ABSTRACT

ROSE, TYLER. Effect of Immersion on Task Performance and Cardiac Response in a Virtual Reality Assembly Training Simulation. (Under the direction of Dr. Karen Chen and Dr. Chang Nam).

Virtual reality (VR) use in occupational training scenarios has seen research attention across many applications. Specifically, researchers have focused on effectiveness of these training regimens in terms of task time and success rate when compared to their real-world counterparts. Few studies, however, have examined these VR-based training programs in terms of the implications that immersion and presence can have. Further, as research in these VR-based studies continue to expand, the subjective and objective methods we use to determine presence in a virtual environment (VE) need to be continuously examined and improved upon.

The primary goal of this study is to investigate the effect of immersion on human task performance in an occupational setting in a VE. The first objective was to investigate the effect of immersion on task performance accuracy in the VE. The second objective was to examine the effect of immersion on subjective responses and objective physiological measures of humans in the VE. A within-subject experiment was designed to address these objectives. Thirty participants completed 18 virtual occupational training simulation tasks, where they were instructed to place 36 air filters in boxes moving across an active conveyor belt using a head-mounted display as viewing medium. Immersion was modified by the vividness and extensiveness of the scenario. Participants were equipped with a heart rate monitor chest strap, which monitored cardiac activity rate throughout each trial. Following the exposure to each set of immersive levels, participants completed a subjective presence questionnaire (SUS) as well as a perceived workload survey (NASA-TLX).

It was hypothesized that greater immersion would lead to improved performance, which is characterized by increased task accuracy. It was also hypothesized that greater immersion would lead to higher subjective presence, both in mean and high responses. NASA-TLX was hypothesized to be significantly affected by greater immersion. Normalized heart rate was similarly hypothesized to be significantly affected by greater immersion. Results of this experiment indicate a consistent upward trend for task accuracy with increased immersion, but not statistically significant. Additionally, subjective presence responses through mean SUS confirmed the user's ability to observe increases in immersion. High SUS response were significantly affected by extensiveness, while perceived workload was significantly affected by vividness. Furthermore, cardiac response was not significantly affected by increasing levels of immersion, through vividness nor extensiveness.

These findings show that while subjective presence responses proved the designed differences in immersion between trials, neither percent task accuracy nor normalized heart rate were significantly affected. While not statistically significant, a consistent upward trend of percent task accuracy was observed with increased immersive levels. Further trials in other occupational training applications are recommended to determine if this trend can be substantiated elsewhere. Although not included in the hypotheses, a statistically significant effect of trial number was found on normalized heart rate. In scenarios similar to our training sessions where cardiac response is not expected to see significant trends with immersion, subjective presence questionnaires would be recommended over normalized heart rate unless extensive measures can be taken to ensure cardiac activity will not be more affected by time than experience.

Effect of Immersion on Task Performance and Cardiac Response in a Virtual Reality Assembly Training Simulation

by
Tyler Lewis Rose

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Industrial Engineering

Raleigh, North Carolina

2018

APPROVED BY:

Dr. Karen Chen Committee Chair	Dr. Chang S. Nam Committee Co-Chair
Dr. David Kaber	Dr. David Dickey

DEDICATION

This research is dedicated to my family, which has supported me in different ways throughout the process of this work. Parents, Tom and Sandy Rose, and siblings, Nick, Matt, and Jenna Rose, provided remote morale support from their homes in Texas. Locally, Aunt Patty and Uncle Glen as well as cousins Leslie, Laura, Ryan, and John, all provided the nourishment I needed to stay focused. Thank you all for your care.

BIOGRAPHY

Tyler Lewis Rose was born in Raleigh, NC on May 22nd, 1994. He graduated high school in Georgetown, Texas, before enrolling at The University of Mississippi to study mechanical engineering. In May 2016, he graduated from The University of Mississippi with a Bachelor of Science in Mechanical Engineering. With a drive to continue his academic career, he wound up back in Raleigh to attend North Carolina State University in pursuit of a master's degree in the Edward P. Fitts Industrial & Systems Engineering Department. In May 2018, he will with a Master of Science in Industrial Engineering.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my co-chairs, Dr. Karen Chen and Dr. CS Nam, for their tremendous support and guidance throughout the development of this research. Communication and accessibility to advisors are two key components to a successful academic career, and there was never a shortage of these components in regards to my advisors. Additionally, I would like to thank my committee members, Dr. David Kaber and Dr. David Dickey. I sincerely appreciate the effort each of you invested in the development and completion of my research.

This research was made possible through fellowship support from the NIOSH (National Institute for Occupational Safety & Health) Southeastern Education and Research Center. A very special thanks is deserved to NIOSH for affording me opportunities, both academically and in research, that I will certainly cherish and plan to build upon as I begin my professional career. The opinions and conclusions of this thesis are mine alone and do not necessarily reflect the views of NIOSH.

Finally, I want to acknowledge the fellow students in the ergonomics lab as well as those I have developed relationships with during my time at NCSU. Sanity is (largely) a necessary factor for completing a thesis, and much of what I was able to maintain can be credited to you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

Training in the workplace is an often necessary step to achieving productivity and safety in a work setting. It has been shown in a systematic review that raising the proportion of workers trained in an industry by one percentage point is associated with an increase in value added per worker of about 0.6% (Dearden, Reed, & Van Reenen, 2006). While many traditional simulation-based training regimens have been approached through human instruction in front of a classroom full of trainees, there has been a gradual supplementation and replacement by computer-based instruction in an attempt to provide a more engaging and cultivating learning environment (Gunasekaran & Love, 1999). More recently, virtual reality (VR) technologies have seen involvement in training programs in different applications, including manufacturing and assembly (Brough et al., 2007; Gavish et al., 2011; Langley et al., 2016).

Though occupational training is an effective tool for productivity and safety, work is still needed in optimizing these procedures. For instance, upper extremity injuries are common issues in manufacturing that resulted in lost time, expensive treatment, and occasionally permanent physical damage (Punnett et al., 2004). Given that VR-based practices have seen increased research attention, further performance research is desired across areas of manufacturing and assembly applications.

At the core of detecting realism and involvement within VR technologies are two analogous concepts, referred to as presence and immersion. Presence has traditionally been quantified using post-experience subjective questionnaires (Schuemie et al., 2001). Slater (2004) has expressed concerns over the use of these questionnaires, noting that responses may be compromised when the topic is discussed and examined. Additionally, the vast list of developed questionnaires can often leave researchers confused over which measure to use in which context. These concerns have turned some researchers to exploring objective measures, from neural-based (Slobounov et al., 2015) to cardiac-based (Meehan et al., 2005; Wiederhold et al., 2001); though the literature on these measures are sparse and can sometimes conflict in their results.

This research aims at contributing to these current voids in the literature of VR-based occupational training and objective presence measurements. The current state of literature will next be examined before expanding the specific research goals and objectives.

2. Literature Review

2.1 Traditional occupational training

Occupational training aims to provide individuals with the knowledge, skills, and attitudes, necessary for gainful employment (Campbell, 1997). It has been shown across a variety of occupational domains that workplace training leads to increased work productivity (Dearden et al., 2006). Specifically, it was reported that raising the proportion of workers trained in an industry by one percentage point is associated with an increase in value added per worker of about 0.6%. Training in the manufacturing sector, often through simulation, remains important because it allows new operators to learn required functions of the process without the pressure of controlling actual outcomes (Hosseinpour & Hajihosseini, 2009).

Furthermore, occupational training has been studied to reduce workplace errors, accidents, and injuries through the use of simulated job situations (Vredenburgh, 2002). For instance, upper extremity injuries are common issues in manufacturing that resulted in lost time, expensive treatment, and occasionally permanent physical damage (Punnett et al., 2004). Specifically, the manufacturing sector accounted for approximately 261,000 cases with days away from work, job transfer, or restriction according to the 2016 Bureau of Labor Statistics release. It has been shown that implementing ergonomically instructed training techniques significantly reduced sick leave reported among a group of assembly workers (Parenmark, Engvall, & Malmkvist, 1988). Though Gershon et al. (2000) found evidence supporting a relation between safety training and lower workplace injury rates, a cross-sectional manufacturing review by Geldart et al. (2010) determined no significant differences among workplace safety with respect to traditional occupational health and safety training commitment. It becomes important to investigate alternative occupational training approaches to enhance work performance.

Training to improve work performance is seen fields outside of manufacturing, such as surgical training and military training. Surgical training, for example, can last a decade of advanced education and up to five years of rigorous residency work, depending on the specialty. This type of training employs a mixture of highly demanding education and on-site labor under direct supervision. Yet, there still exists medical errors and it is estimated that up to 98,000 patients die annually due to preventable medical errors (Anderson, 2004). Of the four medical error classifications, technical and judgmental errors are largely the result of insufficiency in training.

Similarly, military has a long history of extensive soldier preparation programs. This type of training focuses on physical fitness and mental resilience through exercise repetition and discipline (Knapik et al., 2009) . While these methods are regularly being refined for maximum effectiveness, problems with injuries are still prevalent. Injury rates during military training span up to 12 per 100 male recruits per month and as high as 30 per 100 per month for Naval Special Warfare training (Kaufman, Brodine, & Shaffer, 2000). This is a significant issue still being mitigated through measures such as predictive component identification (Lisman, O’Connor, Deuster, & Knapik, 2013).

Although various occupations employ training to improve productivity and safety, the scope of this work aims to study novel factors that may be associated with improving human performance in terms of workplace productivity and safety. Local industry focus is a major contributing factor with North Carolina being the home to over 460,000 manufacturing employees and ranking 5th nationally in manufacturing contribution, according to North Carolina Manufacturing Extension Partnership.

Though training has traditionally been approached with human instruction in front of a classroom of trainees, there has been a gradual supplementation and replacement by computer-based instruction (Gunasekaran & Love, 1999). Specifically, a combination of online video lectures, interactive learning assignments, and evaluation tools are common components of computer-based training methods (Bengu & Swart, 1996). These modern approaches aim at providing an engaging and cultivating learning environment.

2.2 Virtual reality-based training

Virtual reality is the participation in a synthetic environment through three-dimensional and stereoscopic displays (Earnshaw, 2014). There are various media technologies through which VR can be displayed to users. Examples range from less immersive devices, such as 3D monitors, to highly immersive technology, such as Cave Automatic Virtual Environment (CAVE) and head-mounted display (HMD). With a rapid progression in technology and training methods, VR is now being explored as a new occupational training approach (Cha et al., 2012; Sims Jr, 2000). This research focuses on exploring occupational using HMD, due to the recent surge in popularity and accessibility of portable HMDs.

An attractive aspect that draws training programs to VR is the ability to visually replicate expensive equipment or difficult task scenarios with relative ease, all while maintaining an extended sense of realism. Trainings performed in VR or a simulated environment could be safer and economically practical. For instance, VR-based surgical training offers surgeons the opportunity to acquire surgical skills without operating a real patient nor occupying operating rooms, which could be used to perform actual surgeries for those with needs. Seymour et al. (2002) was the first research team to demonstrate the effectiveness of VR surgical training simulation in a randomized, double-blinded study. Sixteen surgical residents were split between two groups, where one used non-VR, standard programmatic training appropriate for postgraduate level and one incorporated VR-based training in supplementation to perform laparoscopic gallbladder removal. The MIST (Frameset v. 1.2), VR-based training system, was used as the VR apparatus through a computer monitor. Not only did the residents who received specialized VR-based training dissected 29% faster, but were also nine times less likely to transiently fail to make progress and five times less likely to cause an injury to the gallbladder.

The Department of Defense has expressed financial interest in the potential of VR-based training systems, developing a novel software titled Distributed Interactive Simulation (Durlach & Mavor, 1995). While initially developed to simulated a detailed reconstruction of the 73 Eastings battle during the Persian Gulf War, more recent researchers are using this software platform to reconstruct virtual battlefields for ground warfare training using HMDs (Yao et al., 2013).

The use of VR-based is not limited to surgery and military; Boud et al. (1999) was among the first to notice the potential of VR-based assembly training and test its effectiveness in an empirical study. Conventional assembly training method (i.e. physical 2D engineering drawing) was compared to two modern training methods, which were VR and AR, as a means for displaying instructions. Augmented reality (AR) integrates and overlays 3D virtual objects onto the physical world, usually through computer-generated headsets or glasses such. Modern examples of AR include Google Glass or Microsoft HoloLens. The VR-based training method used an HMD (Virtual Research, VR4), which had a 240x120 resolution display and 60˚ field of view. A see-through, monocular, and monochrome HMD developed by Seattle Sigh was used for the AR-based training. Task completion times were significantly lower in both of the virtual techniques (i.e. AR & VR) compared to the conventional method. The results did not show outstanding VR-based training outcomes compared to other less immersive virtual scenarios, such as AR. However, given the same experimental setup, Boud et al. (2000) revealed that VR-based training yielded significantly lower task completion time.

Brough et al. (2007) discussed and examined the effectiveness of virtual assembly training task of a novel VR-based assembly operations training system. This proposed system used a consumer-level HMD with interactive wands, which was compare to a traditional video-based training method. User preference was evaluated as part of the experimental design. Aside from the ability to support a wide variety of training preferences, the VR-based training system matched or exceeded almost every users' expectations, according to pre and post-session questionnaires. Gavish et al. (2011) compared VR and AR-based training platforms to instructional videos in terms of training time, performance time, number of unsolved errors, and number of solved errors in an assembly and industrial maintenance task. These assembly training experiments were then followed by a "Transfer of Skill" evaluation, which assessed the assimilation of skills through both qualitative and quantitative methods. While AR-based training was shown to significantly decrease the number of unsolved errors in the task, both platforms were revealed as useful training instruments in regards to "Transfer of Skill" evaluation, relative to instructional videos. Langley et al. (2016) aimed to investigate the effectiveness of their novel VR-based training system prototype using both performance metrics and subjective usability responses in an automotive manufacturing assembly training assignment. When compared to conventional training methods (specific details not contained in study), individuals received VR-based training had lower average task completion time and less overall error. In addition to the increase in overall performance, users expressed subjective preference to the VR-based system.

