTE) lead to enhanced procedural knowledge acquisition and factual knowledge after one week, compared to a VTE without haptic feedback?*" firstly, the research suggests that implementing force and vibrotactile feedback into a VTE can positively influence participants' sense of embodiment. This finding is of significant practical relevance, implying that enhancing the sensory experience within virtual training can lead to increased engagement in learning scenarios. In practical terms, educational institutions and training programs can consider integrating haptic feedback technologies to design more immersive and engaging learning environments. This suggestion could be particularly beneficial in fields where hands-on experience and procedural knowledge are crucial, such as medical training or technical skill development.

Furthermore, a significant positive relation between presence and motivation was also found; however, answering the sub-question that enhancing presence increases motivation when both force and vibrotactile feedback are employed in a VTE is not entirely possible, as the same relation was seen when no haptic feedback was used. Both presence and motivation within the haptic group were found to have a negative and significant relation with procedural knowledge retention after one week (decrease = one week after - post), answering the sub-questions that by increasing presence and motivation, the procedural information has less decay after one week in a VTE, compared to when no haptic feedback is not employed. These findings also help to answer the main research question partially, as illustrated by the CAMIL model path: the interaction between haptic feedback and VR influences the IVR main affordance (presence), which in turn shares a positive relation with one of the cognitive factors (motivation), leading to better procedural knowledge retention.

In addition, the present study provides initial evidence that using haptic feedback does not diminish other cognitive factors like interest, motivation, and self-efficacy compared to non-haptic feedback conditions. The findings indicate that haptic feedback might enhance the overall experience without compromising these critical factors.

Although not statistically significant, the results indicate the potential benefits of haptic feedback in improving knowledge acquisition over time. This finding implies that, with further improvement and investigation, haptic feedback could be a valuable tool for enhancing procedural knowledge in VTEs. This conclusion could be valuable in professions requiring safety and precision, such as emergency response training or aircraft piloting.

Haptic feedback did not improve factual knowledge acquisition either straight after the training or after one week. The results showed how the control group acquired more factual knowledge over time, and this increase in learning was significant. Hence, the VR training simulation can be considered an effective tool for transferring knowledge and increasing the overall user's performance. However, implementing haptic feedback considering factual knowledge acquisition presents limitations that future research must consider and overcome.

It is crucial, however, to acknowledge the study's limitations. Remarkably, some participants in both groups experienced technical issues where their virtual hands floated away from their view, affecting approximately 20% of the haptic feedback group. This limitation might have influenced the attention and learning process of those involved.

Also, the sample size used in this experiment could have been more extensive, affecting the generalisability of the findings. Future research should aim for larger and more diverse participants to enhance statistical power and generalisability. Additionally, more robust exploratory analyses, particularly involving participants' previous experiences, could be followed with a larger sample. Lastly, the inability to conduct repeat training sessions due to time restrictions and participant availability determined the exploration of learning and retention effects. As suggested in Section 5.10, conducting longitudinal studies could help explore the nuances of haptic feedback's impact over time.

In conclusion, while this study raises questions that require further investigation, it highlights the promise of haptic feedback technology in enriching the learning experience within VTE. These findings provide a compelling explanation for ongoing research and development, potentially revolutionising how we approach education and training in virtual settings.

Aspect	Key Findings
Research Objective	Investigate the impact of haptic feedback on procedural knowledge and one-week information retention in VR training simulations, compared to no use of haptic feedback.
Theoretical Framework	Utilizes CAMIL model and Embodied Cognition theory as guidelines.
CAMIL Model	Suggests that haptic feedback in VR can enhance cognitive factors like presence, interest, motivation, embodiment, and self-efficacy, potentially improving procedural knowledge and memory retention.
Experiment Design	Conducted on university students in the Netherlands using a virtual fire safety training simulation.
Impact of Haptic Feedback on Cognitive Factors	- No significant increase in presence, interest, motivation, and self-efficacy with haptic feedback. - Significant increase in embodiment with force and vibrotactile feedback.
Procedural Knowledge	- Significant increase from pre-training to post-training procedural knowledge in both HF and NHF groups. - No significant difference was observed in the decrease of procedural knowledge one week after training compared to post-training between HF and NHF. - The increase from pre-training to the procedural knowledge retained after one week was significant in HF.
Factual Knowledge	- There was no significant difference between the two conditions regarding the pre-training assessment of factual knowledge. - A significant difference in post-training factual knowledge between the two conditions, with the haptic feedback condition increasing less factual knowledge. - No significant decrease from post-training to one-week-after training factual knowledge retention in HF. - Statistically significant difference in factual knowldge one week after training between conditions, with the no-haptic feedback group showing higher scores in retaining more factual knowledge.
Correlations with Cognitive Factors	- Presence positively correlates only with motivation and negatively correlates with procedural knowledge decay after one week. - Increasing presence leads to higher motivation and reduced information decay over time.

