SIMULATION TRAINING IN A VIRTUAL ENVIRONMENT OF AN OFFSHORE OIL INSTALLATION

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Simulation Training in a Virtual Environment of an Offshore Oil Installation

by

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Abstract

Emergency situations on offshore installations demand exemplary employee performance to achieve highly safe performances. Traditional training methods may effectively inform personnel of Escape, Evacuation and Rescue (EER) procedures. However, training under stressful, more realistic situations is practically impossible due to the high degree of danger involved. The objectives of this study were to determine the effectiveness of different modes of learning on task performance during simulation training (ST) in a virtual environment (VE) of an offshore oil installation. Different measures of presence (the experience of feeling located in an environment while being physically located in a different environment) were measured to investigate possible relationships between these measures and with spatial learning in VEs. Active explorers and males demonstrated superior VE task performance. Video game experience was correlated with VE task performance, whereas subjective and objective measures of presence were not correlated with each other, or with VE task performance. Future research should investigate how ST using a VE transfers to similar, real-world environments.

Key terms: Presence, Spatial Learning, Active Learning, Task Performance, Marine Environments, Escape, Evacuation and Rescue (EER)

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"When nothing seems to help, I go look at a stonecutter hammering away at his rock perhaps a hundred times without as much as a crack showing in it. Yet at the hundred and first blow it will split in two, and I know it was not that blow that did it, but all that had gone before."

—Jacob Riis

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List of Symbols, Nomenclature or Abbreviations

3-D	Three-dimensional
A	Active Group
ANS	Autonomic Nervous System
AP	Active and Passive Group
ECG	Electrocardiogram
EER	Emergency, Evacuation, Rescue
GSR	Galvanic Skin Response
HR	Heart Rate
HMD	Head Mounted Display
ITQ	Immersive Tendency Questionnaire
PNS	Parasympathetic Nervous System
PQ	Witmer & Singer Presence Questionnaire
PST	Peripheral Skin Temperature
QPR	Questionnaire on Presence and Realism
RR	Respiration Rate
SA	Situational Awareness
SNS	Sympathetic Nervous System
SS	Simulator Sickness
SSQ	Simulator Sickness Questionnaire
ST	Simulation Training
SUS	Slater-Usoh-Steed Presence Questionnaire
UCL	University College London Presence Questionnaire
VE	Virtual Environment

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Chapter 1: Introduction

1.1: Background of the Study:

Offshore oil installations are often located hundreds of kilometers from land and can employ hundreds of people at any given time. Employees may have to be flown long distances to the installation before working around highly combustible materials and heavy equipment for 12 plus hour days for two to three weeks at a time. As most installations operate 24 hours a day, 365 days of the year, employees are aware that they may be awoken from their beds in the early morning hours at a moments notice to manage an emergency situation as they wait for support from standby vessels, other installations, onshore management, or the coast guard [1]. Emergency situations on these installations can be highly complex, dynamic and often involve underspecified problems, which must be identified and resolved under time-pressure constraints while interacting with a large group of people [2]. These situations demand exemplary operator performance, despite the fact that human error generally increases as stress increases [3].

Despite technological improvements in process safety and error identification and safety and evacuation equipment, maritime accidents due to human error still represent a significant risk to the health and safety of employees [4]. Over the last three decades, several disasters have occurred on offshore installations, possibly relating to human error. In 1980, the Alexander Kielland platform in the North Sea capsized, with only one lifeboat being successfully launched as 123 of the 212 personnel onboard were killed ([5] as read in [3]). Two years later, the Ocean Ranger capsized and sank off the coast of

Newfoundland. All 84 personnel were killed, some of whom died during transfer to a vessel without proper rescue facilities ([6], as read in [3]). An explosion aboard the Piper Alpha platform in the North Sea in 1988 resulted in the death of 167 of the 236 crew on board, with many crew members dying due to unsuccessful evacuation procedures ([7] as read in [3]). In 2007, 22 people were killed on the Usumacinta platform in the Gulf of Mexico, also due in part to unsuccessful evacuation procedures. Another accident occurred in the Gulf of Mexico in 2010, when an explosion on the Deepwater Horizon drilling unit killed 11 workers. In a review of this particular accident, crewmembers described the scene onboard as being "out of control", stating that "there was a sense of urgency" and that "people were frozen up". The crew reported the evacuation as being unorganized, with lifeboats being launched prematurely and some crew members abandoning evacuation procedure and jumping off the platform. Skogdalen et al. [3] concluded that "the consequences of human error in an offshore emergency can be severe" and that "it is important that emergency drills include worst case scenarios to prepare for emergency, evacuation, and rescue (EER) operations during major accidents."

Unfortunately, it often takes disasters such as these for curative changes in safety legislation and training methods to occur. However, traditional on-site training methods meant to complement classroom teaching often take place under benign conditions: For example, an evacuation procedure may take place in the daytime with complete visibility, with no time pressure or emerging hazards to cause stress. While these methods may effectively teach personnel the required spatial and procedural knowledge regarding the installation's egress routes, it is clear that employees will not necessarily be exposed to training designed to increase participant stress. Since stress increases the likelihood of human error [3], stress exposure training (which prepares employees to perform effectively in stressful environments) is necessary to fill the current training gap. As Burian, Barshi, & Dismukes [8] (as read in [2]) stated: "The degree to which training truly reflects real-life emergency and abnormal situations, with all of their real-world demands, is often limited."

Simulation Training (ST) can be used to complement traditional training methods [4] and as a type of stress exposure training. ST complements classroom and on-site training by allowing individuals to gain "artificial" experience with dangerous and stress-inducing scenarios. Since placing employees in these scenarios in the real-world is impossible due to ethical, logistical and financial concerns [9], virtual environments (VEs) are used to allow employees to gain this "artificial" experience. While offshore installation evacuations are often caused by blowouts, extreme weather conditions or process accidents [3], there exists an infinite amount of evacuation variations that conventional training methods cannot possibly prepare personnel for. ST through the use of VEs can train personnel in these rare (but entirely possible) evacuation variations [10].

To successfully implement this type of ST in real-world offshore environments, it is crucial to determine the effectiveness of ST using complimentary VEs. Two key topics which are often thought to determine the effectiveness of ST in VEs are presence and spatial learning. Presence is often defined as the experience of feeling located in an environment (for example, a VE in which ST takes place) while being physically located in another environment [11, 12]. There is a great deal of controversy surrounding the exact definition and importance of presence and it has been studied by an assortment of academics from various research fields [13].

In an EER situation, an employee must travel to a predetermined muster station to await further instructions from the offshore installation manager. To do so, the employee must navigate a highly complex environment with many floors and hundreds of employees while being surrounded by potentially hazardous materials. To arrive at a muster station safely and efficiently, a high level of spatial knowledge regarding the installation is necessary. In ST, spatial learning occurs by navigating a VE and then encoding and subsequently retrieving information regarding the VE and one's orientation within it [14]. In VEs, the extent of spatial learning is often quantified by task performance, such as the time to complete a task or number of errors made while completing a task [13]. Improvements in task performance are considered to represent improvements in spatial learning. Thus, if an individual demonstrates exemplary task performance, that individual is considered to have a large amount of spatial knowledge about the VE, or vice-versa. Although spatial learning can be acquired through the use of maps, videos, descriptions, or navigations of the real-world environments, using a VE for ST may offer advantages in spatial learning that traditional forms of training cannot provide [15-17]. However, it is unclear whether ST involving active exploration, passive exploration, or a combination of both is the best way to acquire spatial learning in VEs.

It is intuitive to think that the sense of presence in a VE is related to task performance and thus spatial learning. Commonly, it is thought that as presence increases, task performance should concurrently increase [18-20]. It has been suggested that it is necessary to increase presence to optimize spatial learning [20]. However, it has also been suggested that a negative relationship exists, as increased presence may decrease attentional resources, therefore having a deleterious effect on task performance [18].

Others suggest that presence and task performance are not related, though increases in presence may be important for the participant's experience within a VE [19]. There is no consensus in the current literature on the relationship between presence and task performance, partly due to the large number of different methodological approaches used to investigate the relationship. Presently, it appears that the relationship between presence and task performance (and thus spatial learning) is not linear and depends on a variety of both identified and possibly unidentified factors. It is imperative to investigate both presence and spatial learning in a VE of an offshore oil installation before implementing this type of ST in a similar real-world environment.

1.2: Objectives of the Study

The objectives of this research are as follows:

1) To determine the effectiveness of different modes of learning (active learning and combined active and passive learning) on task performance during ST in a VE of an offshore oil installation.
2) To examine the relationships between subjective and objective measures of presence.
3) To investigate the relationships between measures of presence and spatial learning during ST in a VE.

1.3: Hypotheses

The following hypotheses are addressed in this study:

1) Participants who participate in active learning will perform better on task performance measurements than participants who participate in combined active and passive learning.
2) Subjective and objective measures of presence will be correlated.
3) Presence will be positively correlated with task performance, and thus spatial learning.

1.4: Significance of the Study

Establishing the mode of learning that causes the greatest increases in task performance may allow for the creation of ST protocols designed to maximize spatial learning. Determining the relationships between different measures of presence will further our knowledge on presence, and if presence and spatial learning are positively correlated in VEs, then it may be possible to manipulate the presence within the VE to maximize spatial learning. Increasing spatial learning within a VE could lead to better ST protocols. Better ST protocols may lead to increases in operator competency during EER situations, subsequently decreasing human error-related maritime accidents, thus saving resources and most importantly, human lives.

Chapter 2: Review of Literature

2.1: Introduction

This review will focus on three main topics: 1) presence, 2) spatial learning, and 3) simulation training. Firstly, the construct of presence and different approaches to measurement will be discussed. Secondly, spatial learning will be discussed using different representations and modes of learning. Studies that have used multi-task simulators (in which an individual interacts with a screen and keyboard/controller interface, often using a desktop computer) to study different modes of learning will be reviewed in depth. Thirdly, the proper implementation of ST will be discussed by reviewing research from a variety of fields. Finally, all three topics will be considered as a possible relationship between presence and spatial learning during ST will be examined.

2.2: Presence

Although presence is a central concept in VE research, the construct has been the subject of debate since investigation began in the early 1990s [12, 21]. Presence is generally defined as the experience of feeling located in an environment even when one is physically located in another environment [11, 12]. Alternative definitions were proposed by Meehan [22], who defined presence as "perceiving stimuli as one would perceive stimuli from the corresponding real environment" and Inkso [23], who defined presence as "the perceptual illusion of nonmediation". Despite the differences, all definitions of presence acknowledge that presence is a multi-dimensional (i.e. having social and physical dimensions) construct that is in part a subjective experience involving the suspension of disbelief [11, 24].

The difficulty in conceptualizing presence has made it challenging to create an operational definition of presence [25]. As noted by Youngblut [18] "presence is not mathematically defined by its constructs." This is complicated by the fact that people experience different degrees of presence, and personal characteristics such as personality, cognitive ability, and prior experience with the medium in question can affect the experience of presence [24]. The study of presence by academics in computer science, engineering, human factors, and other fields has led to a large variety of measurement techniques and approaches. Despite the inherent difficulties, the inter-disciplinary approach to presence research is not necessarily deleterious to its study. This opinion is expressed by van Baren [25], who stated that the "use of a variety of different measures can provide valuable complementary perspectives and converging evidence, thus collectively overcoming weaknesses that any single measure will invariably have." It is thought that a singular, ultimate measure of presence will be an aggregate of a variety of components, and thus will be able to address the different dimensions of presence by being modifiable based on the application [18]. Presence is typically measured using either a subjective or objective approach.