The effectiveness of these VR-based manufacturing training programs are mixed, yet promising. Boud et al. (1999) saw positive results regarding task time in VR-based training scenarios, yet participants in the HMD condition did not yield different performance outcomes from AR-based training. The key difference between these two media being immersion involved. While responses across the board were positive for Langley et al. (2016), an RGB-D sensor (Microsoft Kinect) was the selected system VR apparatus. This technology is a very effective and interactive system for certain purposes but has certain technical limitations when comparing to current HMDs. Specifically, there are rarely mentions of immersion in VEs when discussing industrial training and the effect that immersion can have on user experience.

2.3 Immersion

Out of all of the aforementioned manufacturing VR training studies, none mentioned the impact of immersion, which is the measurable features of VR technology that could make a user feel present in a virtual environment (VE). Moreover, many of the earlier studies have not examined immersion-related variables and their effects on training outcomes. This seems surprising, as immersion and presence have often been leveraged as characteristics of VR research worth manipulating, which will be further discussed in the following sections. To understand the direction of this research, the terms *immersion* and *presence* must be first defined and differentiated as they can often be used interchangeably by mistake.

Slater has laid out a series of definitions for immersion that will be used in this work (Slater, 2003). *Immersion* is what a technology delivers from an objective measure. The more that a system conveys displays that preserve fidelity in relation to their corresponding real-world sensory modalities, the more that it is ‘immersive’. Immersion is something that can be objectively assessed based on capabilities of the hardware and software being used. While there are no widely accepted methods for objectively quantifying immersion, some research groups have attempted to construct tools and frameworks. Cairns et al. (2006) developed a set of questionnaires aimed at quantifying immersion in video games. The effectiveness of this framework was later tested using a computer game, titled Half Life (Jennett et al., 2008). The hypotheses were supported through statistical analysis revealing statistically significant differences between the subjective responses in the immersive and control scenarios.

Immersion, which is a technological aspect of VR, has demonstrated positive effects of education and training. Immersion is a technologically-based and quantitative foundation which describes the extent to which users can feel part of the environment. Researchers have long examined the impact that immersion levels have on human performance and behavior (Gruchalla, 2004; Santos et al., 2009). Less research, however, has examined immersion at the level of core principles which define it.

Several factors influence the level of immersion. Specifically, Slater & Wilbur (1997) identified five primary factors of immersion. Table 2.1 presents these five factors, their brief definitions, as well as the originating support research for inclusion.

Table 2.1: Factors influencing immersion.

Factor	Brief definition	Original support research
Inclusive	The extent to which physical reality is shut out	(Slater & Usoh, 1992)
Vividness	The resolution and fidelity simulated within a particular modality	(Welch et al., 1996)
Proprioceptive matching	Match between the user’s body movements and the information generated on the displays.	(Hendrix & Barfield, 1996a)
Extensiveness	The range of sensory modalities accommodated	(Hendrix & Barfield, 1996b)
Plot	The extent to which the VE presents a story-line and dynamic that are distinct from those currently going on in the “real world”	(Welch et al., 1996)

We are particularly interested in studying vividness and extensiveness for a couple of reasons. Vividness is of interest because of its heavy reliance on visual stimuli. Since virtual environments are graphical interfaces, humans heavily rely on their visual sensory system to perceive their surroundings. Research has shown the value of visual feedback through demonstrating the importance of visual fidelity (McMahan et al., 2012) as well as latency (Meehan et al., 2003). McMahan et al. (2012) found that task completion time and accuracy were significantly affected by visual display and interaction fidelity in a VR gaming scenario. Moreover, the VE with low latency (i.e. low lag of frame rate update) led to a higher subjective sense of presence (Meehan et al., 2003). Given VR is primarily a visual experience (Katz et al., 2008; Weiss et al., 2004), modifications to the scene vividness should result in significant effects.

Additionally, from an experimental design perspective, researchers can quickly manipulate and study different levels of vividness. For example, Slater & Wilbur (1997) use shadows as an example of vividness manipulation. Wang & Doube (2011) manipulated vividness using gradient and color variance to shadow softness as a method of vividness manipulation. More recently, Toczek (2017) used a texture resolution approach, populating high and low vividness conditions with objects of varying pixel resolution. Specifically, 3D mountains in the “highly-realistic” scene were 8192x8192 resolution whereas the “unrealistic” scene contained mountains with 1024x1024 resolution. These established adjustments are beneficial for VR training program designers when settling on appropriate visual changes. While the specific methods to manipulate vividness are somewhat subjective and generally vary from study to study, our research uses a structured and detailed approach, outlined in the methods section.

Next, sensibly modifying extensiveness in VR studies has been shown to have a significant effect on important metrics, such as workload and task time, across a variety of domains. In fact, results from Ma & Kaber (2006) indicated that change in the presence of auditory feedback in a virtual basketball scenario elicited statistically significant differences in subjective workload. Similarly, Corbett et al. (2016) showed that task time and root mean square of error were significantly improved in a VR pointing task when presented constant haptic assistive feedback. These types of research are not uncommon; with a majority of extensiveness studies focusing on technological accessible sensory modalities such as audio and haptics. While both vividness and extensiveness have been evaluated as independent variables across a number of studies, rarely are the two used in conjunction to determine cross effects.

Based on the results of these similar studies, it is hypothesized that greater immersion in occupational training scenarios could support enhanced outcomes. This area has not been fully studied.

2.4 Presence

Although presence is generally described as a human reaction of feeling involved and part of the experience, various models of presence have been formulated throughout the years of VR research. Lee (2004) suggested the evolution of presence theories. ‘Telepresence’ is a separate yet similar term, traditionally used to describe the possibility that remote users could feel a sense of being physically transported through a teleoperating system, first used in literature by Minsky (1980). The evolution of models of telepresence and presence are strongly linked as they are often used synonymously, sometimes to the confusion of researchers. Sheridan (1992) refers to telepresence as “feeling like you are actually there at the remote site of operation”. Draper et al. (1998) generally defines telepresence as “an experience that appears to involve displacement of the user’s self-perception into a computer-mediated environment”, though notes that it is used synonymously with other related terms such as presence and virtual presence. Draper et al. (1996)

also showed evidence of a relationship between presence and expenditure of attentional resources during teleoperation, using the NASA-TLX.

Presence is then defined by Witmer & Singer (1998) as the “subjective experience of being in one place or environment, even when one is physically situated in another”. Witmer & Singer also define immersion as a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences (Witmer & Singer, 1998). This line of thinking has received criticism from Slater, claiming that it measures user response to various aspects of a system rather than presence (Slater, 1999). From each of these models of presence, Slater’s framework is used as foundation of this research due to its simplicity, consistency, and wide-spread use across literature.

Referring back to Slater’s definitions, *presence* is a human reaction to immersion (Slater, 2003). That is to say, the greater level of immersion afforded to a user, the greater potential that presence is extended. This hypothesized relationship is a question constantly studied by inquiring research groups and described in a number of literature. It was concluded in a meta-analysis by Cummings & Bailenson (2016) that immersion has a medium-sized effect on presence via questionnaire response from a pool of 83 studies.

Additionally, research has investigated the contribution that further characteristics, such as media content, play on presence (Baños et al., 2004). In this research, we are more interested with the relationship between immersion and presence. Bowman et al. (2007) highlighted this relationship while also building upon it, providing a restructured approach that treated presence as a list of immersive benefits derived from immersive components. They believed that presence would have an impact on application effectiveness, which led to the hypothesis that greater immersion leads to greater presence and therefore leads to greater application effectiveness. While rudimentary in explanation, this relationship can be shown throughout literature, which much of the literature still trying to answer the key question on how much immersion is enough to lead to presence and where the resources should specifically be allocated to improve immersion.

Despite the hypothesized relationship between immersion and presence, researchers also pointed out another factor that affects presence. Some research suggested that the inherent differences among users disallow us to treat immersion and presence as discrete and static factors. Slater (2003) noted that systems with identical levels of immersion, different people may experience different levels of presence, and also different immersive systems may give rise to the same level presence in different people. While little empirical evidence, these hypotheses appear evident in auxiliary questionnaires catered to determine individual differences in immersive tendencies (Witmer & Singer, 1998).

2.4.1 Presence response measures

Considering the mass attention placed on presence in VR, a seemingly equal amount of focus has been placed on determining effective methods to quantify these levels of presence. Presence could be quantified by subjectively and objectively. This separation is based on a 2015 review which assessed the current state of presence measures (Laarni et al., 2015). Further discussion regarding individual measures within each of the two categories and some recent works follows.

Subjective presence response is traditionally self-report questionnaire based. While a number of questionnaires have developed, the evolution of these questionnaires can be traced back to the work from Slater and colleagues (Slater, Usoh, & Steed, 1994). The most commonly used subjective presence questionnaires in empirical studies are SUS, PQ, IPQ, ITC-SOPI, and Temple Presence Inventory, according to a comprehensive literature review by Rosakranse & Oh (2014).

- **The Slater-Usoh Steed (SUS) questionnaire** aimed at measuring presence in immersive VEs (Slater et al., 1994). Although the reliability of this 6-item questionnaire was not published by the authors, the SUS remains one of the most widely used tools in VR presence studies according to the review by Rosakranse & Oh (2014). Furthermore, a series of studies have been conducted showing correlation between the questionnaire results and objective measures of immersion (Slater, Usoh, & Steed, 1995; Usoh et al., 1999).
- **The Presence Questionnaire (PQ)**, developed by Witmer and Singer (1998), is a 32-item questionnaire designed to measure presence in immersive and semi-immersive VEs. Four experiments were conducted to perform a reliability analysis, yielding a respectable $\alpha = 0.88$ (Cronbach's, N = 152).
- **The IGroup Presence Questionnaire (IPQ)** was also designed to measure presence in VE's (Schubert, Friedmann, & Regenbrecht, 2001). This 14-item questionnaire measures presence across three factors, presence as transportation, presence as immersion, and presence as realism. Two internal experiments yielded high reliability ($\alpha = 0.85$, $\alpha = 0.87$) as validation of tool utility.

While the SUS, PQ, and IPQ work as measurements of presence within a VE, further subjective presence questionnaires have been developed with the intention of measuring presence *across* media environments.

- **The ITC-Sense of Presence Inventory (ITC-SOPI)** is a 44-item, cross-media presence questionnaire. (Lessiter, Freeman, Keogh, & Davidoff, 2001). Reliability of this tools subfactors range significantly from sense of physical space (α = 0.94) to ecological validity (α = 0.76).

- **The Temple Presence Inventory** built upon the existing ITC-SOPI, developing a separate 42-item, cross-media presence questionnaire (Lombard, Ditton, & Weinstein, 2009). Reliability of this tool ranged significantly based on the presence indices just as the ITC-SOPI, but Cronbach's alpha for overall index was high (α = 0.87). The use of presence questionnaires across media environments has been questioned in certain situations by Usoh et al. (2000).

While questionnaires still remain vital and research continues in improving these tools, it is not difficult to imagine why issues might arise when using subjective surveys to measure cognitive experiences. Slater (2004) highlighted this concern by administering a similar survey (outside of VR) but measuring an arbitrary mental attribute, called "colorfulness of experience". It is pointed out from this experiment that similar administering in VR experiments may bring the idea of presence in the mind of VR participants, compromising the integrity of results. Thus, objective responses have been considered as replacement, or at least supplementation, for subjective presence questionnaires. Meehan et al. (2002) includes "objective" as one of the four pillars of pursued presence measures, along with "reliable", "valid", and "sensitive". These proposed objective responses are contained within nebulous sub-categories, including performance-based, behavior-based, cognitive feedback, and other physiological responses.

Performance-based responses take form as memory or other performance metrics. Some evidence has shown that presence is positively correlated with memory. A study by Mania & Chalmers (2001) examined memory capacity as an indicator of presence and task performance, using computer monitors and HMDs, which represented media of different immersive levels. Results indicated superior performance in the more immersive settings, which corresponded with higher subjective presence responses, taken from the SUS questionnaire. On the other hand, Slater et al. (1996) reported a positive correlation between memory and immersion but not with reported presence, from a reduced form SUS questionnaire, during a VR chess-move replication task. Additional performance related metrics, such as task completion time estimation have shown some limited correlation to presence (IJsselsteijn et al., 2001).

Detecting fear or danger within a VE is a revealing sign of immersion and has been connected to virtual presence research. Peperkorn et al. (2015) observed a strong correlation between fear and presence during a virtual spider exposure therapy treatment, but noted that the causal relationship between the two remains unclear. Presence, in this case, was recorded using three metrics, including a self-report questionnaire. Since these fear responses to certain unexpected stimuli are largely unavoidable, they can be effective in assessing immersion, and often detecting presence. Additionally, involving physical movements in VR experiences may lead to increasing presence. Slater & Steed (2000) reported a significant correlation between body movement and presence during a three-dimensional chess task. Specifically, greater movement in a VE is associated with higher levels of reported presence, recorded using a reduced SUS questionnaire. Reliability and validity can be limiting factors of behavior-based presence measures, as there are no collectively accepted methods of measurement.