Figure 5.1: Summary of main findings of the current research presented in the discussion introductory part

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Appendices

A. Appendix A

A.1 A

Variables		HF PRESENCE	HF INTEREST	HF MOTIVATION	HF EMBODIMENT	HF SELF-EFFICACY	NHF PRESENCE	NHF INTEREST	NHF MOTIVATION	NHF EMBODIMENT
HF PRESENCE	Correlation Coefficient	.303								
HF INTEREST	Correlation Coefficient	.303								
HF MOTIVATION	Correlation Coefficient	.387*	.542**							
HF EMBODIMENT	Correlation Coefficient	.335	.318	.584**						
HF SELF-EFFICACY	Correlation Coefficient	.329	.046	.389*	.331					
NHF PRESENCE	Correlation Coefficient	.116	.104	.025	-.041	.018				
NHF INTEREST	Correlation Coefficient	.062	.285	.254	.275	.186	.569**			
NHF MOTIVATION	Correlation Coefficient	-.173	.077	-.235	.009	.034	.532**	.574**		
NHF EMBODIMENT	Correlation Coefficient	.112	.034	.132	.092	.071	.693**	.628**	.430*	
NHF SELF-EFFICACY	Correlation Coefficient	-.005	.001	-.086	.065	.333	.599**	.543**	.785**	.506**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table A.1: Overview of the correlation matrix HF and NHF regarding presence, interest, motivation, embodiment and self-efficacy with (ρ) coefficient and p value

B. Appendix B

B.1 Questionnaires

This section includes the questionnaire that was presented to the participants.

B.2 First Questionnaire: Pre-training

B.2.1 Informed Consent

Thank you for participating in this study for my master's thesis. My name is Monica Vassallo, and I am studying Human-Computer Interaction at Utrecht University. If you have any questions or concerns about the study, you can address them anytime and contact me at m.vassallo@students.uu.nl.
First, you will be presented with a few demographic questions and a tutorial session where you can familiarize yourself with the devices (Oculus Quest Pro and haptic gloves). Subsequently, there will be two sessions, where you will be in two different virtual reality environments, perform the fire safety simulation for each of them and finally fill in a survey after the whole test. The overall session will take around 45 minutes of your time. A short survey will be sent to you one week from the day of the experiment. Please remember to answer the questionnaire I will send you again; this is crucial for the results of my research. You will need to insert your email in the second survey once again.
The data collected from the surveys are and will remain anonymous. All data will be kept safe in the Qualtrics environment. If you want to stop participating while you are still in the simulation, please let me know anytime. Once you stop participating in this session, finishing it another time is impossible. If you feel uncomfortable during the session, you can address this anytime.
I have read the consent form, recognize my rights within this study, and agree to participate under these terms. By participating, you also agree to fill in the second survey you get one week after the first experiment.

B.2.2 Participant Email Address

Please write your email address

B.2.3 Assigned Group

Which group are you in? (Please ask the researcher)

- HF
- NHF

B.2.4 Age

D1. What is your age?

- 18 - 24
- 25 - 30
- 31 - 35
- Over 35

B.2.5 Gender

D2. What is your gender?

- Female
- Male
- Non-binary/third gender
- Prefer not to say

B.2.6 Fire Training Previous Experience

FE1. Have you ever done any fire safety training before? (For example, video lessons and papers to read).

- Yes
- No

B.2.7 Virtual Reality Previous Experience

VRE1. Please select your experience level with virtual reality. How many times have you been in a virtual environment?

- 0 - 15 times (beginner)
- 15 - 30 times (intermediate)
- More than 30 times(advanced)

B.2.8 Haptics Previous Experience

HFE1. Please select your experience level with a haptic device. How many times have you been in a virtual environment? Haptic feedback simulates an object or interaction from the virtual system, producing the feeling of touch by using, for example, vibration.