2.1.2: Subjective Measures of Presence

Subjective measurements often take the form of questionnaires and are the most frequently used measurement tool of presence. Questionnaires have high face validity (Sheridan [26] argued that presence was a subjective experience), are relatively easy to administer and analyze, do not interrupt the participant's VE experience, and are sensitive to varying levels of presence. However, since questionnaires are retrospective in nature, a recency effect may be demonstrated: events closer to the end of the participant's VE experience may be emphasized greater than the events closer to the beginning of the experience [13]. Issues of questionnaire comprehension have been raised by Youngblut [18]. Participants may become fatigued or bored while filling out long questionnaires, and individual differences caused by prior experiences may influence questionnaire responses [23]. Furthermore, demand characteristics created by the researcher, experimental design or laboratory environments may bias participant responses [13].

Witmer [11] developed the 19- item, 7-point scale Presence Questionnaire (PQ) as a subjective measure of presence. The PQ was developed by identifying four categories of factors associated with presence in the literature: 1) control factors, 2) sensory factors, 3) distraction factors, and 4) realism factors. Witmer [11] used the PQ in two experiments using a simple VE (psychomotor tasks) and two experiments using a relatively complex VE (small room navigation). Three subscales (Involved/Control, Natural, and Interface Quality) were identified. An internal consistency of $\alpha = .81$ was found, along with correlations with constructs associated with presence, Simulator Sickness Questionnaire (SSQ) scores, and Immersive Tendency Questionnaire (ITQ) scores. Significant correlations with performance of psychomotor tasks and spatial knowledge were found in some, but not all experiments. The sensitivity of the PQ was questioned by Usoh [27], who found that the PQ could not distinguish between real and virtual conditions. However, Youngblut [28] found that the PQ was sensitive to different conditions in several experiments. Since the PQ is the most frequently used subjective measure of presence, it would appear to be advantageous to researchers to include it, even though other presence questionnaires such as the Slater-Usoh-Steed (SUS) Questionnaire, the University College London (UCL) Presence Questionnaire, and the Questionnaire on Presence and Realism (QPR) are included in the data collection. Since presence has been studied by many different groups and over many different theoretical backgrounds, universal use of the PQ (which has been shown to be sensitive, reliable, and valid [13]), allows for comparison across studies via a systematic review or meta-analysis, potentially providing researchers information on how to increase presence in VEs.

The ITQ was developed by Witmer [11] to complement the PQ by measuring the tendency of an individual to be involved or immersed. The items were developed to identify individual differences that may affect how much presence an individual experiences in any given situation. Like the PQ, the ITQ is scored on a 7-point scale. Witmer [11] stated that both involvement (the psychological state experience due to focusing energy and attention on a coherent set of stimuli) and immersion (a psychological state in which one is enveloped by, included in, and interacting with a continuous stream of environmental stimuli) are necessary for experiencing presence, and that "a valid measure of presence should address factors that influence involvement as well as those that affect immersion". The ITQ should be positively correlated with the PQ, as individuals who tend to become involved in various activities should report more presence in a VE. In a series of four experiments, Witmer [11] found an internal consistency of $\alpha = .75$, and a small, but significant correlation between ITQ and PQ scores.

The SSQ (currently considered the gold standard in measuring simulator sickness [SS] [29] is a subjective corroborative measure of presence, in that it does not directly assess presence, but may be correlated with or support the validity of the PQ [13]. The 16-item, 4-point scale questionnaire divides items into three symptom clusters: 1) oculomotor effects, 2) disorientation, and 3) nausea. While there is generally no indicated symptomatology [30], it is important to limit SS symptoms as much as possible to avoid participant discomfort and dropout. There usually is a significant negative relationship between SSQ scores and subjective presence ratings [18], as it is thought that SS distracts the user from the VE experience[13]. Although SS does not require motion [29], it produces similar symptoms (although generally less severe and of lower incidence) as motion sickness, and is thought of as a byproduct of adverse visual-vestibular interactions caused by poorly-designed simulation technology. Symptoms tend to increase with the intensity and duration of a VE experience, but the incidence of symptoms tends to decrease with repeated exposures [18]. Risk factors for experiencing SS include: prior history of motion sickness, pathology of the vestibular systems, and fatigue, sleep deprivation, or an otherwise unusual state of health [29]. SS symptoms can be decreased by keeping sessions under one hour in length, ensuring a minimum of 24 hours between sessions, and decreasing the field of view of the simulated environment. Currently, no clear relationship exists between age and experience in real-world environments in which the simulated environment is based. However it appears that females may experience SS more often than males [29]. Inter-relationships between simulator sickness, presence, and task performance have not yet been clearly described and are likely to be complex [18].

2.1.3: Objective Measures of Presence

Objective measures of presence are used to combat some of the aforementioned problems of subjective measures by measuring unconscious participant responses to a VE that are theoretically related to the experience of presence. Objective measures utilize the response similarity approach to presence measurement, which asserts that as the fidelity of a VE increases, responses to VE stimuli or events will become increasingly similar to responses in a similar, real-world environment [25]. Since presence is generally described as the experience of feeling located in an environment even when one is physically located in another environment [11, 12], an increased physiological response to stimuli during a VE exposure would seem to indicate that an individual is more "present" in that VE [22]. Common objective physiological measures of presence include heart rate (HR), galvanic skin response (GSR), and peripheral skin temperature (PST). Respiration rate (RR) has been suggested by Inkso [23] as another possible physiological measure of presence; however little research using RR to investigate presence exists (Wiederhold [31] measured but never reported RR).

Objective presence measures are often continuously recorded throughout a VE exposure, thereby eliminating the reliance on participant's memories and allowing researchers to investigate the time-varying qualities of presence. The use of physiological recording systems during VE exposure attempts to avoid participant and researcher biases, and can be relatively unobtrusive provided the participant is given time to get used to the equipment and is unencumbered during the VE exposure. However, the validity of using physiological signals as an objective measure of presence is questionable. Vastly different stimuli can produce similar physiological responses, and these responses may be sensitive to factors that do not relate to presence. Thus, some researchers consider physiological recording to be a(n) [objective] corroborative measure of presence and not a direct measure of presence per se [13, 23]. The investigation of presence via objective physiological measurements is usually accomplished by monitoring autonomic nervous system (ANS) responses to VE exposure.

2.1.4: The Autonomic Nervous System

Homeostasis is the ability of the body to maintain a stable internal environment. The role of the ANS is to maintain and regulate homeostasis. In the brain, the ANS is located in the medulla portion of the brain stem and is centrally controlled by the hypothalamus. While most ANS functions are unconsciously controlled (i.e. respiration), the ANS can be somewhat consciously controlled (i.e. momentarily stopping respiration to hold your breath underwater), as the hypothalamus receives inhibitory inputs from the cerebral cortex and limbic system [32] and [33].

The ANS has two complementary branches which often oppose each other by acting on effector organs: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS is responsible for the "fight-or-flight" response, which mobilizes the body's resources to deal with an impending threat or stressor. SNS activation results in increased HR and strength of myocardial contraction, peripheral blood vessel constriction (causing decreased peripheral skin temperature), bronchiole dilation (causing increased RR), increased perspiration, decreased digestive and urinary output, pupillary dilation and increased glucose metabolism. Conversely, the PNS is responsible for the "rest-and-digest" response, which prepares the body to rest and rebuild. PNS activation results in decreased HR and strength of myocardial contraction, peripheral blood vessel dilation (causing increased PST), bronchiole constriction (causing decreased RR), increased digestive and urinary output, and pupillary constriction [22, 32].

2.1.5: Peripheral ANS Recordings

Peripheral (HR, GSR, RR PST) measures of the ANS are the most commonly used physiological objective measures of presence. HR represents the number of heart beats per minute, and is typically measured by using an electrocardiogram (ECG). GSR (also referred to as skin conductance) measures the change in conductivity of the skin due to perspiration by placing electrodes over the fingertips [23]. RR represents the number of breaths taken per minute, and is often determined by placing a strap across the chest and measuring expansion/contraction cycles. PST changes are a result of changes in peripheral blood flow. PST is generally recorded by placing a small thermocouple on the palmer aspect of the hand. The thermocouple is usually placed on the fingertips; however this may not be possible if a participant requires any significant amount of finger dexterity to control their exposure in a VE. Although previous studies [22] have noted that participants reported forgetting about physiological sensors during VE exposure, it is reasonable to conclude that care must be taken to reduce the amount of fingertip sensors when using a multi-task VE in which a participant must interact with a keyboard, joystick, or video game controller. Restriction of motion may lead to a decrease in interface interaction and controller naturalness, potentially decreasing the experience of presence. Future research is necessary to investigate the effect of recording from different areas on the fingertips and palmer aspect of the hand. Another problem is that PST has a much slower response time compared to HR, GSR, and RR, due to both physiological and hardware (sensor) lag time. Changes in PST may take several (up to five) minutes to reach their peak. Thus, PST changes may not be apparent in short duration VE exposures and averaging PST over the full exposure length may provide more valid data than simply averaging PST immediately before or directly after a VE stressor or event [22, 23].

Wiederhold [33] recorded HR and GSR during a six-minute simulated airplane flight using a head mounted display (HMD). 72 participants wore headphones that emitted realistic noises, and vibratory sensations were delivered to the participant's chair using a subwoofer. GSR positively correlated with the subjective presence questionnaire scores, whereas HR negatively correlated with questionnaire scores. The authors hypothesized that since HR decreases have been correlated with the orienting response to a novel stimulus, the well-immersed participants who had no fear of flying reacted to an unexpected, novel stimulus. Alternatively, since HR did not differ between phobics and non-phobics, it is possible that the HR measure used in this study was simply not sensitive enough to illustrate between group differences.

Meehan [22] conducted a series of three experiments using HR, GSR and PST to investigate presence in a VE which used a HMD. In all experiments, a non-stress inducing room (referred to as the "training room") and a danger-of-falling, stress-inducing room (referred to as the "pit room") were used. In their first experiment, 10 participants were exposed to the pit room three times per day for four separate days. In their second experiment, 52 participants were tasked to walk to the edge of a platform in the pit room. In one session, participants were forced to stand on a real 1.5 inch ledge while looking over the edge of the platform. In another session, no ledge was present. In their third experiment, 33 participants entered the VE four times and were presented with a different frame rate (10, 15, 20 or 30 frames per second) each time. HR and GSR were significantly higher, and PST was significantly lower in the pit room in all three studies. HR, GSR, PST and presence questionnaire scores mostly decreased (although not always significantly) with multiple exposures to a VE. HR, GSR, and questionnaire scores were significantly higher with the wooden ledge than without it. HR was significantly higher when presented with a 30 frames per second frame rate as compared to 15 frames per second frame rate. HR correlated best with questionnaire scores, and was the most sensitive physiological measure, in some cases more sensitive than the questionnaires. GSR also was positively correlated with questionnaire scores. No differences in PST were reported, which the authors attributed to the short duration of VE exposure. HR was the most sensitive physiological measure and was more sensitive than many of the self-reported measures. HR also correlated best with reported presence measures.

2.2: Spatial Learning

To navigate consistently and effectively throughout a VE, spatial learning must occur. Research in the area of spatial learning is concerned with how people construct mental representations of their environment [34]. In order for spatial learning to occur, one must encode and retrieve information about the surrounding environment and their orientation within that environment. Spatial knowledge can be acquired through the use of maps, photos , verbal descriptions, or through the negotiation of real-world environments or VEs. VEs contain similar visual and auditory sensations as in real-world environments, and some VEs may even contain similar kinesthetic and proprioceptive information through the use of full-mission simulators [14]. It appears that spatial knowledge acquired in a VE is similar to spatial knowledge acquired in real-world environments [14, 35]. The major advantage of using VEs to enhance spatial learning is that sensory input can be carefully controlled by eliminating distracting, non-relevant features in the environment. These unwanted features may distract some of the participant's attention, which is crucial in the early stages of spatial learning [15-17].