More recently, brain imaging technology has been utilized as an objective estimate of presence. Such devices like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), are on the forefront of VR presence research. Baumgartner et al. (2008) was the to present findings of associations between virtual presence and specific brain region activation using fMRI. Presence was recorded using the MEC spatial presence questionnaire. However, brain imaging methods may not be easily applied to research. Not only are these devices challenging to obtain and operate, but also cumbersome and may reduce the detachment from reality, which is vital to feeling present in VEs. This use, then, may work against the goal of the presence research. Additionally, it is difficult to yield highly-immersive VR systems (e.g. HMD) when hooked into such large and bulky devices. Some studies have attempted to configure systems and experimental structures using highly immersive devices and also measure brain activities. During a VR navigation study using a portable EEG, Slobounov et al. (2015) found that an FM-theta band increase was significantly associated with a higher reported sense of presence, in addition to greater task success rate. Subjective presence was recorded by a one-question scale, asking the participants “strength of presence”. Similar to fear exposure, causality will remain a limitation until a larger body of research is gathered, according to the literature that was gathered during this review. Given the amount of brain regions to be studied in association to virtual presence, research in this field may just be in its beginning phases. Advances in obtrusiveness and usability of brain imaging technologies should expedite the exposure of these association, if possible.

Further objective, physiological measurements of presence have been studied. Galvanic skin response (GSR) was considered in a series of studies by Meehan et al. (2005), revealing no significant association between change in skin conductance and users reported sense of presence, recorded by the University College London (UCL) questionnaire. On the other hand, a positive correlation between change in heart rate (HR) and reported sense of presence was been revealed as part of the study (Meehan et al., 2005). The research team displayed a virtual pit through an HMD, which aimed at eliciting reaction through fear of height. Frame rate (30 FPS, 20 FPS, 15 FPS) and end-to-end latency (50 ms, 90 ms) were altered as independent variables. However, using an immersive HMD equipped with audio and haptic feedback, a negative correlation between HR and reported sense of presence was reported by Wiederhold et al. (2001) during a VR flight simulation. The Questionnaire on Presence and Realism was used as the self-report presence response. This lack of consensus among correlation directions can generally be explained by understanding the emotional hedonic valence associated with the virtual task. Another significant takeaway from the HR results is the demonstrated ability to correlate significantly with reported sense of presence. While the direction of correlation depends largely on the hedonic valence, gathering cardiac response data is a simple and economical method for collecting objective measures.

3. Problem Statement

From this literature review, it can be seen that many virtual reality industrial training studies are concerned with task time as the dependent variable. While time to train is important due to wage restrictions, this study will be among the first in this domain to focus on task accuracy as a dependent variable. Our group values this metric because of the independent variables being investigated. One of the goals is to determine the effect that two immersion factors, vividness and extensiveness, have on human performance. This being the case, minute accuracy will almost certainly differ between virtual and real settings. Those differences are hypothesized to be evident when altering the immersive factors. Additionally, accuracy is undoubtedly a factor that contributes to human performance.

While the relationship from immersion to presence to application effectiveness can be seen through literature (Bowman et al., 2007; Cummings & Bailenson, 2016), it is important to determine how much immersion is necessary for sufficient effectiveness in certain applications. Optimal immersion would understandably be expected if given the choice, it might not be required in all scenarios, however. Additionally, time constraints during scenario design and resource allocation might not allow for optimal immersion. Audio cue and visual fidelity design can range from relatively simple to rather labor intensive. Part of this experiment focuses on the task performance at varying levels of immersion, which correspond with increasing time commitment in design.

Much of the research in immersion evaluates human performance outcomes with subjective measures (Schuemie et al., 2001). Little has explored these topics with objective measures as an additional point of reference. Overall, objective measures of presence still need to be studied. To improve the understanding in objective measures of presence, as a starting point, it would be useful to accompany potential objective measures of presence with known subjective measures of presence. By using objective methods in supplementation with subjective questionnaires, a clearer picture can be formed regarding the cognitive structures of presence.

The overarching goal of this study is to investigate the effect of immersion on human task performance in an occupational setting in a VE. The first objective was to investigate the effect of immersion on task performance accuracy in the VE. While both safety and performance were identified in the literature review in association with training methods, only performance is addressed in this study. The second objective was to examine the effect of immersion on subjective responses and objective physiological measures of humans in the VE. More specifically, subjective responses were participant subjective ratings on surveys. Objective physiological measures were heart rate that were measured by a portable heart rate monitor. HR was measured and normalized to the individual participant's baseline HR. It is important to look at physiological responses because physical aspects of different immersion level exposures have not been comprehensively investigated, and it is an objective, quantifiable, and measurable dependent variable. From these objectives, hypotheses were formulated and detailed in the following section.

4. Methods

4.1 Participants

Thirty participants were recruited from North Carolina State University (NCSU) [age = 21.4± 4.01; 10 female, 20 male]. Flyers were posted around NCSU campus as a recruitment effort. Participants were at least 18 years of age and possessed normal or corrected-to-normal vision. Compensation was paid at a rate of $10 per session, with one full session being the maximum allowed per participant. Each session lasted approximately 1.5 hours. Participants were excluded if they self-reported neuro-motor impairments, a history of seizures or blackouts, tendency of motion sickness, and/or a sensitivity to flashing lights. Informed consent, approved by the NCSU Institutional Review Board, was received from all participants.

4.2 Independent Variables

4.2.1 Vividness

Vividness is associated with the resolution and fidelity simulated within a particular modality. This experiment used three levels of vividness, those being low, mid, and high. High vividness scenarios were designed to be the “most realistic” while the low vividness scenarios were designed to be the “least realistic”. These differences were made evident by use of colors, textures, and shadows (Table 4.1). Soft shadows have been shown to be “more real” than hard shadows in virtual scenes (Wang & Doube, 2011). It is worth noting that factors within vividness are not examined individually in their relation to the dependent variables, due to the structure of level classifications. The low vividness level was created in roughly four hours, once trained in the software. Each additional vividness level required another four hours of labor to implement the additional details and modify color, texture, and shadows.

Table 4.1: Vividness level classifications.

	Low	**Medium**	**High**
Colors	Black/white	Reduced	Full
Texture	None	Limited	Full
Shadows	None	Hard	Soft

4.2.2 Extensiveness

Extensiveness is associated with the range of sensory modalities accommodated. This experiment used two levels of extensiveness, those being audio cues and no audio cues. Audio cues were in the form of standard industrial environment sounds; such as machines in operation. The trials that had audio cues were displayed through the noise-canceling headphones. The sound pattern was identical across each of the three scenes containing audio cues. Headphones were equipped but muted during no-audio trials. All practice trials were done in no-audio trial scenarios so that verbal communication between participant and experimenter could be possible if necessary.

4.3 Apparatus

4.3.1 Hardware

The entire head-mounted display system (HMD; HTC Vive, HTC Corp., New Taipei City, Taiwan) included the HMD, two wireless controllers, and two base station mounts serving as the tracking system. The HMD was responsible for displaying visual information, such as the virtual environment, to the participants. The HMD has a combined resolution of 2160x1200 (1080x1200 per eye), a 90 Hz refresh rate, and 110° field of view. Both Vive controllers were yielded by the participant during trails, performing as virtual hands. A trigger located on the underside of the controllers can be activated to “grab” virtual objects. The base station mounts were capable of tracking head and hand orientation. Noise-canceling headphones were used for over-the-ear audio experience (Bose Corp., Framingham, MA). A heart rate monitor and accompanying watch were used to record cardiac activity (Polar H7 Bluetooth Smart Heart Rate Chest Transmitter, Polar Electro Inc., Lake Success, NY).

4.3.2 Scenario

Unity, a cross-platform game engine, was used for developing the virtual environment scenario (Unity Technologies, San Francisco, CA). The scenario (Figure 4.1) displays a virtual manufacturing plant, including 40 cylindrical air filters placed on a table, 36 cardboard boxes placed on an operating conveyor belt, and additional manufacturing-related objects included to make sure the plant floor was not completely empty. White figures represented in Figure 4.1, including the speaker symbol and camera symbol, are only visible in editor mode. Same goes with the box surrounding the camera symbol. The conveyor belt was placed 42 inches above the floor, which was designed to fall within the NIOSH standing workspace height recommendations. Long conveyor belts were used to maximize the amount of boxes on a single belt and minimize the chance of a box falling off during belt transition. Boxes were equally spaced 5 feet apart to ensure a consistent arrival stream across all trials. Each side of a virtual cardboard square box had a dimension of 12x12x12 cubic inches. Each cylindrical air filter was 4 inches in diameter and 8 inches tall.

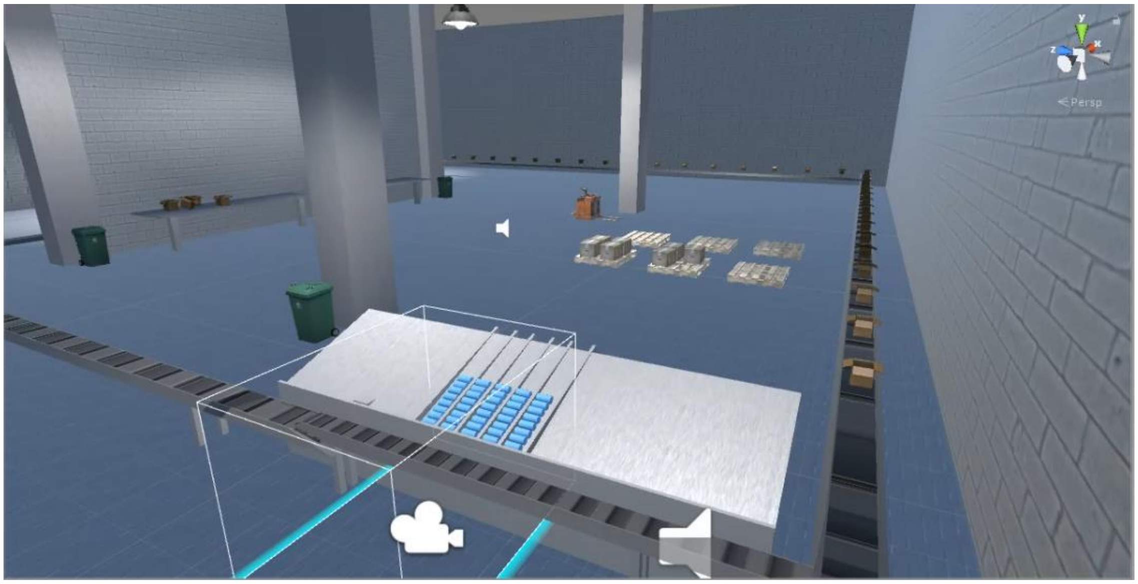


Figure 4.1: Virtual scenario (high vividness) in editor mode.

4.4 Experimental Design

A 3x2 factorial design (vividness X extensiveness) was employed (Figure 4.2). The factors were vividness and extensiveness. The first letter shown in Figure 4.2 represents the vividness level while the second letter represents whether or not auditory cues are present. SUS and NASA-TLX were administered after every three trials There were three levels of vividness (low, medium, and high) and two levels of extensiveness (auditory cues present or absent). All participants experienced all six combinations of vividness and extensiveness. There were three replications for each of the six combinations, which were repeated consecutively, which resulted in 18 experimental trials (Figure 4.2). For instance, "low vividness and auditory cues" combination was repeated three times before moving onto the next combination.

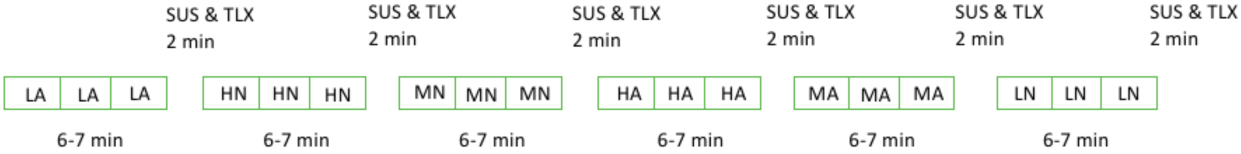


Figure 4.2: Design of complete experiment.

Five unique 6 x 6 Latin squares were used to randomize the order of presentation of combinations across test trials. Literature on the original SUS development study suggested that participants needed to have at least 7 minutes of exposure to a scenario prior to evaluating their sense of presence (Slater et al., 1994). Based on the literature, participants in this study experienced all six combinations for a minimum of 7 minutes before administering the SUS (Figure 4.2). While participants completed SUS, they were also instructed to complete the NASA-TLX in order to capture their subjective workload for a particular combination. The length of the session was designed in attempt to minimize the likelihood of virtual simulator sickness as Kennedy et al. (2000) characterized duration-exposures between 0 and 1 hours as “safe” in regards to simulator sickness.

4.5 Experimental Tasks

4.5.1 Placement task

The main experimental task consisted of picking up a virtual air filter and placing it in a box that is arriving on a moving conveyer belt. Only one air filter was to be placed inside a box. The placement location and orientation of the air filter were accounted for in predefined spaces inside the virtual box (Figure 4.3). All three levels of vividness in Figure 4.3 are illustrating a user moving two controllers and placing an object into an incoming box on a moving conveyer belt. Participants were instructed to pick up and place an air filter as closely to the center of the box bottom surface, and they were asked not to skip any boxes. Participants were instructed to stay standing throughout the task duration and within the 3-foot diameter circle surrounding the starting position, which was displayed in the virtual environment. This circle is programmed through Unity and displayed through HTC Vive throughout each task. All tasks were completed within one experimental session.