- 0 - 15 times (beginner)
- 15 - 30 times (intermediate)
- More than 30 times(advanced)

B.2.9 Factual Knowledge Pre-Training

RI1. 1 How can you distinguish the different fire extinguishers? You can choose multiple answers.

- Color
- Shape
- Size
- Label

RI1.2 Match each type of fire with the correct fire extinguisher(s). You can pick more than one option.

	WATER	FOAM	WET CHEMICAL	DRY POWDER	CO2
Wood and Paper	☐	☐	☐	☐	☐
Flammable liquids	☐	☐	☐	☐	☐
Live electrical equipement	☐	☐	☐	☐	☐
Cooking oil fires	☐	☐	☐	☐	☐

Figure B.1: "Match each type of fire with the correct fire extinguisher(s). You can pick more than one option."

RI1.3 What types of extinguishers should be used with electric equipment? (For example, computer, cellphone) in a fire? You can choose multiple answers.

- CO2
- Dry powder
- Water
- Foam
- Wet chemical

RI1.4 What types of extinguishers should be used in a fire with paper? You can choose multiple answers.

- CO2
- Dry powder
- Water
- Foam
- Wet chemical

B.2.10 Procedural Knowledge Pre-Training

PK1.1 What are the steps to use a fire extinguisher? Please put them in the correct order (For example, Step 1 - Step 2). Use from 1 to 7 words for each step.

PK1.2 What are the steps, in order, you take after knowing there is a fire in another room? (For example: Step 1 - Step 2). Use a maximum of 10 words per step.

PK1.3 When the room is too smokey:

- Call the emergency number
- Find a fire extinguisher and extinguish the fire
- Evacuate the building
- Go to the assembly point

B.3 Second Questionnaire: Post-training

B.3.1 Presence

Please answer the statements below. (These statements are answered on a 5-point Likert scale). Possible answers: 1. Strongly Disagree, 2. Somewhat Disagree, 3. Neither Disagree nor Agree,

4. Somewhat Agree, 5. Strongly Agree.

P1.1 I felt that I was really in this virtual training simulation.
P1.2 I felt the virtual hands move like my actual hands in the virtual environment.
P1.3 I felt that the training scene was like a real-world environment.
P1.4 I felt I could interact with the fire extinguishers as if in the real world.
P1.5 I felt that I was dealing with a really hazardous fire situation.

B.3.2 Interest

Please answer the statements below. (These statements are answered on a 5-point Likert scale). Possible answers: 1. Strongly Disagree, 2. Somewhat Disagree, 3. Neither Disagree nor Agree, 4. Somewhat Agree, 5. Strongly Agree.

I2.1 I lost myself in this experience.
I2.2 The time I spent using this virtual training simulation just slipped away.
I2.3 I felt calm while using this virtual training simulation.
I2.4 I was absorbed in this experience.
I2.5 I found this virtual training simulation clear to use.
I2.6 Using this virtual training simulation was easy.
I2.7 This virtual training simulation was attractive.
I2.8 This virtual training simulation was aesthetically appealing.
I2.9 This virtual training simulation appealed to my senses.
I2.10 Using this virtual training simulation was worthwhile.
I2.11 My experience was rewarding.
I2.12 I felt interested in this experience.

B.3.3 Motivation

Please answer the statements below. (These statements are answered on a 5-point Likert scale). Possible answers: 1. Strongly Disagree, 2. Somewhat Disagree, 3. Neither Disagree nor Agree, 4. Somewhat Agree, 5. Strongly Agree.

M3.1 I think I did pretty well in this virtual training simulation compared to other trainees.
M3.2 After doing the virtual training simulation for a while, I felt pretty competent.
M3.3 I tried very hard on this virtual training simulation.
M3.4 It was important for me to do well at dealing with hazardous situations and extinguishing fires.
M3.5 I would describe this virtual training simulation as very interesting.
M3.6 Fire safety training simulation was fun to do.
M3.7 I felt no pressure from the idea of doing this virtual training simulation.

B.3.4 Embodiment

Please answer the statements below. (These statements are answered on a 5-point Likert scale). Possible answers: 1. Strongly Disagree, 2. Somewhat Disagree, 3. Neither Disagree nor Agree, 4. Somewhat Agree, 5. Strongly Agree.