2.2.2: Route and Survey Representation

Siegal [36] (as read in [37]) described spatial learning as a process in which individuals progressively move from an egocentric (referred to the viewer) to an exocentric (referred to external landmarks in the environment) frame of reference. It appears that spatial knowledge of large environments is organized into a route-type representation (route map) or a survey-type representation (survey map). Route maps represent the environment in an egocentric frame of reference, reflecting the individual's navigational experiences in the environment. In contrast, survey maps represent the environment in an exocentric frame of reference, with distant places being linked together to form a coherent global overview of the environment [35]. Shemyakin [38] (as read in [34]) thought that route maps developed first, and then survey maps developed once the individual acquired enough spatial knowledge to develop a panoramic representation of the environment. This is supported by the fact that spatial knowledge of an environment is improved as the frequency and duration of exploration increases [34]. Siegal [36] (as read in [37]) described three distinct phases of spatial learning. In the first phase, landmarks and locations are encoded, and routes between these landmarks are learned in the second phase. In the third and final phase, these routes become integrated into representations that provide an overview of the environment, providing survey knowledge. However, this rigid progression is not always supported [37], and survey maps may not develop at all in some environments. Survey maps increase wayfinding performance in complex environments where it is difficult to orient oneself [35], and facilitate the use of shortcuts through the environment ([39] as read in [40]).

However, constructing a survey map may not be necessary when navigating simple environments and a survey representation does not improve performance in some tasks such as pointing to an unseen target. The nature of the environment (i.e. an open or closed and a small or large environment) can influence spatial learning and subsequent route or survey representation [35].

2.2.3: Active and Passive Learning

Active exploration occurs when visual stimulation is generated by the motor activity of an individual. Often, a joystick, keyboard, or video game controller is used, creating a tight linkage between self-motion sensory information and motor activity. Visual-motor information, control of action, and decision of action are involved. Passive exploration occurs when the visual stimulation generated by the exploration is not produced by the motor activity of the individual. The individual is passively led through an environment and is only subject to the visual stimulation relative to the exploration [41].

There are many observational studies investigating the effects of active and passive exploration of an environment. When children actively explore a playhouse, they demonstrate a more survey-type representation when compared to children who are passively led around or carried by their parents ([42] as read in [43]). Appleyard [44] (as read in [14, 37, 41]) examined individuals living in urban areas that travelled via different modes of transportation. Bus drivers (or those who actively explored the environment) tended to draw more representative maps of the urban environment as compared to bus passengers (or those who passively explored their environment). Maguire [45] (as read in [43]) suggested this active advantage is further demonstrated by taxi drivers, who have even greater survey knowledge of their environment, presumably because they navigate novel routes. However, some suggest and/or argue that passive learning should have an advantage in some instances, arguing that passive exploration creates less strain on important attentional resources [14].

It is often thought that active exploration is superior to passive exploration in its ability to facilitate survey representations of the environment. However, the current literature suggests a tenuous link between different exploration modes and the construction of survey representations. Procedural differences and changes in VE design make it difficult to compare results across studies, since VE technology is always improving. Furthermore, some argue that individual differences and attention may interact with active-passive differences, making it even more difficult to compare. Many studies have investigated the effects of mode of learning in VEs, however only those involving a multi-task simulator (i.e. desktop computer-based) will be reviewed in depth.

2.2.4: Active and Passive Learning in Multi-Task VEs

Peruch [34] divided 18 participants into 1) active exploration, 2) passive exploration, and 3) snapshot exploration (participant saw a series of still frame pictures from the same path as the passive group) groups. All participants reported that the active condition was the easiest, while the majority of participants reported that the snapshot condition was the most difficult and required the most attention. The active exploration group had significantly shorter times on a wayfinding task throughout the environment, while there was no significant difference between the passive and snapshot groups in wayfinding task performance. There was a significant correlation between wayfinding task performance and spatial knowledge as described by participant reports and drawings. Thus, the active group participants acquired the most spatial knowledge. The authors hypothesized that the active group might have had a greater number of possibilities in which to learn the environment and solve the task as compared to the passive groups, which is discussed by Charstil [43]. Alternatively, the authors suggested that active exploration allowed participants to construct a more accurate internal representation of their environment, possibly because of increased hand sensorimotor activity in the active group.

Wilson [37] completed two experiments using different combinations of active and passive learning. In their first experiment, 72 participants were divided into: 1) active with keyboard interaction, 2) active with no keyboard interaction, 3) passive with keyboard interaction, 4) passive with no keyboard interaction, and 5) control groups. No significant pointing task differences were found between active and passive participants, or between participants who interacted with the keyboard and those who did not. In their second experiment, 36 participants were randomly divided into 1) active, 2) passive and, 3) control groups. The passive exploration group made significantly fewer errors than the control group, however, there were no significant differences in errors made between the active and passive or active and control groups. There were no significant differences between groups in the time taken to find target objects. The authors suggest that the lack of differences between conditions may be attributable to the fact that all participants had to pay attention to the spatial properties of their environments to locate the targets. The authors concluded that if spatial learning does indeed benefit from active exploration in a multi-task VE, then the effect is probably small and difficult to detect.

In a series of experiments, Christou [40] investigated the role of view dependence in scene recognition after active or passive learning. 32 participants were divided into 1) active exploration and 2) passive exploration (who watched a recording of the active explorations) groups. There were no significant differences between active and passive groups view recognition. The authors suggested that the lack of consensus in the literature in active-passive exploration studies may be due to task-specific differences, or to different degrees of difficulty when using motion-input devices.

Gaunet [41] divided 48 participants into 1) active exploration (which explored the environment while being instructed by an experimenter), 2) passive exploration (which observed a pre-recorded video), and 3) snapshot exploration (which observed pre-recorded static images of the path taken by the passive group) groups. There were no significant differences in scene recognition or on a pointing towards the origin task between groups. The snapshot group performed significantly worse reproducing the distance between the origin and end point on the drawing task, while there were no significant differences between the active and passive groups. The authors concluded that continuous stimulation during visual exploration is important for reproducing the path of travel through an environment. Since the active group in this study was directed on what route to take through the environment by an experimenter, the authors suggest that the act of planning action may be the defining factor relating to any benefit from active exploration.

Carassa [35] divided 20 male participants into 1) active and 2) passive groups.70% of the active group and 20% of the passive group successfully performed the wayfinding task, and analysis of the paths taken showed that the active group adopted more efficient strategies during the wayfinding task. There were no significant differences between groups in the pointing towards the origin task. A survey-type organization characterized the environmental maps drawn by 50% of the active group and 30% of the passive group. The authors stated that individual differences may have confounded this result, as all of those with survey-type organization in the active group had good scores on the wayfinding task, whereas none of those with survey-type organization in the passive group had good scores on the wayfinding task. The authors concluded that the differences in task performance caused by active and passive exploration are likely due to different spatial representations, as active explorers tend to construct more survey-type representations.

Peruch [14] conducted two experiments which investigated the transfer of learning from exploration in a multi-task VE to a similar, real-world environment (a college campus). In their second experiment (their first experiment was confounded by an additional learning opportunity for some participants), nine participants were divided into 1) active and 2) passive groups. After exploration, the participants were tested on spatial learning characteristics in the real-world college campus. No significant differences were found between the VE and the real-world environment in directional errors, or estimates of straight-line and shortest path distances. Although there was an advantage for those in the active learning group on making distance estimates, the authors stated that they believe the outcome of active-passive experiments is dependent on procedural variables such as the features of the VE, the type of test administered, and the type of measure employed. The authors hypothesized that "attention may be a more important factor than interactivity", and that an active advantage may only be present if the passive observer does not pay enough attention to their route.

In a review of spatial learning, Charstil [43] discussed potential limitations of the current literature. The authors assert that any advantage of active learning is not evident while using multi-task VEs due to reduced idiothetic (efferent, proprioceptive, and vestibular) information. Even if idiothetic information is not increased through the use of HMD's or other technology, studies by Peruch [14, 34] and Carassa [35] showed an (albeit sometimes slight) advantage for active learning. While studies by Wilson [37], Christou [40] and Gaunet [41] did not show any differences between active and passive learners, it is important to note that none of these studies showed any specific advantage for passive learning over active learning. It would thus seem appropriate for those who want to enhance spatial learning to encourage active exploration, since active learning will increase spatial knowledge to at least the same degree and perhaps more so as passive learning, even without idiothetic information.

Often, differences in attention are used to explain results in active-passive learning experiments [14, 37]. Charstil [43] stated that "active-passive differences appear when attention is directed to non-spatial aspects of the environment", thus claiming that passive explorers learn equally as well as active explorers when they attend to spatial properties of the environment to the same degree. According to the authors, the hypothesis that greater environmental interaction during active exploration increases attention to spatial properties is not supported by the literature. While this may be true, it seems that no research has directly tested this hypothesis. Therefore, the fact remains that directing attention to spatial properties may be more difficult during passive exploration. When exploring an environment, those who can plan and make decisions about their own routes can test how the consequences of these actions affect their resulting view of the environment. Increased autonomy over their routes may help drive attentional allocation [43] and help participants to organize their representation of the environment in a way that is easy to internalize. Increased attention during exploration may account for an active exploration advantage, which is present even in multi-task VEs without idiothetic information.

Charstil [43] argued that "it is important to match the views seen by the participants to the greatest extent possible". They reason that if active participants are allowed to freely explore the environment while passive participants are guided through designated routes, the active group may have more exposure to the VE, thus making comparisons between the two groups uncontrolled. They recommended that passive exploration participants should be exposed to playback from active participant's exploration, thus equating the visual input between groups. This appears to be valid while designing experiments that are strictly for the advancement of knowledge in the field of spatial learning. However, if an additional objective of an experiment is to generalize their results so that those in industry may implement similar VEs, then equating the visual input in this fashion does not seem to be ecologically valid. Industrial environments typically have pre-planned egress routes, which provide the safest means of evacuation in case of an emergency [3]. For training purposes, these designated routes would likely be implemented in any passive exploration. Thus, researchers should be careful to design their experiments to fit their target audience(s), and to be mindful of the ecological validity of their design.

Waller [46] emphasized the role of individual differences in spatial learning in VEs. He found that spatial visualization skills, orientation skills and interface proficiency significantly correlated with spatial learning in a VE. He also found that effects of gender on spatial learning are likely to interact with spatial ability and interface proficiency. If possible, researchers should measure these variables, as they may be a source of between-group variation, and a thus possible explanation of between-group differences.

2.3: Simulation Training

ST refers to the acquisition of cognitive or psychomotor skills through the use of a VE [16]. Typically, ST involves placing an individual in a VE that closely resembles their work environment. The VE is either a full-mission simulator (in which the individual is physically immersed in the environment, often using a HMD) or a multi-task simulator [9]. Individuals are instructed to treat the VE as they would a real-life environment and their ability to safely and effectively perform tasks (such as operating on a patient or evacuating a building) is evaluated.

ST has been implemented in a vast array of fields, including but not limited to engineering, education, economics, medicine and the military [47]. Over the past several decades, the aviation industry has consistently used ST more than any other safety-critical industry [2]. Marine-based industries have recently begun to emulate the training protocols of the aviation industry by researching and implementing ST. The oil and gas industry is of particular interest because of the conditions regarding the offshore installations used for the extraction, processing and storage of oil and natural gas.

2.3.2: Implementing Simulation Training

The aviation industry spearheaded the first investigations of the effectiveness of ST as a preventative strategy to increase employee safety and as a form of stress exposure training. Hytten [48] interviewed the crew of a Sea King Rescue Helicopter, which crashed into the frigid waters of Norway during the winter season. Of the six crew members, five survived. Four survivors had prior experience with ST, while the deceased crew member did not. The crew reported that ST had allowed them to stay calm during the crash, and avoid panicked reactions. The crew also communicated that ST had allowed them to anticipate what would happen during the crash (i.e. how fast water would rush into the cockpit), and what the proper steps were to safely exit the aircraft (i.e. to not come up for air in the oil-polluted vicinity of the crash). The main benefit of ST reported was increased self-efficacy in their evacuation abilities. This caused the crew to form a stimulus and response expectancy based on their training; they truly believed that if they stayed calm and executed their training, then they would successfully evacuate.