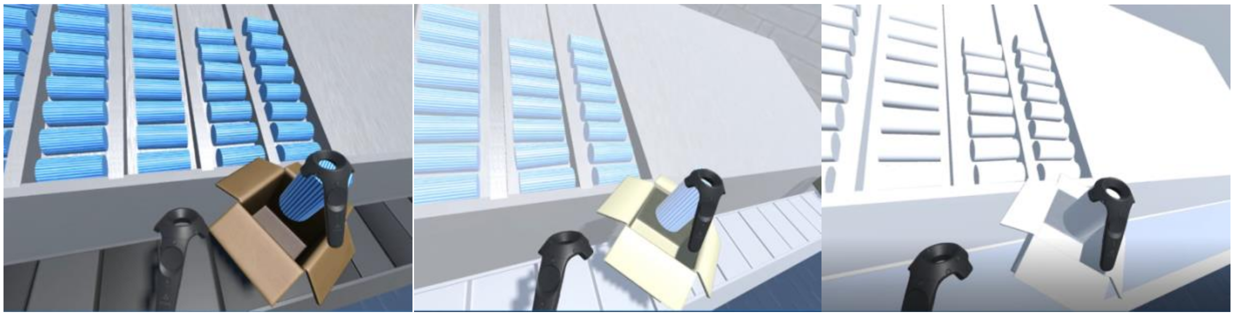


Figure 4.3: High (Left), Medium (Middle), and Low (Right) levels of vividness.

4.5.2 Practice task

The practice task was administered prior to data collection. It was similar to the placement task, which aimed to familiarize participants in viewing virtual scenes and interacting with virtual objects using VR devices, as well as to reduce learning effects. The practice task consisted of picking up virtual objects, in the form of air filters, and placing them in boxes on a moving conveyer belt. Participants were complete with practice trials when 10 consecutive successful filter placements occurred, which lasted approximately 1.5 to 2 minutes.

4.6 Procedure

Upon informed consent, participants were given a general demographic questionnaire upon arrival as well as the Immersive Tendencies Questionnaire (ITQ) to capture differences in the tendencies of individuals to experience presence. Participants were then equipped with the HMD and HR monitor and completed practice task until 10 consecutive filters were placed into oncoming boxes.

Each participant completed the placement task for all six combinations of immersion according to the planned Latin square. Practice trial assignments were then randomized for each participant so that each treatment was equally represented and randomly distributed. The complete experimental treatment for participants can be found in Appendix A, with the experimental trials shaded.

Each placement task trial lasted approximately 150 seconds with a total of 36 boxes moving across the conveyors per trial. The SUS questionnaire and NASA-TLX were administered every three trials. The HMD and HR monitor were not removed for the entirety of trials unless significant discomfort was revealed by a participant. Following the completion of all experimental trials, the participants sat still for 5 minutes to determine a baseline cardiac activity level, in terms of beats per minute. Behavioral observations were noted by the experimenter during trials, looking for common tendencies or unusual behavior.

4.7 Dependent variables

4.7.1 Percent task accuracy

Percent task accuracy was the number of accurate placements within a trial divided by 36 (i.e. the total number of boxes in a trial). Filters placed within a 7-inch diameter circle on the bottom surface of the box were operationally defined as “accurate”, while placements outside of the circle “inaccurate”. Placements outside of the box, due to boxes falling during conveyor maneuver out of control of the participant, were excluded from the analysis. These cases made up only 1.8 percent of all placement possibilities. A series of C# scripts were developed and utilized in Unity to extract all relevant data.

4.7.2 Subjective presence

Two unique values derived from the same six-question SUS questionnaire (Slater et al., 1994) responses were evaluated. First, mean values from responses of the 6-item SUS presence questionnaire were calculated before analysis. Second, “high” SUS responses were calculated from questions that received a score of 6 or 7. Responses were recorded on paper evaluation sheets.

4.7.3 Subjective workload

An online NASA-TLX tool from Sharek (2011) was used for perceived workload evaluation on this experiment. One of the fifteen pairwise comparisons can be found in Appendix C. Ratings were combined to compute an overall workload score for each test trial. The overall NASA-TLX score is the combined weighted response of from the subscales: demand, including physical, mental, effort, performance, frustration, and temporal.

4.7.4 Mean percent HR increase

Heart rate was focused as a dependent physiological and objective presence response due to ease of collection compared to brain imaging devices as well as accessibility. If HR is to be used in VR training, it is important that researchers and training designers be able to easily access the necessary technology. Additionally, modern HR recording devices are unobtrusive and do not pose physical conflicts to VR technology. All HR observations were recorded and normalized to account for individual differences. Normalization was achieved by subtracting mean resting HR from test responses and dividing by the mean resting HR response for each participant.

4.8 Hypotheses

H1. It was hypothesized that greater immersion, characterized by vividness and extensiveness, would lead to improved performance, which is characterized by increased task accuracy. This positive relationship between task performance and immersion has been seen in similar VR studies (Ma & Kaber, 2006; McMahan et al., 2012).

H2. It was also hypothesized that greater immersion would lead to higher subjective presence, both in mean and high responses from the SUS questionnaire. Response on SUS questionnaire has shown to be sensitive to increases in immersion via shadow adjustment and virtual realism (Hvass et al., 2017; Slater, Usoh, & Chrysanthou, 1995).

H3. NASA-TLX was hypothesized to be significantly affected by greater immersion. Perceived workload by the NASA-TLX has shown to be a sensitive tool in VR studies, associated with changes in extensiveness and presence (Draper & Blair, 1996; Ma & Kaber, 2006).

H4. Finally, it was hypothesized that greater immersion would significantly affect normalized heart rate, recorded by a portable heart rate device. Prior literature shows a mixed relationship between immersion and cardiac response (Meehan et al., 2005; Wiederhold et al., 2001).

4.9 Data Analysis

Diagnostics were conducted on all response measures to assess normality and constant variance assumptions of the ANOVA model. Shapiro-Wilk's test was used for assessing conformance with the residual normality assumption. Bartlett's test was used to assess data conformance with homoscedasticity. In the case of assumption violations, data transformations were applied.

Two-way ANOVA models were developed to test the effect of vividness and extensiveness on the dependent variables, with the level of statistical significance set at $\alpha = 0.05$. Based on the experimental design, an Analysis of Variance (ANOVA) model was constructed to assess the effects of vividness and extensiveness on the various response measures. The statistical model was structured as follows:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha_i\beta_j + E_{ijk} \text{ (Equation 1)}$$

Where μ = grand mean; α_i = vividness effect (i=1, 2, 3); β_j = extensiveness effect (j=1, 2); γ_k = participant effect (k=1 … 30); $\alpha_i\beta_j$= interaction between vividness and extensiveness; E_{ijk}: Error.

Spearman's correlation analysis was conducted between normalized heart rate and mean SUS scores.

5. Results

Among the response measures, SUS mean responses met all ANOVA normality assumptions. Mean percent HR increase responses, task accuracy, SUS high responses, and NASA-TLX responses were successfully transformed for analysis. Table 5.1 represents mean and standard deviation values of each of the dependent variables values in regards to the immersive level scenarios. As a note, SUS mean is on a 1 (low presence) through 7 (high presence) scale, while SUS "high" count is on a 1 (low presence) through 6 (high presence) scale.

Table 5.1: Mean [SD] of dependent variable values by immersive level scenarios

Immersive Level	Percent task accuracy	SUS mean	SUS "high" count	NASA-TLX	Mean percent HR increase
Low vividness; No audio	85.00% [17.33]	3.63 [1.26]	1.07 [1.60]	29.43 [15.48]	0.15 [0.07]
Medium vividness; No audio	85.18% [17.92]	4.07 [1.29]	1.34 [2.02]	26.66 [12.77]	0.14 [0.08]
High vividness; No audio	85.92% [17.76]	4.19 [1.10]	1.03 [1.67]	25.64 [12.27]	0.15 [0.09]
Low vividness; Audio	86.84% [13.56]	4.09 [1.41]	1.79 [1.94]	29.05 [16.24]	0.14 [0.08]
Medium vividness; Audio	86.51% [17.52]	4.14 [1.20]	1.72 [2.05]	30.60 [16.16]	0.16 [0.09]
High vividness; Audio	87.82% [14.08]	4.71 [1.19]	2.21 [2.09]	26.35 [12.03]	0.14 [0.08]

5.1 Percent task accuracy

Percent task accuracy was derived from the raw task accuracy data (number of accurate placement divided by the total number of placement). Figure 5.1 shows mean percent task accuracy across different levels of immersion. Box-Cox transformation was applied to the normalized accuracy data for statistical analysis since they did not meet normality assumptions initially. A two-way ANOVA revealed that there was no main effect of vividness (F (2, 139) = 1.9132, p =

0.1515) nor extensiveness (F (1, 139) = 0.7256, p = 0.3958). There was no statistically significant interaction effect between vividness and extensiveness (F (2, 139) = 0.4013, p = 0.6702).

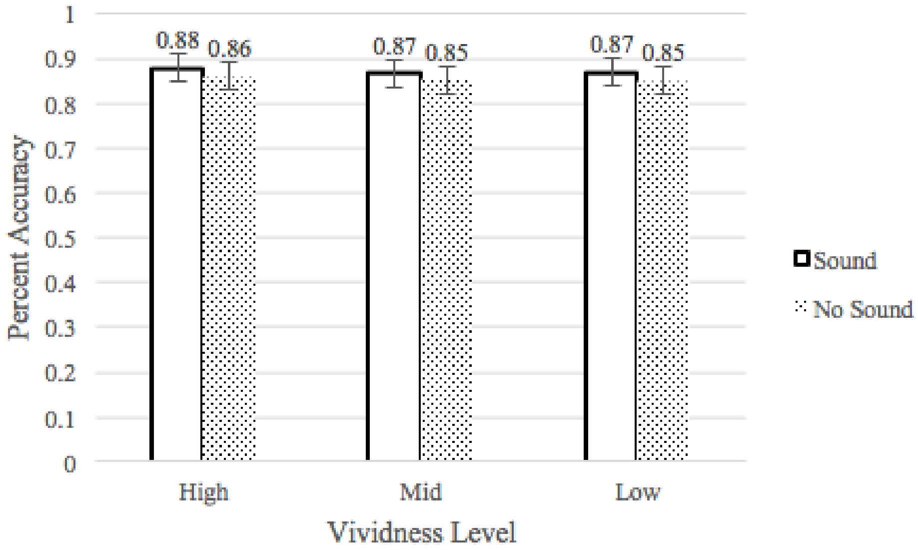


Figure 5.1. Mean percent task accuracy across different levels of vividness and extensiveness (+/- 1 SE).

5.2 Subjective presence

Mean SUS rating across the 6-item questionnaire was used as the primary measure of subjective presence, originally used in this format by Usoh et al. (2000). Mean SUS response data met normality and homoscedasticity assumptions. A two-way ANOVA indicated a statistically significant main effect of vividness (F (2, 145) = 9.9102, p < 0.01). A 0.20 decrease in SUS was seen between high and mid-level vividness while mid and low-levels yielded a 0.92 decrease. A statistically significant main effect was found for extensiveness (F (1, 145) = 21.5030, p < 0.01). Removing the auditory cues from the scenario decreased the mean SUS response by an average of 0.44. No statistically significant interaction effect was found between vividness and extensiveness (F (2, 145) = 0.0841, p > 0.05). Tukey's post-hoc test revealed significant differences between high and low levels of vividness. Figure 5.2 shows mean subjective presence response in terms of mean SUS score across different levels of immersion.

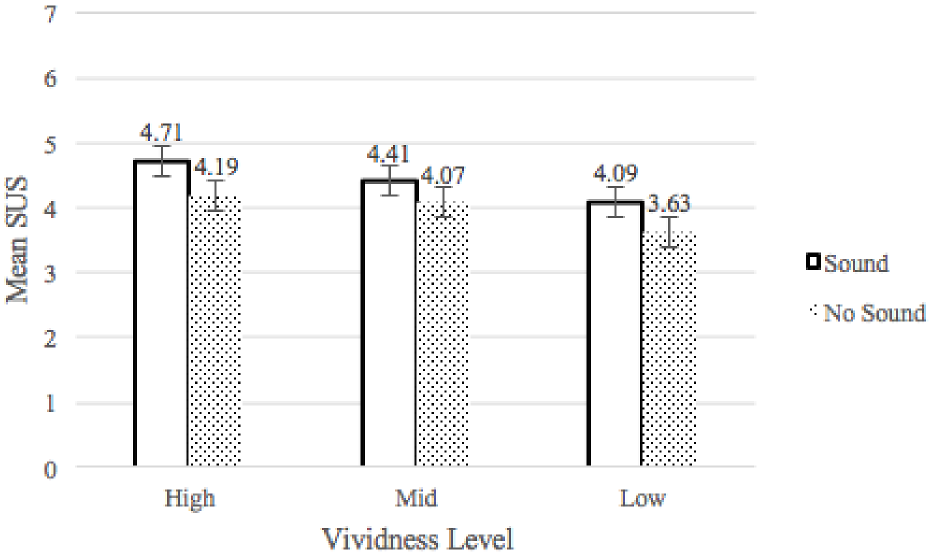


Figure 5.2: Mean SUS response across different levels of vividness and extensiveness (+/- 1 SE).