E4.1 It seemed like I was looking directly at my own hands rather than at virtual hands.
E4.2 It seemed like the virtual hands began to resemble my real hands.

E4.3 It seemed like the virtual hands belonged to me.
E4.4 It seemed like the virtual hands were part of my body.
E4.5 It seemed like the virtual hands were my hands.
E4.6 It seemed like my hands were in the location where my virtual hands were.
E4.7 It seemed like the virtual hands were in the location where my hands were.
E4.8 It seemed like the touch I felt was caused by touching the virtual objects.
E4.9 It seemed like I could have moved the virtual hand if I had wanted.
E4.10 It seemed like I was in control of the virtual hands.

B.3.5 Self-Efficacy

Please answer the statements below. (These statements are answered on a 5-point Likert scale). Possible answers: 1. Strongly Disagree, 2. Somewhat Disagree, 3. Neither Disagree nor Agree, 4. Somewhat Agree, 5. Strongly Agree.

SE5.1 I am confident that I can deal efficiently with unexpected events.
SE5.2 When I am confronted with fire, I can usually find a solution.
SE5.3 I feel that I can handle minor tasks related to fire safety I might be given.
SE5.4 I consider myself to be very competent in the skills and knowledge required for the fire safety training procedure.
SE5.5 When I am assigned an important task (responsible for the fire safety measures), I feel confident that I can complete the task successfully.
QSE.6 I feel confident identifying different types of fire causes.
QSE.7 I feel confident finding important features on the different fire extinguishers.
QSE.8 I feel confident comparing and contrasting the colours of different fire extinguishers.
QSE.9 I feel confident judging the relative size of the various components of the fire extinguishers.
QSE.10 I feel confident that I can use haptic gloves.
QSE.11 I feel confident that I can use VR to complete the fire safety simulation without assistance.
QSE.12 I find working with VR very easy.

B.3.6 Factual Knowledge Post-Training

RI2.1 How can you distinguish the different fire extinguishers? You can choose multiple answers.

- Color
- Shape
- Size
- Label

RI2.2 Match each type of fire with the correct fire extinguisher(s). You can pick more than one option.

RI2.3 What types of extinguishers should be used with electric equipment? (For example, computer, cellphone) in a fire? You can choose multiple answers.

- CO_2
- Dry powder

	WATER	FOAM	WET CHEMICAL	DRY POWDER	CO2
Wood and Paper	☐	☐	☐	☐	☐
Flammable liquids	☐	☐	☐	☐	☐
Live electrical equipement	☐	☐	☐	☐	☐
Cooking oil fires	☐	☐	☐	☐	☐

Figure B.2: "Match each type of fire with the correct fire extinguisher(s). You can pick more than one option."

- Water
- Foam
- Wet chemical

RI2.4 What types of extinguishers should be used in a fire with paper? You can choose multiple answers.

- CO2
- Dry powder
- Water
- Foam
- Wet chemical

B.3.7 Procedural Knowledge Post-Training

PK2.1 What are the steps to use a fire extinguisher? Please put them in the correct order (For example, Step 1 - Step 2). Use from 1 to 7 words for each step.

PK2.2 What are the steps, in order, you take after knowing there is a fire in another room? (For example: Step 1 - Step 2). Use a maximum of 10 words per step.

PK2.3 When the room is too smokey:

- Call the emergency number
- Find a fire extinguisher and extinguish the fire
- Evacuate the building
- Go to the assembly point

B.4 Thid Questionnaire: One Week After-training

B.4.1 Introduction

Thank you for participating in this study for my master's thesis. The following survey is part of my project's second part: a short survey will be presented, and it will take between 5 and 7 minutes of your time.The questions refer to the virtual simulation (fire training) you did one week ago.
If you have any questions or concerns about the second part of my study, do not hesitate to contact me at m.vassallo@students.uu.nl.
The data collected from the surveys are and will remain anonymous. All data will be kept safe in the Qualtrics environment.

B.4.2 Participant Email Address

Please write your email address

B.4.3 Factual Knowledge One Week After-Training

RI3.1 How can you distinguish the different fire extinguishers? You can choose multiple answers.

- Color
- Shape
- Size
- Label

RI3.2 Match each type of fire with the correct fire extinguisher(s). You can pick more than one option.