The increased self-efficacy due to ST may have contributed to increased situational awareness (SA). Saus [4] defines SA as "an individual's perception, understanding and projection of a complex environment." High levels of SA allow individuals to correctly perceive, rationally comprehend and accurately predict events in the near future during navigation-based tasks. If an individual has a high level of SA in an emergency situation, they are more likely to detect critical environmental signals, determine what actions need to be taken to ensure survival and then anticipate the consequences of these actions. Experience in emergency situations is positively correlated with the ability to achieve and maintain SA [4]. Since all surviving crew members in Hytten's [48] study demonstrated optimal disaster behavior, ST may work by increasing individuals SA in emergency situations, which in turn reduces the likelihood of human errors, thereby increasing the safety of workers in marine environments.

Even if employees have been trained in a particular emergency situation, the knowledge and skills obtained during training may have degraded over time. Possible environmental and dynamic hazards render successful evacuation of an offshore installation to be an extremely complex task. Complex tasks require greater organization, which refers to the sequencing of a series of subtasks. Since increasing task complexity generally means faster skill degradation, it is reasonable to assume that much of the emergency response training may be forgotten over time. O' Hara [49] studied the effects of watchkeeping skill loss in a marine cadets using ST. The cadets initially experienced ST and were evaluated on their performance of the following skills in a real-world environment: 1) general watchkeeping, 2) watch relief, 3) navigation, 4) collision avoidance, 5) equipment test, and 6) arrival preparation. The cadets were then divided into two groups: one group received "skill refresher" ST six months after the initial training period, while another group received no such training. Nine months later, both groups of cadets were evaluated on their performance in the aforementioned watchkeeping skills. Watchkeeping skills declined over the nine month interval. ST improved watchkeeping skills, and 30 minutes of refresher training using the simulator was effective in mitigating skills loss in five of the six watchkeeping skills. The author notes that all of these skills are considered routine, and none would be classified as emergency skills. If routine skills diminish significantly over a nine month period, then it is reasonable to suggest that emergency skills may decline even more rapidly, since stress impairs cognitive processes ([50] as read in [3]). Thus, a major application of ST could be to implement brief, routine, recurrent training of skills taught either in the classroom, on-site, or using simulation itself.

Tichon [51] stated that "The use of simulator technology alone cannot ensure a successful training outcome without prior consideration of the best use of its features." Ideally, ST should maximize the information yield while minimizing the technical skills required for interacting with the VE interface ([52] as read in [47]). VEs need a certain level of fidelity (realism) in order to be effective [9], however there is a debate over the level of fidelity required to render ST effective. While photorealistic VEs may provide for a more immersive experience, focusing too much on photorealism can lead designers to ignore the most important part of ST in a VE: the re-creation of tasks which are performed in real-world situations [51]. Clearly a balance must be achieved: simulators must be realistic enough to create immersive experiences, but they must also reproduce realistic tasks and operational scenarios.

Gallagher [16] discussed the optimal application of ST. Prior to ST, conventional training methods consisting of classroom and on-site training should occur first. These training methods effectively educate individuals in the procedural and knowledge-based skills necessary for optimal performance in emergency situations. ST should then be used to assist in the formation of psychomotor and cognitive skills acquisition in the context of an emergency scenario. Individuals should then practice these emergency scenarios in an interval fashion to cognitively consolidate their learning skills. The emergency scenarios should be configurable based on difficulty and should become progressively more difficult as an individual acquires skills and experience in the scenarios. After sufficient practice (which will be specific to the individual), individuals should attempt a benchmark test, made based on criterion performance standards. After the test, individuals should be given specific, measureable feedback on their performance with an emphasis on breaking each task down into its essential components. The most valuable feedback in ST is the frequency and severity of errors made. The use of a benchmark performance tests allows for the creation of a competence assurance regime [9]. This approach allows ST to be used as a preventative strategy to increase marine safety, as individuals are exposed to stress-inducing situations and are allowed time to develop self-efficacy and SA in these scenarios.

Salas [53] stated that "Preparing people for performance in complex environments requires a complex approach to training." ST can complement traditional training methods by providing the element of complexity caused by stress-inducing and dangerous environments. However, ST must be properly implemented if this element of complexity is to be provided. According to Gallagher [16], the question one should ask when implementing ST is not: "Is the ST as realistic as possible?"—rather, the main question should be: "Does the ST train the appropriate skills and create enough SA so that individuals will be able to safely and effectively perform the task in a real-world environment?"

2.4: Is There a Relationship between Presence and Task Performance During ST?

A positive relationship between presence and task performance (and thus the extent of spatial learning) in VEs has long been assumed; however, there is no consensus in the current literature on such (if any) relationship. The most frequently used measures of task performance are the time taken to complete a task and the number of errors made during task completion [13]. In a review of presence in VEs by Youngblut [18], 51% of the studies included found a correlation (with the majority of them being positive) between presence and task performance. However, many of these tasks are simple in nature [18] and do not compare to tasks performed in multi-level complex VEs. Surveying the literature for trends is difficult due to the wide range of measurement approaches and VEs used to study the relationship. Further compounding the problem is changes in VE technology have occurred so rapidly that the VEs of today do not nearly resemble the VEs used even five years ago, let alone 10 or 20 years ago when a many of the studies on the relationship were published. Consequently, the current literature on the relationship between presence and task performance (and thus spatial learning) may not be generalizable to today's multi-level, complex VEs.

It was often thought that the very reason VEs were useful for ST was due to a high level of presence that was induced by the VE. Indeed, the notion of increasing presence to increase spatial learning within a VE has appreciable face validity [18, 20]. Theoretically, a high level of presence should increase task performance since positive transfer between two tasks increases as long as the training and transfer tasks are structurally similar [20]. If the relationship has face and theoretical value, then why is a positive relationship unsupported by the current literature? Slater [19] argued that beyond face value, there is no reason to expect presence to improve task performance in a VE, as presence is merely concerned with the match between a person's behavior in a VE and the same person's behavior in a real-world environment, not with how the person performs in an environment.

Slater [19] provides an alternative hypothesis on the importance of presence: "In our view, presence is important because the greater the degree of presence, the greater the chance that the participants will behave in a VE similar to their behavior in similar circumstances in everyday reality." The authors suggest that presence is crucial in VEs where the goal is for participant's to behave appropriately in the VE and then transfer the skills learned in the VE to the real-world, such as firefighters or surgeons. Thus, even if presence and task performance are unrelated, it appears that presence is a key factor when designing VEs used for stress exposure training.

The relationship between presence and spatial learning during ST is complex and likely to depend on a variety of factors, including the definition of presence used, the measurement approach taken, the VE, and participant characteristics [18]. Welch [54] suggests that the relationship is task dependent, with presence facilitating some tasks, hindering others, and having minimal effects on the remainder. Ultimately, continuing research is necessary to determine the importance of presence and the presence-task performance relationship in ST.

2.5: Summary of Review of Literature

While the exact definition of presence has been a subject of debate, presence is typically measured using a subjective (i.e. questionnaires) or objective (i.e. physiological measures) approach. Research in the area of spatial learning is concerned with how people construct mental representations (i.e. exocentric or egocentric) of their environment. Active exploration may lead to enhanced spatial learning compared to passive exploration, possibly due to increased attention. Researchers must be mindful of the ecological validity of their design when conducting spatial learning studies. ST often involves placing an individual in a VE that closely resembles their work environment. If properly implemented, ST can be used as a complement to traditional training methods and as a form of stress-exposure training. The common assumption of a positive relationship between presence and task performance (and thus the extent of spatial learning) in VEs has long been assumed. However, the current literature does not fully support this relationship as it is likely complex and VE dependent.

Chapter 3 : Methodology

3.1: Experimental Overview

An independent groups (between-participants) experimental design was used. Participants were randomly assigned to one of two groups: 1) an active exploration group (A) and 2) an hybrid active and passive exploration group (AP). Participants were required to attend four sessions (three training sessions and one testing session) on four separate days, with a minimum of 24 and a maximum of 48 hours between sessions. The first training session for each participant was either Monday or Tuesday, and the testing session was either Thursday or Friday. Training sessions occurred between 0900 and 1800 hours, while testing sessions occurred between 1200 and 1800 hours. The first training session lasted approximately 50 minutes (Figure 3-1), the second and third training sessions lasted approximately 35 minutes (Figure 3-2), and the testing session lasted between 45 and 70 minutes (Figure 3-3). The total exploration time for each group was 30 minutes per training session, for a total of 90 minutes of exploration.

3.2: Participants

46 participants volunteered to participate in this study. Participants were verbally informed of all procedures and the overall goal of the experiment, but were naïve concerning the specific hypotheses and testing conditions. All participants signed a written informed consent form (Appendix A) prior to participation. None of the participants had previous experience with the VE used in this experiment or with navigating the real-world environment (i.e. offshore oil and gas installation) used within

the model of the VE. During all training and testing sessions, participants were instructed to stay on task for the duration of the session. Prior to the testing session, participants were instructed to refrain from exercise, smoking and caffeine for four hours, alcohol for 24 hours, and fasting for greater than two hours. During the testing session, participants wore a cotton t-shirt, long pants, and full shoes. No participants reported any neurological or psychiatric diseases, previous head trauma, specific phobias, or sensory or cognitive impairments. All participants had normal vision or corrected-to-normal vision. This study was approved by Memorial University of Newfoundland's Interdisciplinary Committee on Ethics in Human Research (ICEHR).

3.3: Materials

A graphic PC-based desktop workstation was used to create a VE of a complex, nine-level three-dimensional (3-D) offshore oil installation (see Figures 3-4 and 3-5). The VE was custom-designed and written in C++ in Microsoft Visual Studio 2010. An OGRE 3D graphics engine, FMOD audio library, NVIDIA's PhysX physics library, and the Boost C++ libraries were used to provide a first-person viewpoint in the VE. The VE was created by two 3-D artists using Autodesk SoftImage software, working from blueprints, video and photo references, and not-to-scale floor plans and safety maps. An approximate scale of 1:10 (1 m in real life corresponds to 10 virtual units) was used, and all reporting was done in meters. Exterior platforms included several staircases, a helicopter pad, a drilling deck, and a lifeboat deck and had a total area of 16, 762 m^2. The total area of the interior platforms (representing the total area of floors and not the actual area of the corridors and rooms) totaled 8, 169 m^2, for a total playable area of 24, 931 m^2.The frame rate varied from 25-35 frames per second, depending on the complexity of a given scene or area of the platform.

Three videos were created for the AP group by capturing footage of gameplay in the VE using FRAPS software. The lengths of the videos were 205, 296 and 216 seconds for navigational routes one, two and three respectively. The audio narration was recorded separately using Audacity software. Windows Live Moviemaker was used to edit the video footage together with the audio narration. The finished videos were then converted to the Ogg Theora video format using VLC Media Player.

Participants controlled movement in the VE by using a wired Microsoft® Xbox 360 controller. Three movement options were given: 1) no movement, 2) walking (at a speed of 4.8 km/h), and 3) running (at a speed of 12 km/h) [55]. Analog sticks were not inverted, and a moderate analog stick sensitivity and thus a moderate rotation speed was used. Possible movements in the VE were: forward/backward translation, left/right translation, up/down rotation, and left/right rotation. It was possible to move in one direction while looking in another. Participants sat in an ergonomically designed office chair with their eyes approximately 0.5 meters from the 19-inch flat monitor, which was set at a height of approximately 1.1 m. An instructor station consisted of a 42-inch monitor was situated out of the line of sight of the participant (Figure 3-6).