The average count of 6 or 7 responses across the 6-item SUS questionnaire were noted as “high” SUS responses, initially used in this format by Usoh et al. (2000). “High” SUS response data met normality and homoscedasticity assumptions. A two-way ANOVA indicated no statistically significant main effect of vividness (F (2, 140) = 1.4380, p = 0.2409). A statistically significant main effect was found for extensiveness (F (1, 140) = 15.8886, p < 0.01). Removing the auditory cues from the scenario decreased the high SUS responses by an average of 0.75. No statistically significant interaction effect was found between vividness and extensiveness (F (2, 145) = 1.1098, p = 0.3325). Figure 5.3 shows average “high” subjective presence responses across different levels of immersion.

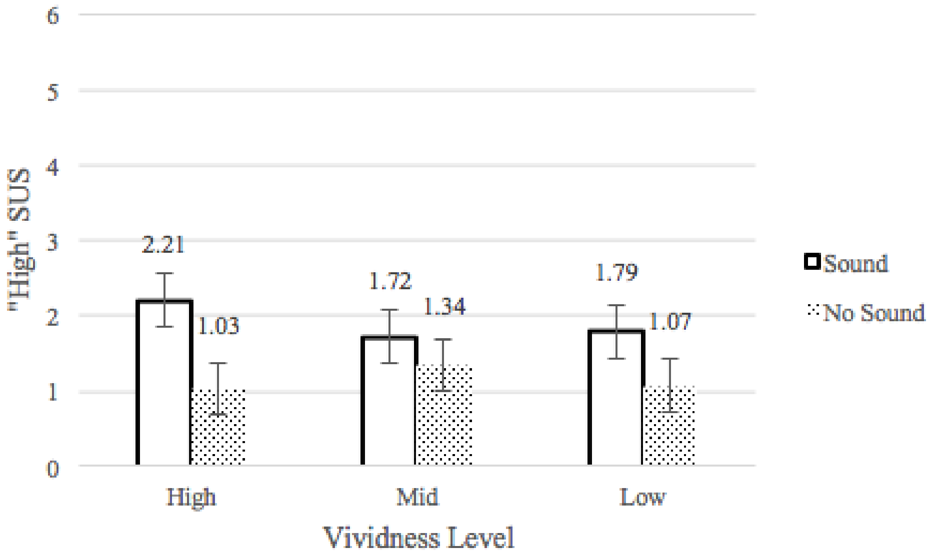


Figure 5.3: Mean "high" SUS responses across different levels of vividness and extensiveness (+/- 1 SE).

5.3 Subjective workload

Aggregated NASA-TLX response data met normality and homoscedasticity assumptions. A two-way ANOVA indicated a statistically significant main effect of vividness (F (2, 138) = 3.8304, p = 0.0240). A 2.65 increase in NASA-TLX was seen when going from high to mid-level vividness while mid to low-levels yielded a 0.49 increase. No statistically significant main effect was found for extensiveness (F (1, 138) = 1.1276, p = 0.2902). A marginally statistically significant interaction effect was found between vividness and extensiveness (F (2, 138) = 2.8347, p = 0.0622). Figure 5.4 shows mean subjective workload response across different levels of immersion. None of the weighted NASA-TLX subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration) were found to be significantly affected by vividness nor extensiveness.

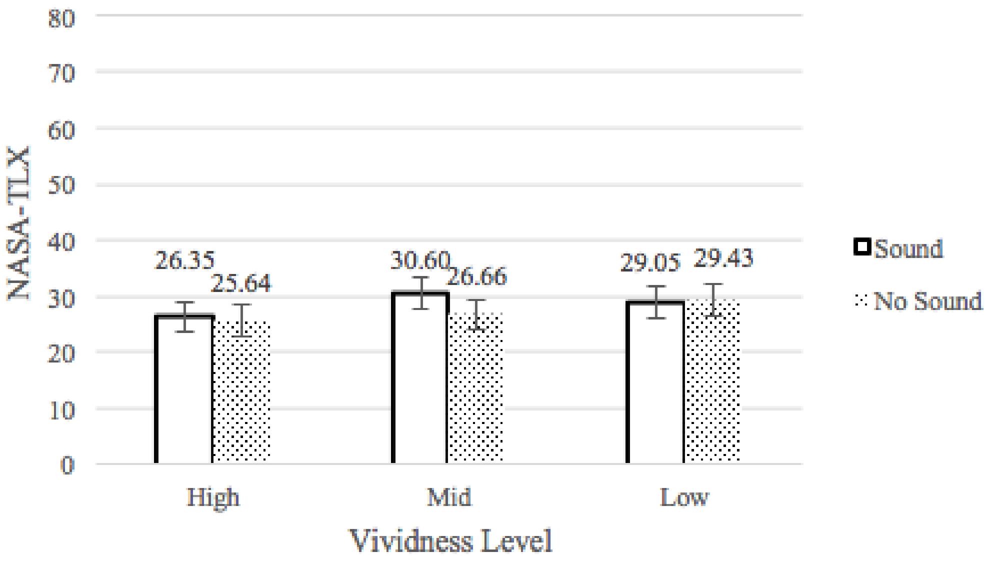


Figure 5.4: NASA-TLX response across different levels of vividness and extensiveness (± 1 SE)

5.4 Mean percent HR increase

Mean percent HR increase data were obtained by dividing the difference between raw heart rate and baseline heart rate data by the baseline heart rate of the participant. Figure 5.5 shows mean percent HR increase across different levels of immersion. Natural logarithmic transformation was applied to the mean percent HR increase data for statistical analysis since they did not meet normality assumptions initially. A two-way ANOVA revealed that there was no main effect of vividness ($F(2, 142) = 0.4213$, $p > 0.05$) nor extensiveness ($F(1, 142) = 0.3644$, $p > 0.05$). There was no statistically significant interaction effect between vividness and extensiveness ($F(2, 142) = 1.3730$, $p > 0.05$).

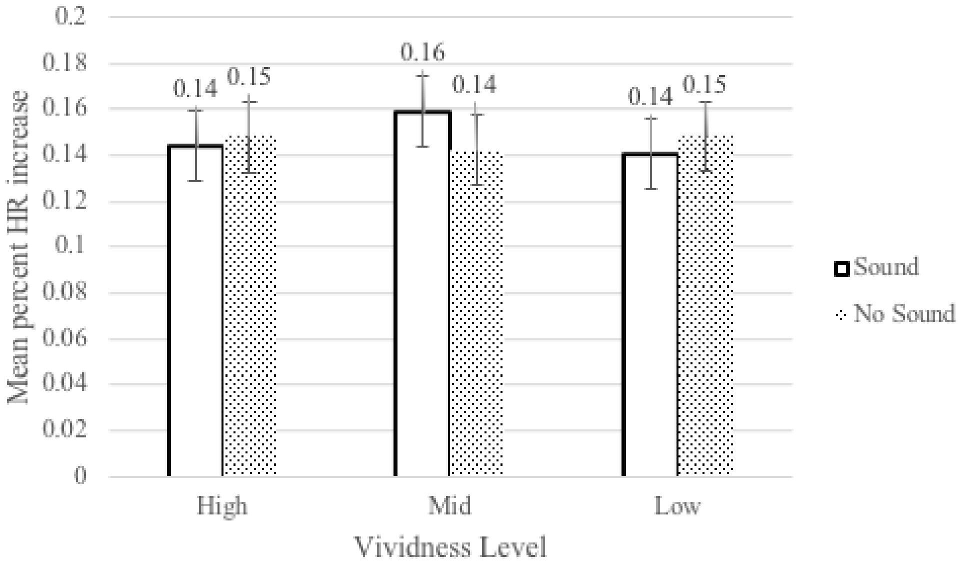


Figure 5.5: Mean percent HR increase across different levels of vividness and extensiveness (+/- 1 SE)

5.6 Correlation analysis

Previous studies have looked into correlations between subjective presence response and examined objective measures (Slater, Usoh, & Steed, 1995; Usoh et al., 1999). Despite the statistical insignificance in terms of main effect of mean percent HR increase, Spearman’s rho correlation analysis revealed a statistically significant positive correlation between mean percent HR increase and subjective presence via mean SUS response (ρ= 0.2627, p = 0.0004).

6. Discussion

The central goal of this study was to investigate the effect of immersion on human task performance in an occupational setting in a VE. The first objective was to investigate the effect of immersion on task performance in the VE, characterized by percent task accuracy. The second objective was to examine the effect of immersion on subjective presence and workload responses and objective physiological measures in the VE. The assignment itself was a virtual occupational training simulation, where participants were tasked with placing air filters in individual boxes moving across an active conveyor belt.

6.1 Percent task accuracy

Hypothesis 1 stated that percent task accuracy would increase with greater levels of immersion. This trend was hypothesized based on prior VR studies by Ma & Kaber (2006) and McMahan (2012) with similar virtual setups. Percent task accuracy was measured as the percentage of filters placed within a predefined, central placement location on boxes moving across a conveyor belt. Three levels of vividness and two levels of extensiveness were the independent variables, which characterized immersion.

A two-way ANOVA revealed that there was no main effect of vividness ($p = 0.1515$) nor extensiveness ($p = 0.3958$) on percent task accuracy. Additionally, each of the six immersive level combinations had at least 85% task accuracy. This prevailing high amount can largely be attributed to task design and difficulty, as well as the predefined filter placement tolerances. A higher degree of task difficulty or smaller placement tolerances would likely cause greater variation in percent task accuracy, but it is difficult to conclude whether this increased variation in results would result in a significant main effect of immersion. Although levels of immersion did not have a statistically significant effect on percent task accuracy, there was a slight increasing in percent task accuracy as the level of immersion increased (Figure 5.1). This trend might be significantly substantiated in statistical analysis if additional trials were conducted.

Further examination of percent task accuracy data revealed a statistically significant effect (F (18, 529) = 1.6455, p = 0.04) of trial number on mean percent task accuracy (Figure 6.1). It is probable that this pattern was due to a learning effect, where the participants have become more proficient in performing the task. Mean percent task accuracy was never below 80% during any trial number, though, showing that near proficiency could be achieved almost immediately.

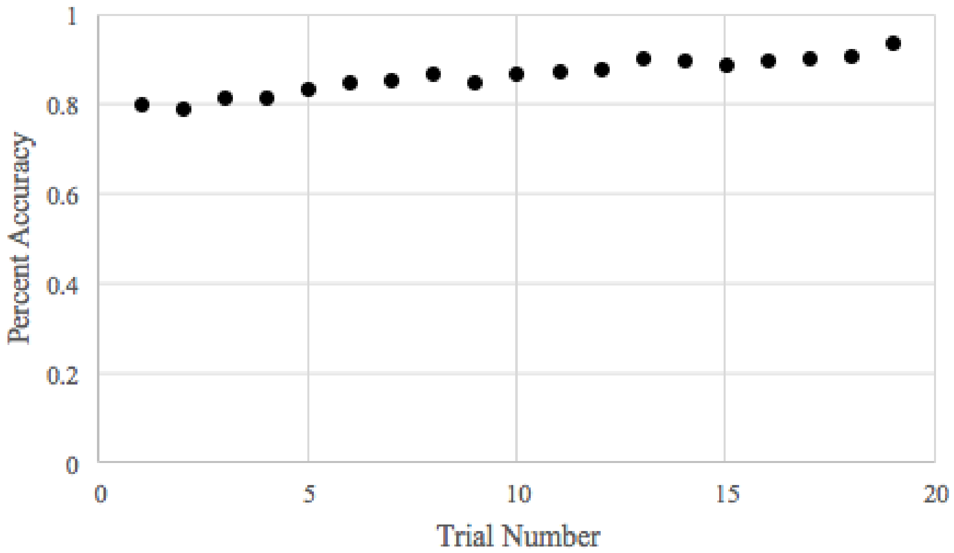


Figure 6.1: Aggregated percent task accuracy over time (in terms of trial number)

In general, task accuracy in a simple VR-based occupational task, such as air filter placement, was not highly influenced by levels of immersion. This suggests that in simple occupational task simulation, the level of complexity in simulation design would not affect task performance in terms of accuracy. It would be worth investigating how task performance is affected by vividness and extensiveness in more complex scenarios, particularly with additional tasks or objects providing distractions similar to real working environments.

6.2 Subjective presence

Hypothesis 2 stated that subjective presence response would increase with greater levels of immersion. A two-way ANOVA revealed significant main effects of vividness ($p < 0.01$) and extensiveness ($p < 0.01$) on mean SUS rating. A separate two-way ANOVA revealed significant main effect of extensiveness ($p < 0.01$) on “high” SUS response but not vividness ($p = 0.2409$).

Levels of extensiveness (i.e. with or without auditory cue) had a pronounced effect on subjective presence on the SUS, both mean and high responses. When task-relevant auditory cues were present, mean participant SUS response was 0.44 higher than when auditory cues were not present. The presence or absence of task-relevant auditory cues has been shown to significantly impact the user’s sense of presence via questionnaire response (Ma & Kaber, 2006). Auditory cues were also shown to increase the average amount of high SUS Reponses by 0.75 questions. This knowledge is useful in knowing that task-relevant auditory cues are important in developing subjectively realistic virtual training environments.