	WATER	FOAM	WET CHEMICAL	DRY POWDER	CO2
Wood and Paper	☐	☐	☐	☐	☐
Flammable liquids	☐	☐	☐	☐	☐
Live electrical equipement	☐	☐	☐	☐	☐
Cooking oil fires	☐	☐	☐	☐	☐

Figure B.3: "Match each type of fire with the correct fire extinguisher(s). You can pick more than one option."

RI3.3 What types of extinguishers should be used with electric equipment? (For example, computer, cellphone) in a fire? You can choose multiple answers.

- CO2
- Dry powder
- Water
- Foam
- Wet chemical

RI3.4 What types of extinguishers should be used in a fire with paper? You can choose multiple answers.

- CO2
- Dry powder
- Water
- Foam
- Wet chemical

B.4.4 Procedural Knowledge One Week After-Training

PK3.1 What are the steps to use a fire extinguisher? Please put them in the correct order (For example, Step 1 - Step 2). Use from 1 to 7 words for each step.

PK3.2 What are the steps, in order, you take after knowing there is a fire in another room? (For example: Step 1 - Step 2). Use a maximum of 10 words per step.

PK3.3 When the room is too smokey:

- Call the emergency number
- Find a fire extinguisher and extinguish the fire
- Evacuate the building
- Go to the assembly point

C. Appendix D

C.1 Exploratory Analysis

This section includes the graphs showing the difference of factual knowledge score between the two groups filtered by previous experience in haptics and VR.

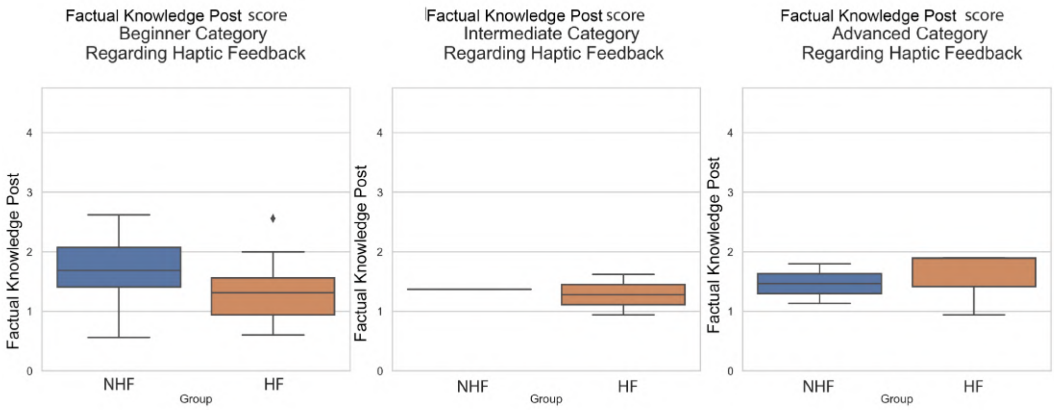

Figure C.1: Group HF (orange) and NHF (blue): Post-training difference regarding factual knowledge filtered for previous haptic feedback experience at the beginner level