To detect backtracking, a detection algorithm was parameterized with a horizontal range and a vertical range. The current point was compared against all previous points. If the current point was within the horizontal and vertical range compared to any given previous point, then the current point was recorded as being a "backtracking point". The backtracking time was calculated by summing the differences of a backtracking point's time stamp from its predecessor. Similarly, backtracking distances were determined by summing the distances between each backtracking point and its predecessor.

3.4: Procedure

3.4.1: Training Session One

Upon completion of the consent forms, the participant was given a standardized briefing, which consisted of the rationale of the experiment, the duration and goal of the session, and a reminder to efficiently explore and to treat the VE as a real-world environment (Appendix H). Following the briefing, the participant completed the ITQ (Appendix E) and a Video Game Experience Questionnaire (VGEQ) (Appendix D) which was created by the investigators. The VGEQ assessed general and specific video game experience, since prior experience with similar video games and interfaces may interact with presence and spatial learning [24, 56].

A five-minute pre-training period was used to allow the participant to familiarize him or herself with the controller and user interface. The participant was given a controller schematic and stayed on the top floor of the structure to avoid an additional opportunity for active learning. A five-minute duration was chosen based on pilot work, and during the experiment, all participants indicated that they were familiar with the controls and interface. The participant was randomly assigned to Group A or group AP. Each group was provided with a set of floor plans and was allowed to self-select the degree to which they used them. The floor plans were drawn to scale and showed a top-down view of each of the 8 floors of the structure. Features such as stairwells, separate rooms and inaccessible processing areas were shown and inside and outside routes were differentiated. These floor plans were only used in the training sessions and were not given to participants in the testing session. All training and testing sessions started on the top floor of the structure. The goal for each group was to learn to navigate to the assigned lifeboat platform that was located on the bottom floor of the structure. Participants filled out a SSQ immediately after their first training session.

Participants in Group A were instructed to freely explore the environment with the constraint that they stay on task and try to learn how to navigate to the lifeboat platform as quickly as possible. Group AP watched three videos of an avatar following a predetermined path from the top floor of the structure to the lifeboat platform. Each video demonstrated a different navigational route and the avatar stopped several times along each route to discuss the landmarks located on each floor (i.e. "the games room is located on this floor."). The avatar also discussed alternate routes to take in the event that a stairway or hallway was blocked. A walkthrough of these alternate routes was not given and participants in this group were unable to access the alternate routes during their exploration. After watching a video, the participant attempted to imitate the route taken by the avatar. This process continued for the entire 30 minute time period, with the order of the videos being randomized for each session.

3.4.2: Training Sessions Two and Three

Training sessions two and three began with a standardized briefing similar to that of the first training session (Appendix H). After the briefing, participants in each group completed a 30-minute training session.

3.4.3: Testing Session

The objective for the participant during the testing session was to reach the lifeboat platform as quickly as possible. Three testing conditions were completed in a randomized order: 1) Day, 2) Night and 3) Hazard. Prior to each condition, the participant sat quietly for 5-7 minutes to establish a resting baseline for the physiological measures. The Day condition mimicked the training scenarios and was characterized by high levels of visibility. The Night condition was similar to the Day condition, except visibility was greatly reduced. During the Night condition, participants could employ a virtual flashlight to increase visibility (although not as much as in the Day condition) if they successfully remembered how to operate their flashlight from the three training sessions. The Hazard condition had high levels of visibility, but had several routes blocked by virtual hazards and included a jet fire, an electrical fire, and heavy smoke (Figure 3-6).

The physiological measures were recorded with the NeXus-10 Mark II hardware system (with accessory sensors) and the accompanying BioTrace+ V2012 C software (Mind Media B.V., Roermond-Herten, Netherlands). This hardware has eight analog and two digital inputs (input impedance $\geq 10^{10}\ \Omega$, common more rejection rato $\geq$ 80 dB, 12-bit analog-to-digital (A/D) board). All physiological measures (GSR, ST, RR, and HR) were sampled at 32 Hz,. Ag/AgCl (4630 pre-gelled electrodes, hypoallergenic, disc-shaped, 1 cm in diameter, Stens Corporation, San Rafael, California, U.S.A.) electrodes were used to record GSR and HR. GSR was measured using the NeXus Skin Conductance Sensor and by securing two electrodes to the fourth digit of each hand. HR was measured using the NeXus EXG Sensor and a standard three-lead ECG set-up. ST was measured using the NeXus Temperature sensor and by a thermistor placed on the palmer aspect of the first web space between the first and second digit. RR was measured using the NeXus Respiration Sensor by placing a sensor over the sternum.

The task performance measurements used to quantify spatial learning were: 1) time to evacuation, 2) distance travelled during evacuation, 3) backtracking time during evacuation and 4) distance travelled during evacuation. Each measure of task performance was recorded in each condition. Immediately after completing the three conditions, participants filled out a second SSQ (Appendix G) and a PQ (Appendix F).

3.5: Statistical Analyses

Three participants withdrew from the study: Two withdrew due to issues with simulator sickness, while one withdrew due to scheduling difficulties. Outliers were identified using the first quartile (Q1), the third quartile (Q3), and the interquartile range (IQR). The IQR is equal to Q3 – Q1. A participant was considered an outlier if their datum point fell outside of the range given by the following equation in any of the three conditions (Day, Night, or Hazard) for any of the four task performance measures (time to evacuation, distance travelled during evacuation, backtracking time during evacuation, and distance travelled during evacuation): [Q1 – 3(IQR), Q3 + 3(IQR)]. In the A Group, four females were outliers, with one female unable to complete the Hazard condition. In the AP group, one male was an outlier.

A Shapiro-Wilk test of normality was performed, with significant deviations from normality for several of the task performance variable. Thus, non-parametric statistics were used for all statistical tests. To determine the effects of group on task performance, two-sample Kolomogorov-Smirnov Tests were performed. To determine within-group differences in the A and AP groups between the three conditions, Friedman's tests were performed. To determine the effects of gender on task performance, all participants were grouped by gender and a two-sample Kolomogorov-Smirnov test was performed. To determine within-group effects of gender on task performance, a two-sample Kolomogorov-Smirnov test was performed within each group. A Spearman's rho (ρ) correlation coefficient was used for all reported correlations. All tests were two-tailed. An alpha level of $p < 0.05$ was used to determine statistical significance. Results include all 38 participants unless otherwise stated. Written results are expressed as mean ± standard error where appropriate.