Similarly, vividness had a significant effect on subjective presence via mean SUS response. High SUS response, conversely, was not significantly affected by vividness. Levels of vividness were modified with various gradients of color, levels of object texture, and shadow softness (Table 4.1). The mean SUS score, an indicator of subjective presence, increased as the level of vividness increased. Tukey’s post-hoc analysis revealed significant differences between only high and low levels of vividness. The mean SUS score at the high-level vividness was 0.20 units greater than at the mid-level vividness. The mean SUS score at the mid-level vividness was 0.92 units greater than at the low-level vividness. There was a noticeably larger jump from medium to low-levels

(0.92 difference) than high to mid-levels (0.20 difference). The greater difference between low and medium vividness levels (0.92 units) could be explained by the greater transitions of colors/shadows/etc. Specifically, black and white to reduced colors, no object texture to limited object texture, and no shadows to hard object shadows. Similar to auditory cues, it appears that the transition from nothing to something (e.g. some audio vs no audio, some shadows vs no shadows) has a more profound effect on the way users perceive the environments and subjectively represent their sensation of presence.

6.3 Subjective workload

Hypothesis 3 stated that subjective workload ratings were expected to be significantly affected by the level of immersion. This premise was formulated based on a prior study by Ma & Kaber (2006), which concluded that workload was significantly affected by both auditory cue presence and user viewpoint.

In our findings, total subjective workload ratings from NASA-TLX were not statistically affected by increasing presence or absence of task-relevant auditory cues. Vividness, on the other hand, was shown to significantly affect perceived workload, which was indicated by the aggregated NASA-TLX response. The largest change in workload response came between high and mid-levels of vividness, where mid-level vividness scenarios yielded 2.49 units higher in NASA-TLX response than high-level vividness scenarios. Simply put, participants were under *less* perceived overall workload when at higher levels of vividness. It is difficult to say which individual vividness factor (colors, texture, shadows) affected this trend the most without further investigation into them.

Individual NASA-TLX subscales (mental, physical, temporal, performance, effort, frustration) were not statistically significantly affected by vividness. Mental workload, in particular, did not show a significant increase which runs contrary to some previous research in expenditure of attentional resources during virtual experience (Draper & Blair, 1996). Nonetheless, temporal demand saw the highest weighted score (6.85) across all trials while frustration received the lowest (1.78). Temporal demand was given the definition, “How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?”. Frustration was given the definition, “How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?”. From these two definitions, it can be presumed that participants felt comfortable with the task design and difficulty but less with the pace of assembly.

6.4 Mean percent HR increase

Hypothesis 4 stated that mean percent HR increase would be significantly affected by the level of immersion. Neither vividness nor extensive was shown to be a statistically significant effect on cardiac response, characterized by normalized mean HR over trials. These results can be rationalized by one of two possible explanations.

First, the designed task and environments were insufficient in eliciting the hedonic valence necessary for noticeable physiologic response. Further, a lack of consensus exists in the literature among correlation direction. Meehan et al. (2005) reported a positive correlation between HR and subjective response in a fear of heights VR study while Wiederhold et al. (2001) reported the opposite trend in a VR flight simulation study. Simply stated, cardiac response in VR experiences can vary depending on the hedonic valence associated with the virtual task or experience. This particular assembly task, while engaging by its objective, might not have elicited enough subconscious emotional reaction to notice a statistically significant effect across immersive levels.

Second, HR might not be a sufficient objective presence measure in this type of VR experience. Despite a few of the earlier studies have demonstrated significant correlations between HR and subjective presence (Meehan et al., 2005; Wiederhold et al., 2001), it is possible that certain physiological measures may be more suitable indicators of presence in certain simulation contexts.

6.5 Trial effect

Further examination of the data revealed that mean percent HR increase was significantly by trial number as it progressively decreased toward baseline over time. A one-way ANOVA revealed that mean percent HR increase decreased over time ($F (18, 549) = 9.0341$, $p < 0.0001$). It is suspected that as participants became more familiar with the scene or task, their individual cardiac response steadily approached baseline. The familiarity also might be involved the technology itself. Of the 30 participants, only 4 self-reported as many as two VR experiences per month. 16 participants self-reported some VR exposure but less than two per month, and 10 participants self-reported no prior VR experience. Future experiments investigating cardiac response in VR studies, presence related or not, should be conscious of this subconscious human tendency of familiarity.

6.6 Informal behavioral observations

From informal behavioral observations during the experimental sessions, it was noted that participants seemed to hold the virtual filter in hand longer as the trials progressed. It was assumed that the more comfortable the participant became with the task, the quicker they would move onto placing the next object. This trend was not substantiated upon analysis, though. No statistically significant effect was discovered between trial number and time of filter in hand.

7. Conclusion

The overarching goal of this study was to investigate the effect of immersion on human task performance in an occupational setting in a VE using a HMD. A between-subjects experiment was conducted to determine the effects that vividness and extensiveness played on task-related and physiological dependent variables.

Results of this experiment indicate a consistent upward trend for task accuracy with increased immersion, but not statistically significant. Additionally, subjective presence responses through mean SUS confirmed the user's ability to observe increases in immersion. High SUS response were significantly affected by extensiveness, while perceived workload was significantly affected by vividness. Furthermore, cardiac response was not significantly affected by increasing levels of immersion, through vividness nor extensiveness.

7.1 Applications

Task accuracy saw slight increases when immersion was increased. While not statistically significant, the observed trend was consistent among immersive levels. It is difficult to say whether this pattern would apply to additional occupational training applications, such as surgical training or pilot training. Increasing sense of presence through immersion is assumed to cause suspension of disbelief, leading the users to believe that they are truly in an occupational setting. This study showed that VE's with higher levels of immersion lead to increased sense of presence and may increase the likelihood for users to exhibit their true and natural behavior in a virtual training environment. We anticipate that a virtual training environment that has greater resemblance to the physical training environment may be important in complex training scenarios.

Though increases in immersion were shown to have positive influences on subjective presence, that relationship was not continued onto improvements in the application effectiveness, characterized by our task performance variable. This could be explained by task design influences, causing a lack of discrepancy between participant's performance outcomes. Alternatively, this could point to deficiencies in the hypothesized relationship from immersion to presence to application effectiveness. While shown in some literature, it has been argued that increased presence does not necessarily have to lead to improved task performance (Welch, 1999).

Given mean percent HR increase was not significantly affected by increasing level of immersion through vividness nor extensiveness, it would not be a recommended measure of presence in hedonic-neutral occupational training in VR. In scenarios similar to our training sessions where cardiac response is not expected to see significant trends, subjective presence questionnaires would be recommended until research is able to demonstrate some objective presence response that is reliable across experiences.

7.2 Limitations

Participants would periodically verbally or non-verbally note that the wire running from the headphones to the HMD was coming in contact with their hands. While vividness and extensiveness in the VE were shown to have a positive effect on subjective presence, this brief "break in presence" withheld the participant from becoming completely immersed in the environment. Going forward, it would be recommended that wireless headsets be used when available.

This was a simple occupational task simulation, which may not include the complexity of a real occupational environment. The levels of task intensity may not be as strenuous as a real task, which might involve unanticipated actions, stripped in the perfectly replicable virtual scenarios. These would have affected HR.

Emotional involvement as something previously discussed that effects cardiac response. Given that this assembly task was relatively neutral in terms of emotional involvement, it is not extremely surprising that there was no statistically significant effect from level of immersion. If an emotion-evoking element, such as joy or fear, were introduced to the experience, whether that be through a reward system or some inclusion of some automation, there might be a greater chance of observing a positive influence of immersion on cardiac response. That will be something that is looked at incorporating into future related studies. That said, if it is expected that cardiac response will only statistically significantly react to immersion during particularly emotional-evoking experiences, there are inherent limitations of applying it as a measure of presence.

7.3 Future work

Future research dedicated to physiological measures of VR presence should consider a focus on trial effects. Particularly involving cardiac responses which were shown in this study to significantly decrease over trial. Two self-reported covariates, ITQ and VR experience, were individually shown to have statistical significance on rate of HR change. If additional factors could be identified that share this characteristic, a multivariate equation could be fit, aimed at determining an aggregate HR decrease function. This way, researchers or training directors would have a better idea of when participants will individually reach a regulated HR, based on common self-report measures.

Further immersive factors, defined by Slater & Wilbur (1997) or otherwise, should be investigated for effects on task performance and subjective and physiological response measures. Vividness and extensiveness were used in this experiment for reasons discussed in section 2.3, but other factors such as proprioceptive matching, inclusiveness, and plot could be investigated. It is possible that another factor could have significant effects on task accuracy which vividness and extensiveness did not.

REFERENCES

Anderson, J. G. (2004). Surgical Training, Error. *JAMA*, *291*(14), 11–12.

Baños, R. M., Botella, C., Alcañiz, M., Liaño, V., Guerrero, B., & Rey, B. (2004). Immersion and Emotion: Their Impact on the Sense of Presence. *CyberPsychology & Behavior*, *7*(6), 734–741. https://doi.org/10.1089/cpb.2004.7.734

Baumgartner, T., Speck, D., Wettstein, D., Masnari, O., Beeli, G., & Jäncke, L. (2008). Feeling present in arousing virtual reality worlds: prefrontal brain regions differentially orchestrate presence experience in adults and children. *Frontiers in Human Neuroscience*, *2*, 8.

Bengu, G., & Swart, W. (1996). A computer-aided, total quality approach to manufacturing education in engineering. *IEEE Transactions on Education*, *39*(3), 415–422. https://doi.org/10.1109/13.538767

Boud, A. C., Baber, C., & Steiner, S. J. (2000). Virtual Reality: A Tool for Assembly? *Presence: Teleoperators and Virtual Environments*, *9*(5), 486–496. https://doi.org/10.1162/105474600566970

Boud, A. C., Haniff, D. J., Baber, C., & Steiner, S. J. (1999). Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks. *Information Visualization, 1999. Proceedings. 1999 IEEE International Conference*, 32–36. https://doi.org/10.1109/IV.1999.781532

Bowman, D. a, Mcmahan, R. P., & Tech, V. (2007). Virtual Reality: How Much Immersion Is Enough? (Cover story). *Computer*, *40*(7), 36–43. https://doi.org/10.1109/MC.2007.257

Brough, J. E., Schwartz, M., Gupta, S. K., Anand, D. K., Kavetsky, R., & Pettersen, R. (2007). Towards the development of a virtual environment-based training system for mechanical assembly operations. *Virtual Reality*, *11*(4), 189–206. https://doi.org/10.1007/s10055-007-

0076-4

Cairns, P., Cox, A., Berthouze, N., Jennett, C., & Dhoparee, S. (2006). Quantifying the experience of immersion in games. *Cognitive Science of Games and Gameplay Workshop at Cognitive Science 2006*, 7. https://doi.org/10.1016/j.ijhcs.2008.04.004

Campbell, C. P. (1997). Workforce Requirements: The Basis for Relevant Occupational Training. *Journal of European Industrial Training*, *21*(8), 278–297. https://doi.org/10.1108/03090599710184662

Cha, Moohyun., Han, Soonhung., Lee, Jaikyung., Choi, B. (2012). A virtual reality based fire training simulator integrated with fire dynamics data. *Fire Safety Journal*, *50*, 12–24.

Corbett, B., Nam, C. S., & Yamaguchi, T. (2016). The Effects of Haptic Feedback and Visual Distraction on Pointing Task Performance. *International Journal of Human-Computer Interaction*, *32*(2), 89–102. https://doi.org/10.1080/10447318.2015.1094914

Cummings, J. J., & Bailenson, J. N. (2016). How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence. *Media Psychology*, *19*(2), 272–309. https://doi.org/10.1080/15213269.2015.1015740

Dearden, L., Reed, H., & Van Reenen, J. (2006). The impact of training on productivity and wages: Evidence from British Panel Data. *Oxford Bulletin of Economics and Statistics*, *68*(4), 397–421. https://doi.org/10.1111/j.1468-0084.2006.00170.x

Draper, J. V, & Blair, L. M. (1996). Workload, Flow, and Telepresence during Teleoperation. *Robotics and Automation*.

Draper, J. V, Ridge, O., Ridge, O., David, B., & Usher, J. M. (1998). Telepresence. *Human Factors*, *40*(3), 354–375.

Durlach, N., & Mavor, A. (1995). *Virtual Reality: Scientific and Technological Challenges*.

National Academy Press.

Earnshaw, R. (2014). *Virtual Reality Systems*. Academic Press.

Gavish, N., Gutierrez, T., Webel, S., & Rodriguez, J. (2011). Transfer of Skills Evaluation for Assembly and Maintenance Training. *The International Conference SKILLS*, *29*, 1–4. https://doi.org/10.1051/bioconf/201101000

Geldart, S., Smith, C. A., Shannon, H. S., & Lohfeld, L. (2010). Organizational practices and workplace health and safety: A cross-sectional study in manufacturing companies. *Safety Science*, *48*(5), 562–569. https://doi.org/10.1016/j.ssci.2010.01.004

Gershon, R. R. M., Karkashian, C. D., Grosch, J. W., Murphy, L. R., Escamilla-Cejudo, A., Flanagan, P. A., … Martin, L. (2000). Hospital safety climate and its relationship with safe work practices and workplace exposure incidents. *American Journal of Infection Control*, *28*(3), 211–221. https://doi.org/10.1067/mic.2000.105288

Gruchalla, K. (2004). Immersive well-path editing: investigating the added value of immersion. *Virtual Reality*, 157–164.

Gunasekaran, A., & Love, P. E. . (1999). A review of multimedia technology in manufacturing. *Computers in Industry*, *38*(1), 65–76. https://doi.org/10.1016/S0166-3615(98)00108-0

Hendrix, C., & Barfield, W. (1996a). Presence within Virtual Environments as a Function of Visual Display Parameters. *Presence: Teleoperators and Virtual Environments*, *5*(3), 274–289.