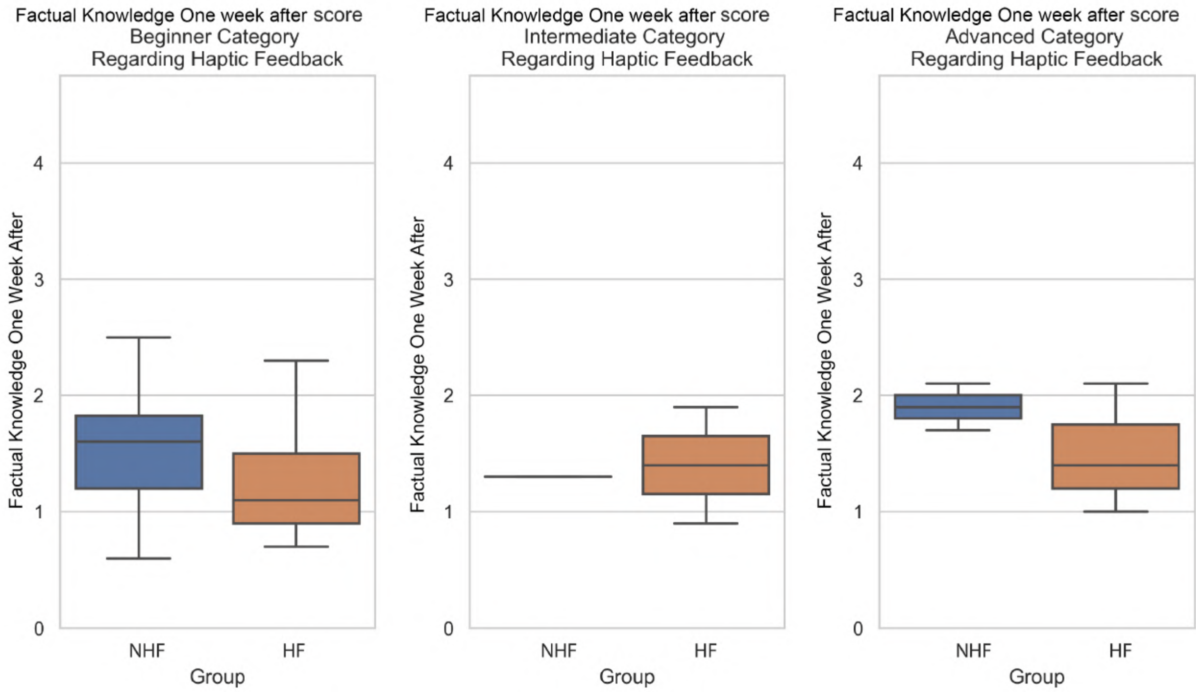

Figure C.2: Group HF (orange) and NHF (blue): One-week after training difference regarding factual knowledge filtered for previous haptic feedback experience at the beginner level

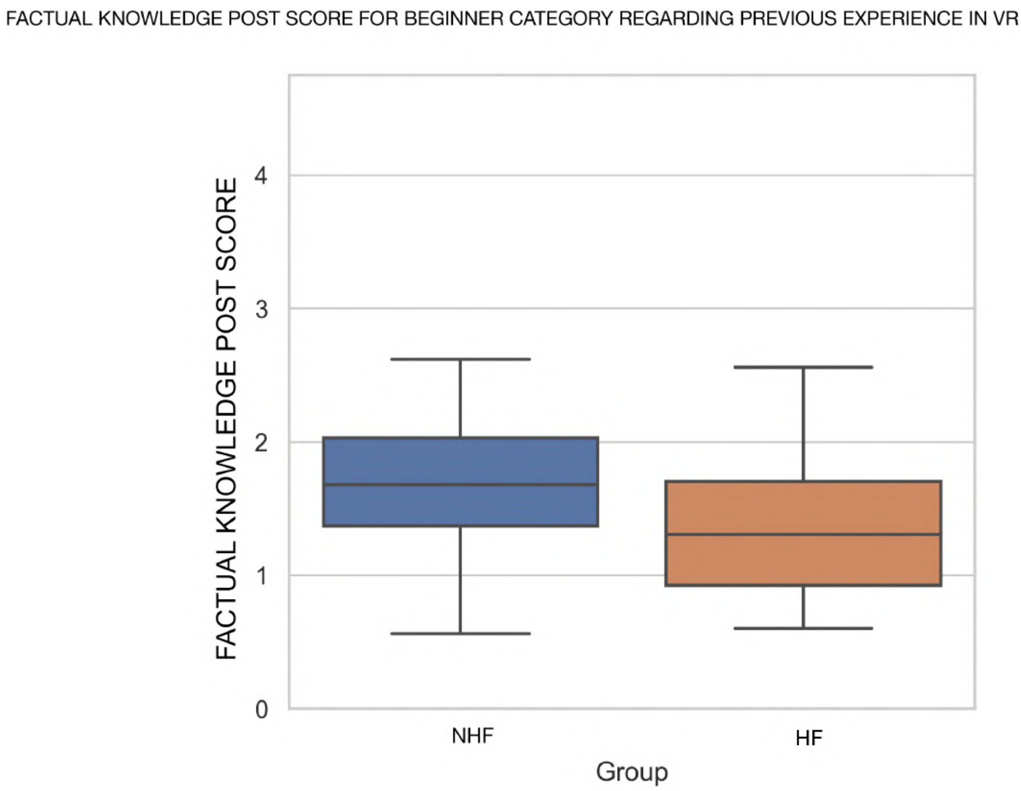

Figure C.3: Group HF (orange) and NHF (blue): Post-training difference regarding factual knowledge filtered for previous virtual reality experience at the beginner level