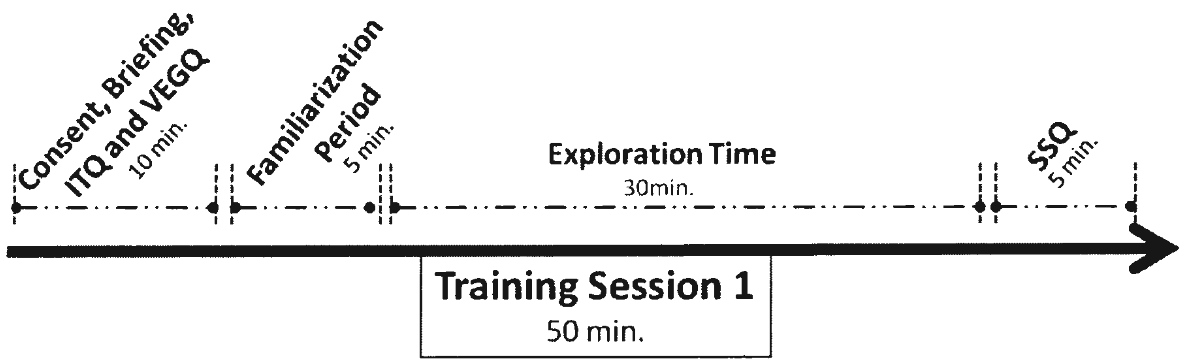


Figure 3-1: Schematic Representation of Training Session One

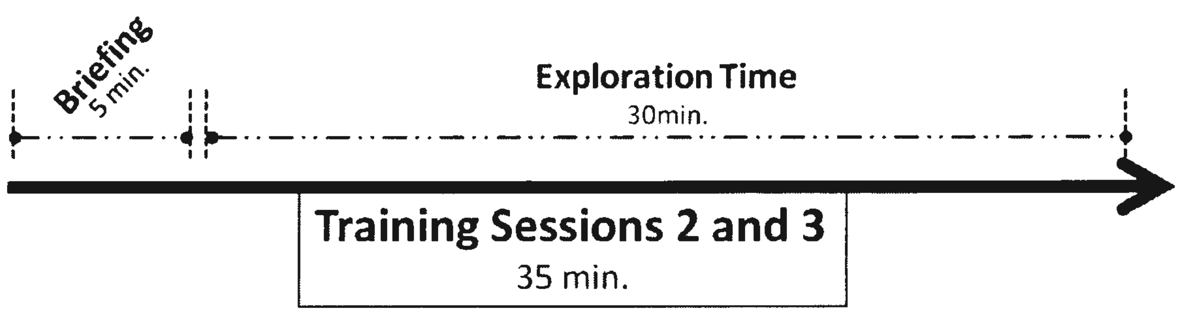


Figure 3-2: Schematic Representation of Training Sessions Two and Three

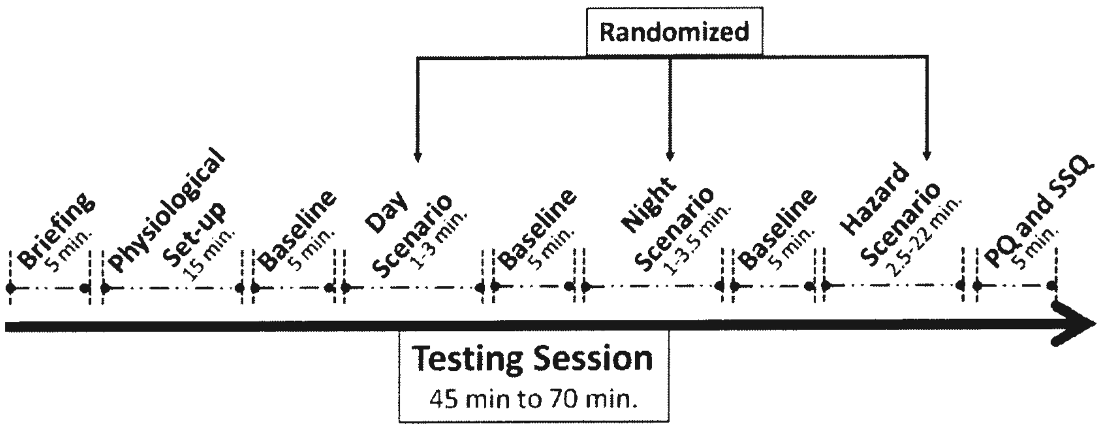


Figure 3-3: Schematic Representation of the Testing Session

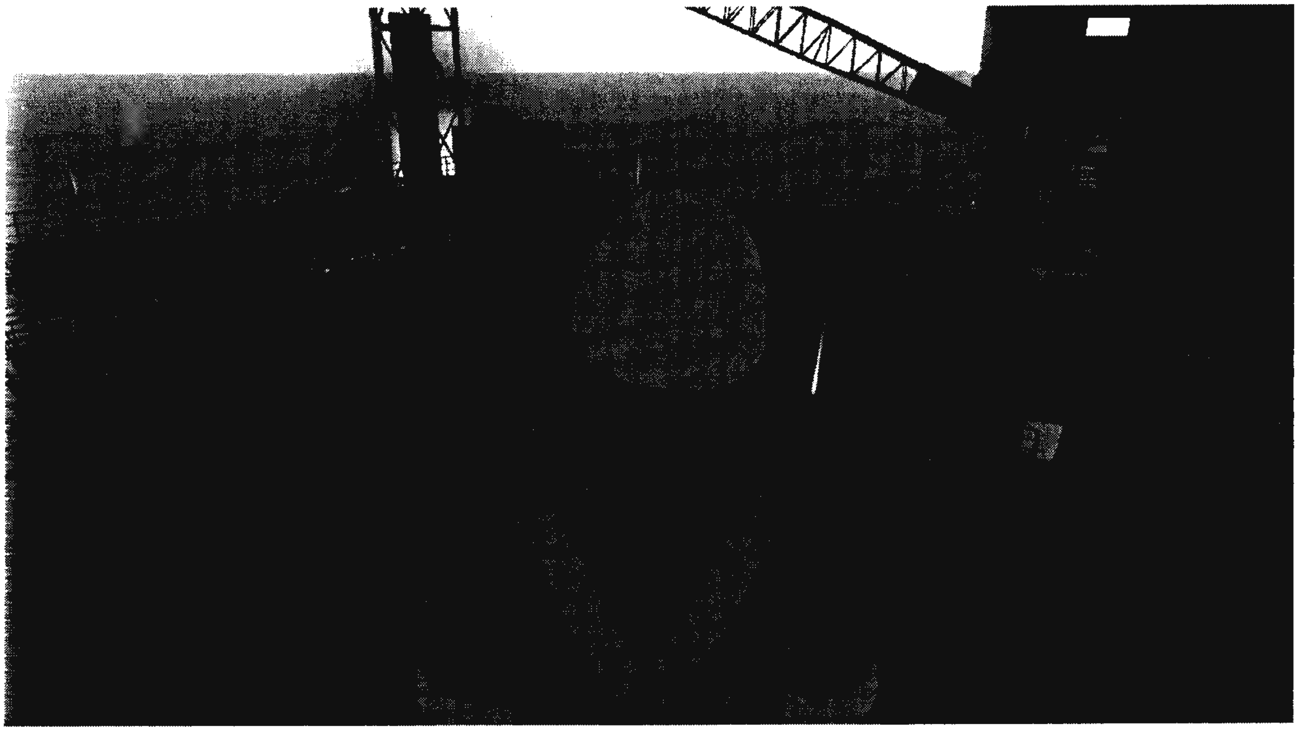


Figure 3-4: Screenshot Illustrating the VE of the Offshore Oil Installation

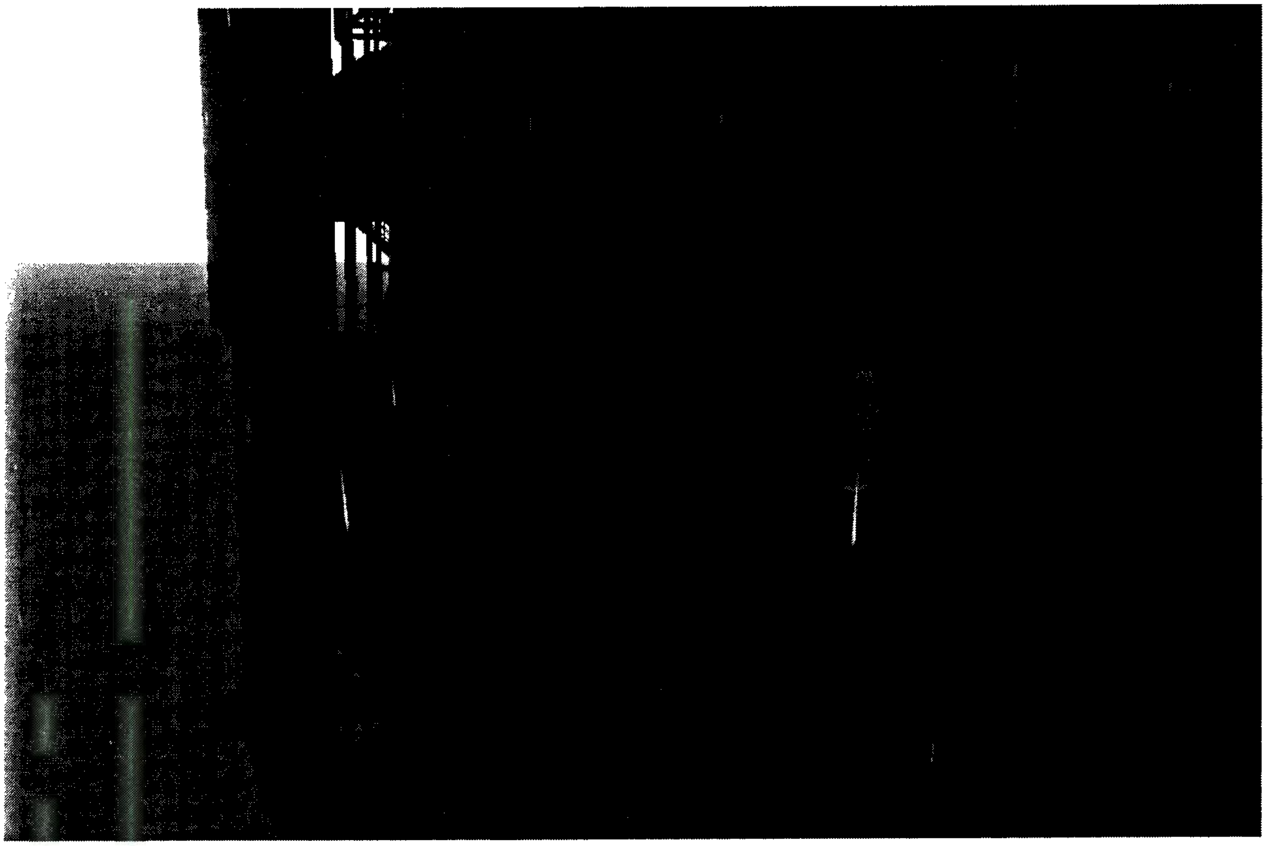


Figure 3-5: Screenshot Illustrating Multiple Levels of the VE

Figure 3-6: The Participant and Instructor Stations

Figure 3-7: An Example of a Jet Fire Hazard

Chapter 4 : Results

4.1: Task Performance

4.1.1: AP group Training Sessions

The average number of videos watched per session by the AP group was 4.38 ± 0.23 videos. Thus, the AP group spent 14.45 minutes (58% of each training session) in passive exploration and 12.55 minutes (42% of each training session) in active exploration.

4.1.2: The Effect of Group on Task Performance

Descriptive statistics are reported in Table 4-1. Figures 4-1 – 4-4 illustrate the effect of group on task performance. In the Hazard condition, time to evacuation, distance travelled during evacuation, backtracking time, and backtracking distance travelled were significantly ($p < .05$) higher in the AP group by approximately 43, 35, 103, and 102%, respectively compared to the A group. In the Day condition, backtracking time and backtracking distance travelled were significantly ($p < .05$) higher in the AP group by approximately 72 and 20%, respectively compared to the A group.

In the A group, the Hazard time to evacuation, distance travelled during evacuation backtracking time, and backtracking distance travelled significantly ($p < .001$) increased by approximately 235, 194, 2500, 2197%, respectively compared to the Day and Night conditions. In the AP group the Hazard time to evacuation, distance travelled during evacuation, backtracking time, and backtracking distance travelled significantly ($p < .001$) increased by approximately 340, 298, 2961, and 3722% respectively compared to the Day and Night conditions. Furthermore, in the AP group time to evacuation and distance travelled during evacuation significantly ($p < .05$) increased by approximately 9 and 7%, respectively from the Day to Night condition. To summarize, differences between the Day and Night conditions were minimal, regardless of group. However, during the most challenging condition (Hazard), the A group demonstrated consistently superior performance compared to the AP group.

4.1.3: The Effect of Gender on Task Performance

Table 4-2 shows the effect of gender on task performance. In the Day condition, time to evacuation, distance travelled during evacuation, backtracking time, and backtracking distance travelled were significantly ($p < .05$) higher in the female group by approximately 24, 4, 134, and 53% respectively compared to the male group. In the Night condition, time to evacuation, distance travelled during evacuation, backtracking time, and backtracking distance travelled were significantly ($p < .05$) higher in the female group by approximately 41, 10, 423, and 295%, respectively compared to the male group. In the Hazard condition, time to evacuation, distance travelled during evacuation, backtracking time, and backtracking distance travelled were significantly ($p < .05$) higher in the female group by approximately 116, 76, 236, and 183% respectively compared to the male group.

In the A group, backtracking time and backtracking distance travelled during the Day condition were significantly ($p < .05$) higher in females by approximately 181 and 19%, respectively compared to males. Time to evacuation during the Night condition was significantly ($p < .05$) higher in females by approximately 62%, compared to males. Time to evacuation and backtracking time during the Hazard condition were significantly (p < .05) higher in females by approximately 160 and 307%, respectively compared to males. In the AP group, backtracking time and backtracking distance travelled during the Night condition were significantly (p < .05) higher in females by approximately 441 and 266%, respectively compared to males. Scores on VGEQ2 and VGEQ4 were significantly (p < .05) decreased in females by approximately 96% and increased by 16%, respectively compared to males. The results show that males consistently demonstrated superior task performance compared to females. It is important to note that females were substantially under-represented in the sample distribution and most of the outliers excluded from the analysis were females.

4.2: Presence Correlations

4.2.1: The Relationships between Subjective Presence Measures, Questionnaires, and Objective Presence

Table 4-3 shows the strength of relationships (based on Spearman's rho value) between subjective measures of presence, questionnaires, and objective measures of presence. SSQ score significantly (p < .05) correlated with GSR and RR during the Day condition and GSR in the Night condition. ITQ score significantly (p < .05) correlated with GSR during the Night condition. VGEQ4 score significantly (p < .05) correlated with GSR during the Hazard condition. Thus, a relationship between subjective presence measures and objective presence measures is not supported.

Table 4-4 shows relationships between subjective measures of presence and questionnaires. SSQ score significantly (p < .01) correlated with ITQ score. VGEQ1 score significantly ($p < .001$) correlated with VGEQ2, VGEQ3 and VGEQ4 scores. VGEQ2 score significantly ($p < .001$) correlated with VGEQ3 and VGEQ4 scores. VGEQ3 score significantly correlated with VGEQ4 score. Subjective measures of presence were not well correlated; however different measures of video game experience were highly correlated.