Hendrix, C., & Barfield, W. (1996b). The Sense of Presence within Auditory Virtual Environments. *Presence: Teleoperators and Virtual Environments*, *5*(3), 290–301.

Hosseinpour, F., & Hajihosseini, H. (2009). Importance of Simulation in Manufacturing. *World Academy of Science, Engineering and Technology*, *51*(3), 292–295.

Hvass, J. S., Larsen, O., Vendelbo, K. B., Nilsson, N. C., Nordahl, R., & Serafin, S. (2017). The effect of geometric realism on presence in a virtual reality game. *2017 IEEE Virtual Reality (VR)*, 339–340. https://doi.org/10.1109/VR.2017.7892315

IJsselsteijn, W., Ridder, H. de, Freeman, J., Avons, S. E., & Bouwhuis, D. (2001). Effects of Stereoscopic Presentation, Image Motion, and Screen Size on Subjective and Objective Corroborative Measures of Presence. *Presence: Teleoperators and Virtual Environments*, *10*(3), 298–311. https://doi.org/10.1162/105474601300343621

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human Computer Studies*, *66*(9), 641–661. https://doi.org/10.1016/j.ijhcs.2008.04.004

Katz, L., Parker, J., Tyreman, H., & Levy, R. (2008). *Virtual reality*. *Computers in Sport* (Vol. 32). https://doi.org/10.2495/978-1-84564-064-4/01

Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: Surveillance, research, and prevention. *American Journal of Preventive Medicine*, *18*(3 SUPPL.), 54–63. https://doi.org/10.1016/S0749-3797(00)00114-8

Knapik, J. J., Rieger, W., Palkoska, F., Van Camp, S., & Darakjy, S. (2009). United States Army physical readiness training: Rationale and evaluation of the physical training doctrine. *Journal of Strength and Conditioning Research*, *23*(4), 1353–1362. https://doi.org/10.1519/JSC.0b013e318194df72

Laarni, J., Ravaja, N., Saari, T., Böcking, S., Hartmann, T., & Schramm, H. (2015). Ways to Measure Spatial Presence: Review and Future Directions (pp. 139–185). Springer.

Langley, A., Lawson, G., Hermawati, S., D’Cruz, M., Apold, J., Arlt, F., & Mura, K. (2016). Establishing the Usability of a Virtual Training System for Assembly Operations within the

Automotive Industry. *Human Factors and Ergonomics in Manufacturing*, *26*(6), 667–679. https://doi.org/10.1002/hfm

Lee, K. M. (2004). Presence, Explicated. *Communication Theory*, *14*(1), 27–50.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2001). A Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators and Virtual Environments*, *10*(3), 282–297. https://doi.org/10.1162/105474601300343612

Lisman, P., O'Connor, F. G., Deuster, P. A., & Knapik, J. J. (2013). Functional movement screen and aerobic fitness predict injuries in military training. *Medicine and Science in Sports and Exercise*, *45*(4), 636–643. https://doi.org/10.1249/MSS.0b013e31827a1c4c

Lombard, M., Ditton, T. B., & Weinstein, L. (2009). Measuring Presence: The Temple Presence Inventory. *Proceeding of Presence 2009 : The 12th International Workshop on Presence*, 1–14. Retrieved from http://www.temple.edu/ispr/prev_conferences/proceedings/2009/Lombard_et_al.pdf

Ma, R., & Kaber, D. B. (2006). Presence, workload and performance effects of synthetic environment design factors. *International Journal of Human-Computer Studies*, *64*(6), 541–552.

Mania, K., & Chalmers, A. (2001). The Effects of Levels of Immersion on Memory and Presence in Virtual Environments: A Reality Centered Approach. *CyberPsychology & Behavior*, *4*(2), 247–264.

McMahan, R. P., Bowman, D. A., Zielinski, D. J., & Brady, R. B. (2012). Evaluating display fidelity and interaction fidelity in a virtual reality game. *IEEE Transactions on Visualization and Computer Graphics*, *18*(4), 626–633. https://doi.org/10.1109/TVCG.2012.43

Meehan, M., Insko, B., Whitton, M., & P., F. B. J. (2002). Physiological measures of presence in stressful virtual environments. *ACM Transactions on Graphics (TOG)*, *21*(3), 645–652.

Meehan, M., Razzaque, S., Insko, B., Whitton, M., & Brooks, F. P. (2005). Review of four studies on the use of physiological reaction as a measure of presence in stressful virtual environments. *Applied Psychophysiology Biofeedback*, *30*(3), 239–258. https://doi.org/10.1007/s10484-005-6381-3

Meehan, M., Razzaque, S., Whitton, M. C., & Brooks, F. P. (2003). Effect of latency on presence in stressful virtual environments. *Proceedings - IEEE Virtual Reality*, *2003–Janua*, 141–148. https://doi.org/10.1109/VR.2003.1191132

Minsky, M. (1980). Telepresence. *Omni*, *2*, 45–51.

Parenmark, G., Engvall, B., & Malmkvist, A. K. (1988). Ergonomic on-the-job training of assembly workers. Arm-neck-shoulder complaints drastically reduced amongst beginners. *Applied Ergonomics*, *19*(2), 143–146. https://doi.org/10.1016/0003-6870(88)90008-7

Peperkorn, H. M., Diemer, J., & M??hlberger, A. (2015). Temporal dynamics in the relation between presence and fear in virtual reality. *Computers in Human Behavior*, *48*, 542–547. https://doi.org/10.1016/j.chb.2015.02.028

Punnett, L., Gold, J., Katz, J. N., Gore, R., & Wegman, D. H. (2004). Ergonomic stressors and upper extremity musculoskeletal disorders in automobile manufacturing: A one year follow up study. *Occupational and Environmental Medicine*, *61*(8), 668–674. https://doi.org/10.1136/oem.2003.008979

Rosakranse, C., & Oh, S. Y. (2014). Measuring Presence: The Use Trends of Five Canonical Presence Questionaires from 1998-2012. *Proceedings of the International Society for Presence Research*, 25–30.

Santos, BS., Dias, P., Pimental, A., Baggerman, JW., Ferreira, C., Silva, S., & Madeira, J.

(2009). Head-mounted display versus desktop for 3D navigation in virtual reality: a user study. *Multimedia Tools and Applications*, *41*(1), 161.

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The Experience of Presence: Factor Analytic Insights. *Presence: Teleoperators and Virtual Environments*, *10*(3), 266–281. https://doi.org/10.1162/105474601300343603

Schuemie, M. J., Van, D. S., Krijn, M., & A.P.G., C. V. D. M. (2001). Research on presence in virtual reality: A survey. *CyberPsychology & Behavior*, *4*(2), 183–201.

Seymour, N. E., Gallagher, A. G., Roman, S. a, O'Brien, M. K., Bansal, V. K., Andersen, D. K., & Satava, R. M. (2002). Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Annals of Surgery*, *236*(4), 458-63–4. https://doi.org/10.1097/01.SLA.0000028969.51489.B4

Sharek, D. (2011). A useable, online NASA-TLX tool. *Proceedings of the Human Factors and Ergonomics Society*, 1375–1379. https://doi.org/10.1177/1071181311551286

Sheridan, T. (1992). Musings on telepresence and virtual presence. *Presence: Teleoperators and Virtual Environments*, *1*(1), 120–126.

Sims Jr, B. (2000). Safety training comes alive in virtual reality.

Slater, M. (1999). Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *8*(5), 1–13. https://doi.org/10.1162/105474699566477

Slater, M. (2003). A Note on Presence Terminology. *Emotion*, *3*, 1–5.

Slater, M. (2004). How Colourful was Your Day? *Why Questionnaires Cannot Assess Presence in Virtual …*, 1–11. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.417.4475&rep=rep1&type=pdf

Slater, M., Linakis, V., Usoh, M., & Kooper, R. (1996). Immersion, presence, and performance in virtual environments: an experiment with tri-dimensional chess. *Proceedings of the 3rd ACM Symposium on Virtual Reality Software and Technology (VRST 1996), Hong Kong, China*, (JUNE), 163–172. https://doi.org/10.1.1.34.6594

Slater, M., & Steed, A. (2000). A Virtual Presence Counter. *Presence*, *9*, 413–434.

Slater, M., & Usoh, M. (1993). An Experimental Exploration of Presence in Virtual Environments. *Department of Computer Science Technical Report No. 689*, 1–35. Retrieved from http://publicationslist.org/data/melslater/ref-269/first paper.pdf

Slater, M., Usoh, M., & Chrysanthou, Y. (1995). The Influence of Dynamic Shadows on Presence in Immersive Virtual Environments. *Virtual Environments*, (December 2012). https://doi.org/10.1007/978-3-7091-9433-1

Slater, M., Usoh, M., & Steed, A. (1994). Depth of Presence in Immersive Virtual Environments. *Presence-Teleoperators and Virtual Environments*, *3*(2), 130–144.

Slater, M., Usoh, M., & Steed, A. (1995). Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction*, *2*(3), 201–219. https://doi.org/10.1145/210079.210084

Slater, M., & Wilbur, S. (1997). A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments*, *6*(6), 603–616. https://doi.org/10.1007/s10750-008-9541-7

Slobounov, S. M., Ray, W., Johnson, B., Slobounov, E., & Newell, K. M. (2015). Modulation of cortical activity in 2D versus 3D virtual reality environments: An EEG study. *INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY*, *95*(3), 254–260. https://doi.org/10.1016/j.ijpsycho.2014.11.003

Toczek, Y. G. (2017). The influence of visual realism on the sense of presence in virtual environments The Influence of Visual Realism on the Sense of Presence in Virtual Environments by Yvonne Toczek Identity number 0923032 In partial fulfilment of the requirements for the de.

Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A., Slater, M., & Brooks, F. P. (1999). Walking > walking-in-place > flying, in virtual environments. *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '99*, 359–364. https://doi.org/10.1145/311535.311589

Usoh, M., Catena, E., Arman, S., & Slater, M. (2000). Using Presence Questionnaires in Reality. *Presence: Teleoperators and Virtual Environments*, *9*(5), 497–503. https://doi.org/10.1162/105474600566989

Vredenburgh, A. G. (2002). Organizational safety: which management practices are most effective in reducing employee injury rates? *JOURNAL OF SAFETY RESEARCH*, *33*(2), 259–276.

Wang, N., & Doube, W. (2011). How real is reality? A perceptually motivated system for quantifying visual realism in digital images. *Proceedings - 2011 International Conference on Multimedia and Signal Processing, CMSP 2011*, *2*, 141–149. https://doi.org/10.1109/CMSP.2011.172

Weiss, P. L., Rand, D., Katz, N., & Kizony, R. (2004). Video capture virtual reality as a flexible and effective rehabilitation tool. *Journal of NeuroEngineering and Rehabilitation*, *1*, 1–12. https://doi.org/10.1186/1743-0003-1-12

Welch, R. B. (1999). How can we determine if the sense of presence affects task performance? *Presence (Cambridge, Mass.)*, *8*(5), 574–7. https://doi.org/10.1162/105474699566387

Welch, R. B., Blackmon, T. T., Liu, A., Mellers, B. A., & Stark, L. W. (1996). The effects of pictorial realism, delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence: Teleoperators and Virtual Environments*, *5*(JUNE), 263–273. https://doi.org/10.1162/pres.1996.5.3.263

Wiederhold, B. K., Jang, D. P., Kaneda, M., Cabral, I., Lurie, Y., May, T., … Kim, S. I. (2001). An investigation into physiological responses in virtual environments: an objective measurement of presence. *Towards Cyberpsychology: Mind, Cognitions and Society in the Internet Age*.

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*(3), 225–240. https://doi.org/10.1162/105474698565686

Yao, F., Cui, L., Chai, S., & Zhang, G. (2013). Distributed interactive 3D combat simulation system for the army training and testing. *Control and Decision Conference (CCDC)*.

APPENDICES

Appendix A: Treatment for participants

Participant	Training	Trials 1-3	Trials 4-6	Trials 7-9	Trials 10-12	Trials 13-15	Trials 16-18
1	MN	LA	HN	MN	HA	MA	LN
2	LN	MA	HA	LN	MN	HN	LA
3	MN	HA	MN	LA	MA	LN	HN
4	HN	MN	MA	HN	LN	LA	HA
5	LN	LN	LA	MA	HN	HA	MN
6	HN	HN	LN	HA	LA	MN	MA
7	LN	HN	HA	MA	LA	MN	LN
8	MN	MA	HN	HA	LN	LA	MN
9	HN	HA	LA	MN	HN	LN	MA
10	HN	LN	MA	HN	MN	HA	LA
11	MN	MN	LN	LA	HA	MA	HN
12	LN	LA	MN	LN	MA	HN	HA
13	HN	MN	LN	HA	LA	MA	HN
14	LN	LA	MA	LN	HN	HA	MN
15	MN	HN	LA	MA	MN	LN	HA
16	MN	HA	HN	LA	MA	MN	LN
17	HN	LN	MN	HN	HA	LA	MA
18	LN	MA	HA	MN	LN	HN	LA
19	MN	MN	LN	HA	LA	MA	HN
20	MN	LA	MA	LN	HN	HA	MN
21	LN	HN	LA	MA	MN	LN	HA
22	HN	HA	HN	LA	MA	MN	LN
23	LN	LN	MN	HN	HA	LA	MA
24	HN	MA	HA	MN	LN	HN	LA
25	HN	LN	HN	HA	MA	MN	LA
26	MN	MN	MA	HN	HA	LN	LA
27	LN	HN	LN	MA	MN	LA	HA
28	MN	HA	LA	LN	HN	MA	MN
29	HN	LN	HA	MN	LA	HN	MA
30	LN	MA	MN	LA	LN	HA	HN

Appendix B: SUS Questionnaire

Scenario #: ____ Subject ID: ____

1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.