4.2.2: The Relationships between Presence Measures and Task Performance

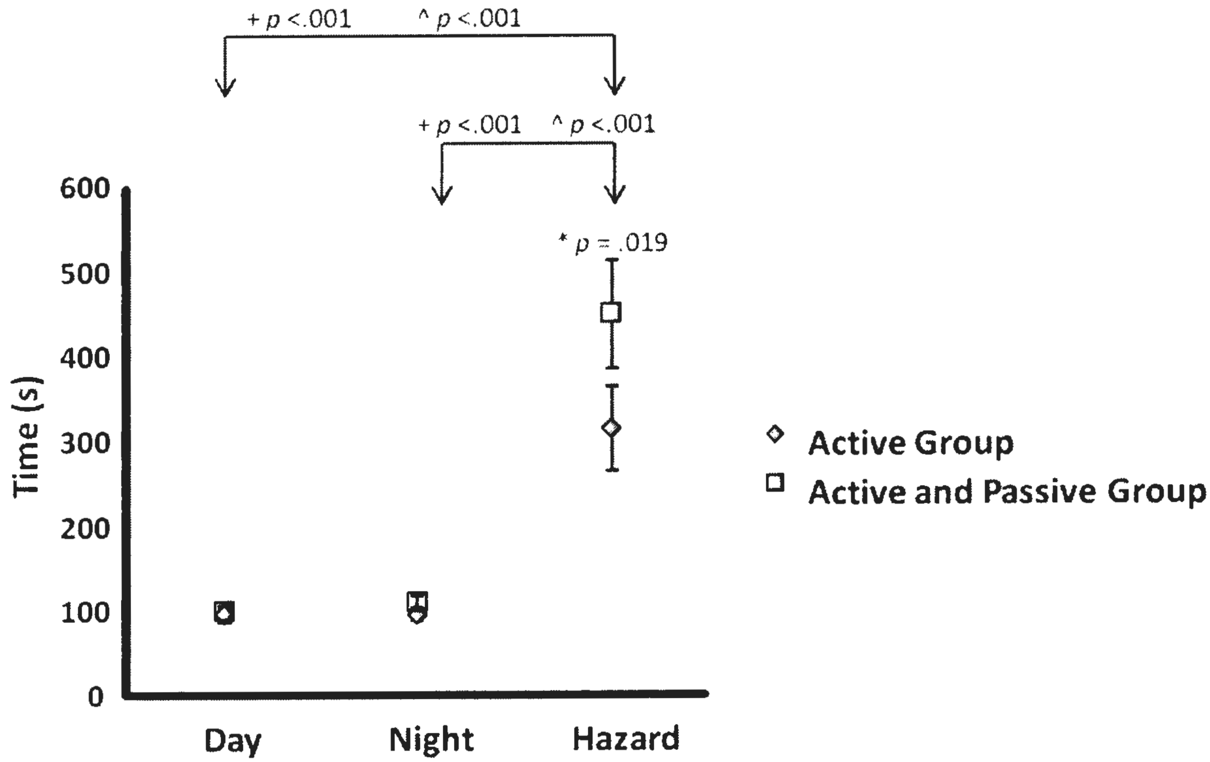
Table 4-5 shows relationships between task performance measures and subjective measures of presence and questionnaires. VGEQ1 score significantly ($p < .05$) correlated with time to evacuation during the Day, Night and Hazard conditions, distance travelled during the Day and Hazard conditions, backtracking time during the Day, Night and Hazard conditions and backtracking distance travelled during the Day, Night and Hazard conditions.

VGEQ2 score significantly ($p < .001$) correlated with time to evacuation during the Day, Night and Hazard conditions, distance travelled during the Day, Night and Hazard conditions, backtracking time during the Day, Night and Hazard conditions and backtracking distance travelled during the Day, Night and Hazard conditions.

VGEQ3 score significantly ($p < .01$) correlated with time to evacuation during the Day, Night and Hazard conditions, distance travelled during the Day, Night and Hazard conditions, backtracking time during the Day, Night and Hazard conditions and backtracking distance travelled during the Day, Night and Hazard conditions.

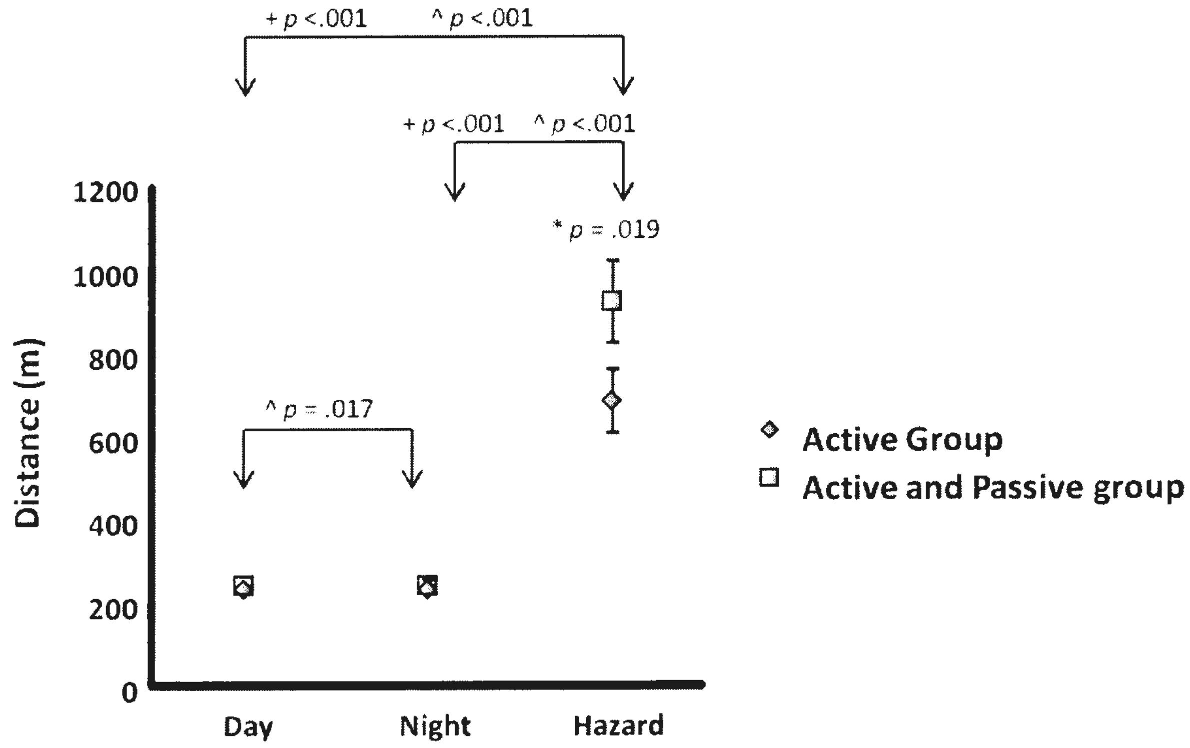
VGEQ4 score significantly ($p < .01$) correlated with time to evacuation during the Day, Night and Hazard conditions, distance travelled during the Day, Night and Hazard conditions, backtracking time during the Day, Night and Hazard conditions and backtracking distance travelled during the Day, Night and Hazard conditions.

Table 4-6 shows relationships between task performance measures and objective measures of presence. HR significantly ($p < .05$) correlated with distance travelled during the Night condition. A relationship between presence measures (subjective and objective) and task performance was not well supported, however, video game experience was highly correlated with task performance.



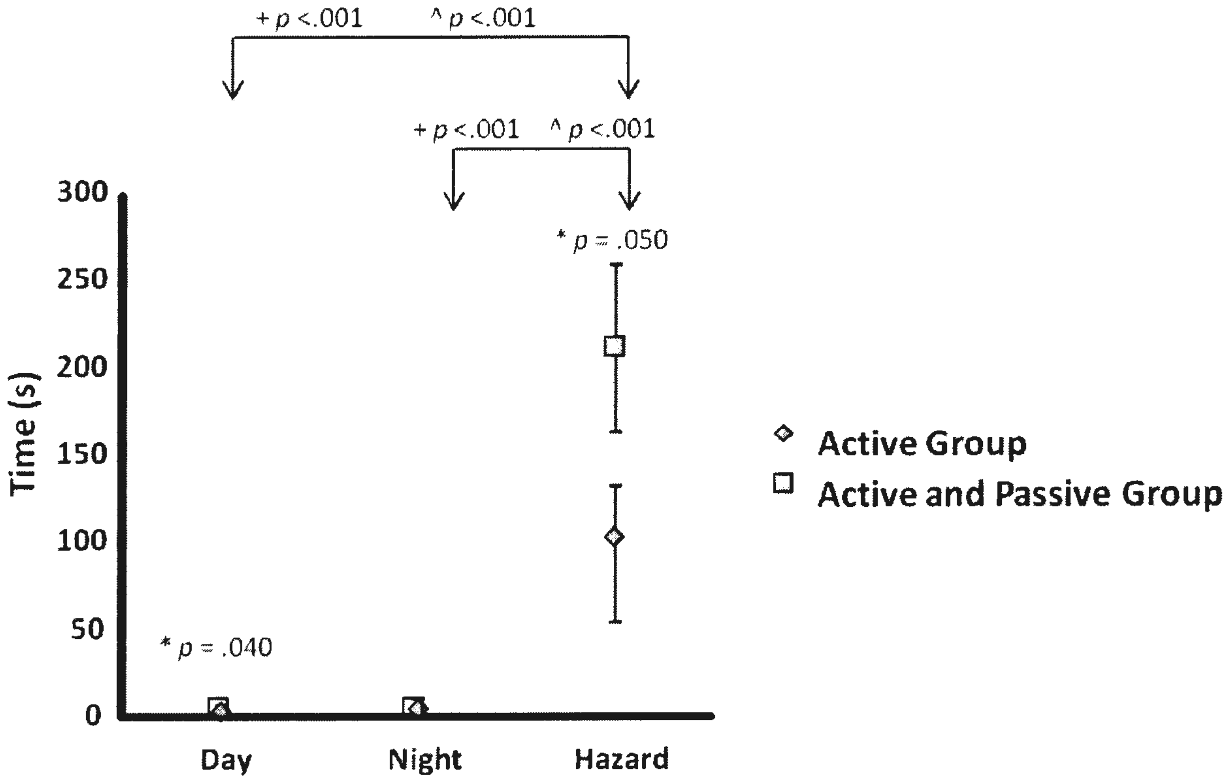
Error bars represent standard error (SE).
+ = Active Group within-group difference.
^ = Active and Passive Group within-group difference.
* = Between group difference.

Figure 4-1: Time to Evacuation



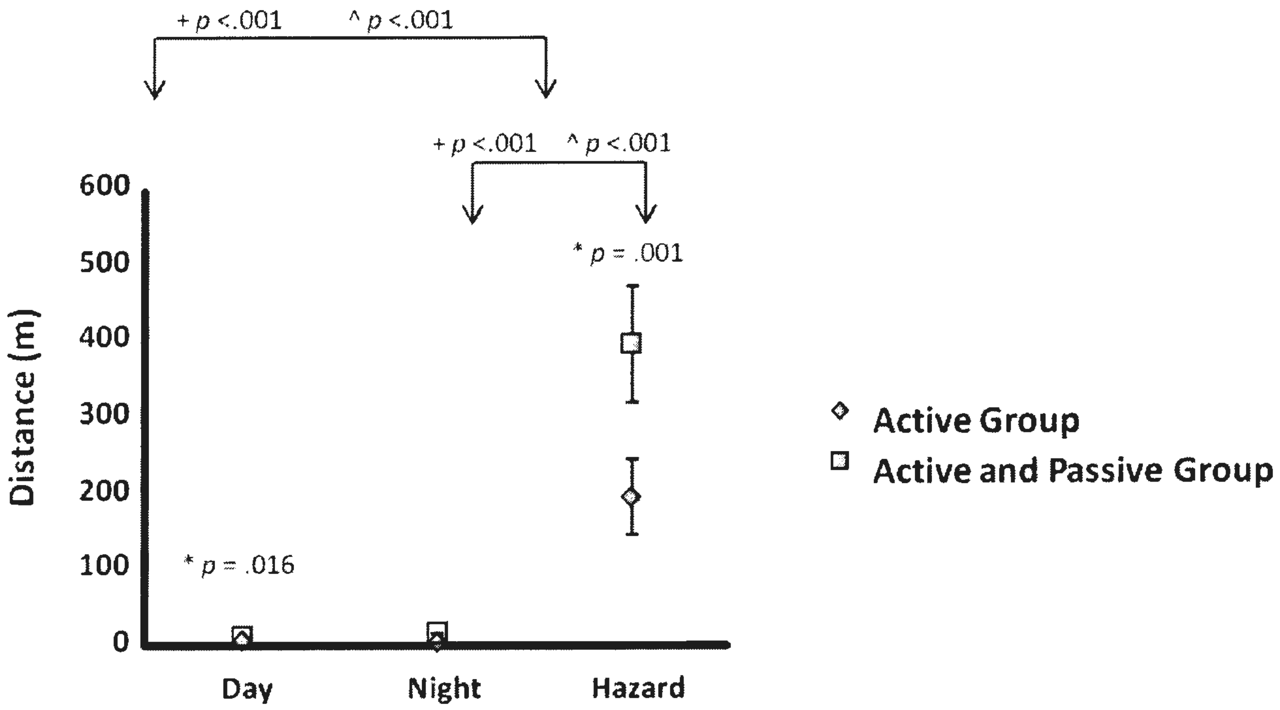
Error bars represent standard error (SE).
+ = Active Group within-group difference.
^ = Active and Passive Group within-group difference.
* = Between group difference.