(1) Not at all. (7) Very much.

1	2	3	4	5	6	7

2. To what extent were there times during the experience when the virtual environment was the reality for you?

(1) At no time. (7) Almost all the time.

1	2	3	4	5	6	7

3. When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?

(1) Images that I saw. (7) Somewhere that I visited.

1	2	3	4	5	6	7

4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere?

(1) Being elsewhere. (7) Being in the virtual space.

1	2	3	4	5	6	7

5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By ‘structure of the memory’ consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.

(1) Not at all. (7) Very much so.

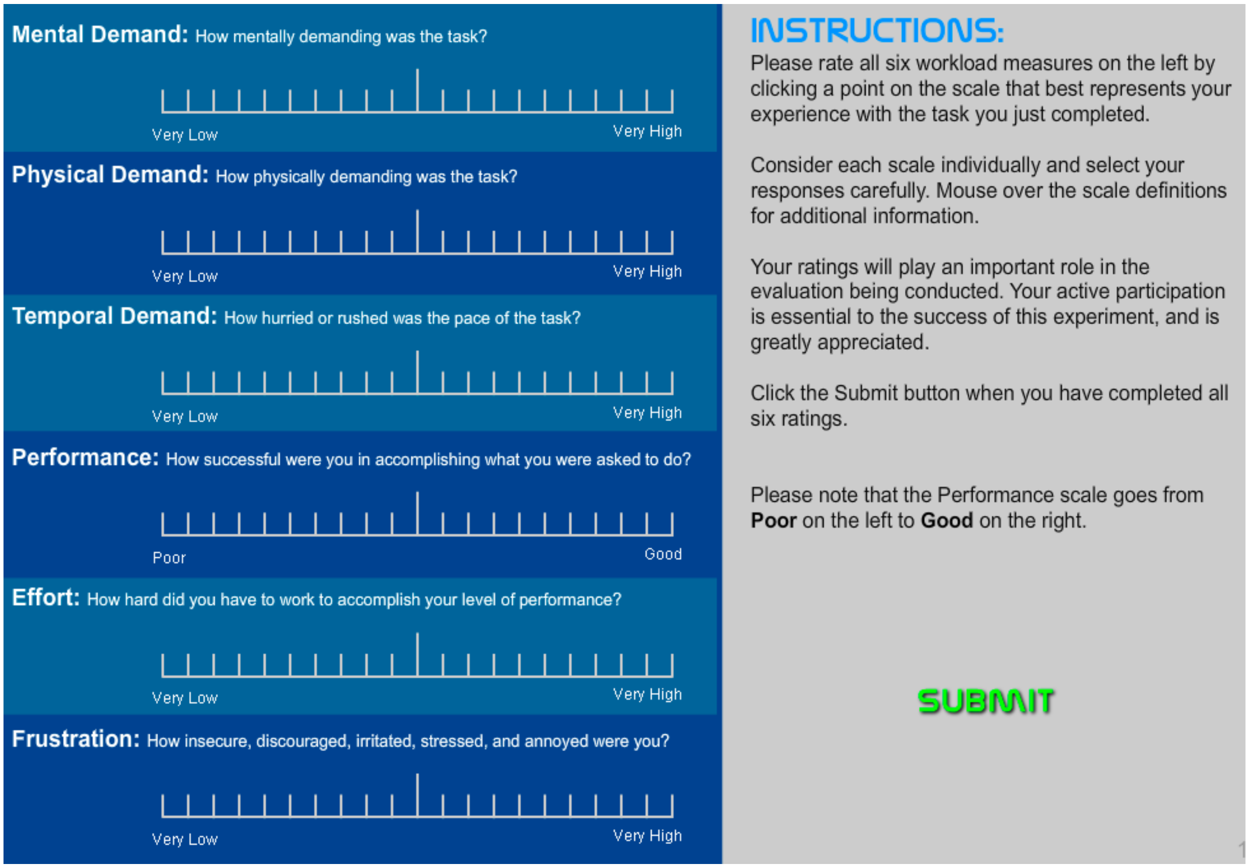
1	2	3	4	5	6	7

6. During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

(1) Not very often. (7) Very much so.

1	2	3	4	5	6	7

Appendix C: NASA-TLX



Mental Demand: How mentally demanding was the task?

Physical Demand: How physically demanding was the task?

Temporal Demand: How hurried or rushed was the pace of the task?

Performance: How successful were you in accomplishing what you were asked to do?

Effort: How hard did you have to work to accomplish your level of performance?

Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

INSTRUCTIONS:

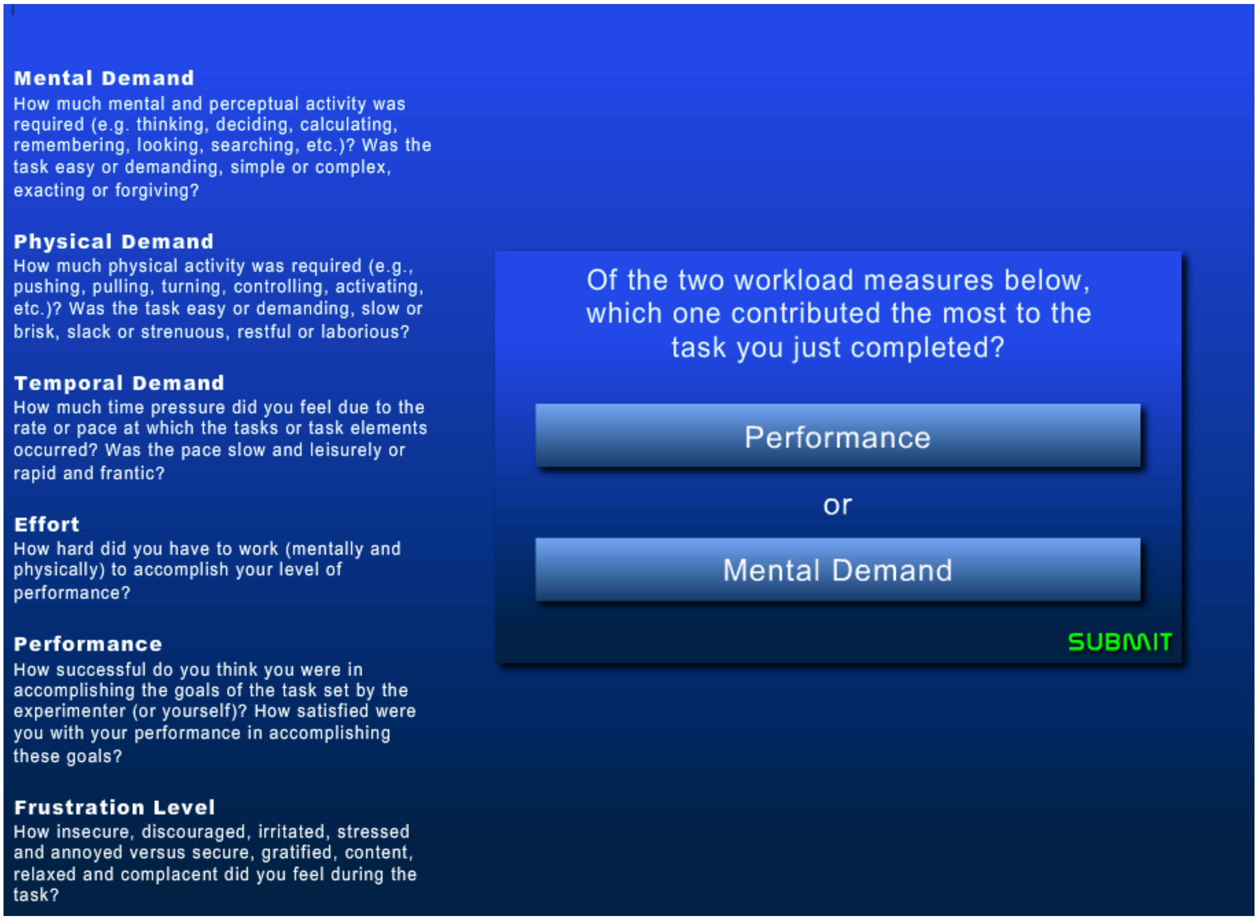
Please rate all six workload measures on the left by clicking a point on the scale that best represents your experience with the task you just completed.

Consider each scale individually and select your responses carefully. Mouse over the scale definitions for additional information.

Your ratings will play an important role in the evaluation being conducted. Your active participation is essential to the success of this experiment, and is greatly appreciated.

Click the Submit button when you have completed all six ratings.

Please note that the Performance scale goes from **Poor** on the left to **Good** on the right.



Mental Demand
How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand
How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand
How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Effort
How hard did you have to work (mentally and physically) to accomplish your level of performance?

Performance
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration Level
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Of the two workload measures below, which one contributed the most to the task you just completed?

Appendix D: Informed Consent

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study: Study of human performance and cardiac feedback in virtual reality
Principal Investigator: Tyler Rose Faculty Sponsor: Karen B. Chen

What are some general things you should know about research studies?

You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of this study is to learn how people perceive, interact, and move virtual objects represented in a virtual reality headset, and how people's brain activity varies under in virtual reality. Virtual reality is an environment with 3D graphics generated by a computer. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?

The purpose of this study is to learn how people perceive, interact, and move virtual objects represented in a virtual reality headset, and how people's cardiac activity varies under the influence of different visual feedback. (i.e., an environment with 3D graphics generated by a computer). You will be asked to perform simple manufacturing tasks in a virtual reality setting. The virtual reality setting is displayed to you through a virtual reality headset, which is a large pair of 3D goggles that is worn over the head, as well as a heart rate device to monitor cardiac activity.

What will happen if you take part in the study?

If you agree to participate in this study, you will receive a brief introduction to the study upon arrival at the lab office (Room 448 in Daniels Hall). After being introduced, you will complete a demographic questionnaire as well as an immersive tendencies questionnaire. Once the questionnaires are completed, you will put the virtual reality headset over your head and carry out some practice tasks to familiarize you with the experimental task. You will be in a standing, relaxed posture. The practice task is identical to the experimental task. The task is to place virtual objects in predefined spaces located on a moving virtual conveyor belt. There will be rest breaks between every trial and more breaks will be provided as needed. Additionally, a presence questionnaire and workload questionnaire will be administered during each rest break. Lastly, you will fill out a payment form and depart the lab. This whole session will take approximately 1.5 hours.

Risks and Benefits

There are minimal risks associated with participation in this research. You will perform arm movements that are similar to the movements made throughout the day and there is the likelihood that you will experience muscle fatigue. No more than minimal risk is expected from using the motion sensor. It is possible that you will experience visual fatigue from extended exposure to the visuals shown by the virtual reality headset. You will be able to remove the virtual reality headset and take a break after training trials. You will receive a short break after every test trial throughout the experiment.

It is also possible that you will experience motion sickness symptoms while using the virtual reality headset. Notify the researcher if signs of motion sickness or any discomfort arise, and remove the virtual reality headset and sit down until the symptoms subside. If the symptoms do not subside, you will be able to terminate your involvement in the study without penalty.

There are no direct benefits to your participation in the research. It is possible that you will gain knowledge and experience using a head-mounted display.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely in a locked cabinet and on password-protected computers in the Ergonomics Laboratory. No reference will be made to your identity in oral or written reports. Your identity will be protected by the use of a code number that is linked to the data collected from you. The video recordings will be digitized and stored on password-protected computers located in the Ergonomics Laboratory. If the video will be shown as academic demonstration, the image related to your identity (your face) would be blurred and protected.

Compensation

For participating in this study you will receive compensation at the rate of $10. If you withdraw from the study prior to its completion, you will receive compensation at a rate of $10 for the time committed to the experiment up to that point.

Emergency Medical Treatment

If you are hurt or injured during the study session(s), the researcher will contact the University's emergency medical services at 1-919-515-3333 for necessary care. There is no provision for free medical care for you if you are injured as a result of this study.

What if you are a NCSU student?

Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you are a NCSU employee?

Participation in this study is not a requirement of your employment at NCSU, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher, Karen Chen, Ph.D., Fitts Department of Industrial and System Engineering, Campus Box 7906, North Carolina State University, 1-919-515-6403.

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator at dapaxton@ncsu.edu or by phone at 1-919-515-4514.

Consent To Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Participant's signature____ **Date** _________________

Investigator's signature_____________________________________ **Date** __________________

Appendix E: Demographic Questionnaire

General Demographic Questionnaire – Study of cardiac activity during virtual reality occupational training simulation

1. Subject ID: ____________________
2. Ethnic background: (circle one)
    a. American Indian or Alaskan Native
    b. Asian
    c. Native Hawaiian or Other Pacific Islander
    d. Black or African American, not of Hispanic origin
    e. Hispanic
    f. White, not of Hispanic origin
    g. Other
3. Gender:
    a. Female
    b. Male
4. Age: _________________________years old
5. Height: _______________________[ft or cm]
6. Weight:________________[lb or kg]
7. Interpupillary distance: _____________________________mm
8. Dominant hand
    a. Right
    b. Left
9. Have you ever experienced virtual reality through a head-mounted display (HMD)?
    a. Yes
    b. No

If yes, please circle the frequency of use (per month)

Rarely (0-1 times)   Occasionally (2-4)   Weekly (5-10)   Frequently (11+)