Figure 4-2: Distance Travelled During Evacuation



Error bars represent standard error (SE).
\+ = Active Group within-group difference.
^ = Active and Passive Group within-group difference.
* = Between group difference.

Figure 4-3: Backtracking Time During Evacuation



Error bars represent standard error (SE).
+ = Active Group within-group difference.
^ = Active and Passive Group within-group difference.
* = Between group difference.

Figure 4-4: Backtracking Distance Travelled During Evacuation

Condition	Variable	Active Group			Active-Passive Group		
		Male	Female	Total	Male	Female	Total
	N	16	2	18	10	10	20
Day	Time to evacuation (s)	90.61 ± 5.97 (.078)	129.37 ± 1.10 (.078)	94.92 ± 6.06 (.247)	93.90 ± 9.06 (.052)	111.01 ± 6.79 (.052)	102.46 ± 5.85 (.247)
	Distance travelled during evacuation (m)	232.37 ± 10.73 (.275)	249.34 ± 12.02 (.275)	234.25 ± 9.64 (.386)	227.46 ± 12.66 (.168)	237.74 ± 5.31 (.168)	232.60 ± 6.79 (.386)
	Backtracking time (s)	3.38 ± 1.99 (.039)*	9.49 ± 3.50 (.039)*	4.05 ± 1.85 (.040)*	4.80 ± 1.85 (.397)	9.10 ± 2.73 (.397)	6.95 ± 1.68 (.040)*
	Backtracking distance travelled (m)	8.50 ± 5.63 (.039)*	10.08 ± 1.64 (.039)*	8.67 ± 4.99 (.016)*	7.79 ± 2.85 (.397)	13.09 ± 3.72 (.397)	10.44 ± 2.36 (.016)**
Night	Time to evacuation (s)	90.06 ± 5.97 (.039)*	146.00 ± 11.30 (.039)*	96.28 ± 6.86 (.233)	96.48 ± 10.27 (.052)	127.63 ± 8.90 (.052)	112.05 ± 7.52 (.233)
	Distance travelled during evacuation (m)	231.64 ± 8.80 (.196)	252.45 ± 10.13 (.196)	233.95 ± 7.99 (.247)	239.29 ± 15.59 (.418)	259.69 ± 12.64 (.418)	249.49 ± 10.04 (.247)
	Backtracking time (s)	3.38 ± 1.91 (.065)	21.49 ± 14.50 (.065)	5.39 ± 2.48 (.097)	2.90 ± 1.74 (.012)*	15.70 ± 3.20 (.012)*	9.30 ± 2.30 (.097)
	Backtracking distance travelled (m)	5.43 ± 2.72 (.098)	21.62 ± 13.61 (.098)	7.23 ± 2.92 (.100)	6.29 ± 3.89 (.012)*	22.99 ± 4.83 (.012)*	14.64 ± 3.57 (.100)
Hazard	Time to evacuation (s)	268.41 ± 34.44 (.039)*	698.68 ± 227.88 (.039)*	316.21 ± 48.43 (.019)*	308.33 ± 44.67 (.052)	594.25 ± 101.99 (.052)	451.29 ± 63.34 (.019)*
	Distance travelled during evacuation (m)	620.39 ± 56.27 (.078)	1233.06 ± 429.38 (.078)	688.47 ± 76.61 (.019)*	713.42 ± 81.87 (.168)	1139.50 ± 153.66 (.168)	926.46 ± 97.82 (.019)*
	Backtracking time (s)	78.03 ± 21.68 (.039)*	317.56 ± 141.52 (.039)*	104.65 ± 28.86 (.050)*	115.79 ± 29.16 (.052)	309.70 ± 82.91 (.052)	212.75 ± 48.21 (.050)*
	Backtracking distance travelled (m)	155.92 ± 39.16 (.078)	531.52 ± 263.41 (.078)	197.66 ± 49.76 (.001)**	251.23 ± 57.50 (.168)	546.92 ± 133.29 (.168)	399.08 ± 78.37 (.001)**
	PQ Score	75.69 ± 3.39 (.680)	74.00 ± 2.00 (.680)	75.50 ± 3.01 (.956)	77.10 ± 5.41 (.169)	71.88 ± 3.73 (.169)	74.78 ± 3.40 (.956)
	ITQ	44.75 ± 2.12 (.131)	54.00 ± 1.00 (.131)	45.78 ± 2.01 (.637)	44.90 ± 3.08 (.123)	49.89 ± 3.75 (.123)	47.26 ± 2.41 (.637)
	SSQ	7.71 ± 2.38 (.582)	14.96 ± 11.22 (.582)	8.52 ± 2.36 (.523)	4.11 ± 0.87 (.232)	10.47 ± 3.56 (.232)	7.29 ± 1.93 (.523)
	VGEQ1	10.88 ± 1.48 (.634)	8.50 ± 3.50 (.634)	10.61 ± 1.35 (.316)	11.10 ± 2.33 (.136)	4.90 ± 1.75 (.136)	8.00 ± 1.59 (.316)
	VGEQ2	3.03 ± 1.26 (.105)	0 ± 0 (.105)	2.69 ± 1.14 (.112)	2.38 ± 0.72 (.007)**	0.10 ± 0.10 (.007)**	1.24 ± 0.44 (.112)
	VGEQ3	2.63 ± .24 (.059)	1.00 ± 0 (.059)	2.44 ± .25 (.533)	2.50 ± 0.22 (.057)	1.80 ± 0.20 (.057)	2.15 ± 0.17 (.533)
	VGEQ4	2.63 ± 0.22 (.477)	1.50 ± 0.50 (.477)	2.50 ± .22 (.681)	2.90 ± 0.18 (.005)**	1.80 ± 0.20 (.005)**	2.35 ± 0.18 (.681)
	Age	24.13 ± 1.66 (.503)	25.00 ± 3.00 (.503)	24.22 ± 1.49 (.106)	24.70 ± .90 (.058)	22.10 ± 0.46 (.058)	23.40 ± .57 (.106)

All values are reported as means ± standard error (*p* - value) (* indicates *p* < 0.05, ** indicates *p* < 0.01)

Table 4-1: Descriptive Statistics

Condition	Variable	Gender	N	Mean	SE	*p*-value
Day	Time to evacuation	Male	26	91.88	4.96	.002**
		Female	12	114.07	5.97	
	Distance travelled during evacuation	Male	26	230.48	8.06	.030*
		Female	12	239.68	4.81	
	Backtracking time	Male	26	3.92	1.40	.002**
		Female	12	9.17	2.30	
	Backtracking distance travelled	Male	26	8.22	3.58	.001**
		Female	12	12.59	3.10	
Night	Time to evacuation	Male	26	92.53	5.31	.002**
		Female	12	130.69	7.76	
	Distance travelled during evacuation	Male	26	234.58	7.92	.011*
		Female	12	258.48	10.54	
	Backtracking time	Male	26	3.19	1.33	<.001**
		Female	12	16.67	3.25	
	Backtracking distance travelled	Male	26	5.76	2.20	<.001**
		Female	12	22.76	4.33	
Hazard	Time to evacuation	Male	26	283.76	27.01	<.001**
		Female	12	611.65	89.54	
	Distance travelled during evacuation	Male	26	656.17	46.68	.001**
		Female	12	1155.10	137.85	
	Backtracking time	Male	26	92.55	17.46	.001**
		Female	12	311.01	70.65	
	Backtracking distance travelled	Male	26	192.58	33.32	.008**
		Female	12	544.36	114.75	

* Indicates $p < 0.05$, ** indicates $p < 0.01$

Table 4-2: The Effect of Gender on Task Performance

	GSR - Day (N = 38)	GSR - Night (N = 38)	GSR - Hazard (N = 37)	ST - Day (N = 37)	ST - Night (N = 37)	ST - Hazard (N = 37)	RR - Day (N = 38)	RR - Night (N = 38)	RR - Hazard (N = 38)	HR - Day (N = 38)	HR - Night (N = 38)	HR - Hazard (N = 38)	Age (N = 38)
PQ (N = 36)	.124 (.470)	.272 (.109)	.218 (.208) (N = 35)	.091 (.604) (N = 35)	.081 (.645) (N = 35)	-.022 (.898) (N = 35)	.158 (.357)	.173 (.313)	.173 (.313)	-.135 (.434)	-.286 (.091)	-.037 (.832)	.141 (.412)
ITQ (N = 37)	-.228 (.175)	-.363 (.027)*	-.304 (.071) (N = 36)	-.090 (.601) (N = 36)	-.195 (.254) (N = 36)	-.213 (.213) (N = 36)	-.071 (.674)	.001 (.996)	.001 (.996)	-.071 (.677)	-.211 (.209)	-.312 (.060)	-.163 (.336)
SSQ	-.332 (.042)*	-.507 (.001)**	-.302 (.069)	.014 (.935)	-.210 (.213)	-.038 (.821)	-.336 (.039)*	-.228 (.168)	-.228 (.168)	.125 (.454)	-.024 (.886)	-.295 (.072)	-.047 (.781)
VGEQ1	-.006 (.972)	.002 (.989)	-.034 (.842)	.120 (.480)	.234 (.163)	.102 (.549)	.164 (.325)	.092 (.581)	.092 (.581)	.215 (.194)	.089 (.594)	.039 (.815)	-.080 (.631)
VGEQ2	-.073 (.665)	.010 (.951)	-.093 (.584)	-.076 (.657)	.045 (.792)	-.099 (.560)	.105 (.532)	.017 (.919)	.017 (.919)	-.016 (.923)	-.155 (.353)	-.261 (.114)	-.058 (.732)
VGEQ3	.018 (.916)	.081 (.629)	.057 (.737)	-.042 (.805)	-.006 (.972)	-.073 (.669)	.042 (.803)	-.099 (.555)	-.099 (.555)	.168 (.314)	-.040 (.813)	-.010 (.950)	-.237 (.152)
VGEQ4	.156 (.349)	.288 (.079)	.328 (.048)*	.164 (.333)	.266 (.111)	.165 (.330)	.174 (.297)	.075 (.654)	.075 (.654)	.001 (.999)	-.175 (.294)	-.107 (.521)	.026 (.876)
Age	.258 (.118)	.244 (.140)	.189 (.263)	.144 (.394)	.111 (.511)	.019 (.911)	-.039 (.818)	-.015 (.928)	-.015 (.928)	-.226 (.172)	-.037 (.825)	-.098 (.557)	-

All values are reported as Spearman's rho (*p*-value) (* indicates, $p < 0.05$, ** indicates $p < 0.01$).

Day values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Day Condition.

Night values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Night Condition.

Hazard values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Hazard Condition.

Table 4-3: The Relationship Between Subjective Presence Measures and Objective Presence Measures

	PQ (N = 36)	ITQ (N = 37)	SSQ (N = 38)	VGEQ1 (N = 38)	VGEQ2 (N = 38)	VGEQ3 (N = 38)	VGEQ4 (N = 38)
PQ (N = 36)	-	.190 (.275) (N = 35)	-.266 (.117) (N = 35)	-.052 (.764)	.169 (.325)	.056 (.745)	.139 (.420)
ITQ (N = 37)	.190 (.275) (N = 35)	-	.436 (.007)**	-.038 (.824)	-.042 (.805)	.026 (.879)	-.154 (.362)
SSQ	-.266 (.117)	.436 (.007)**	-	-.204 (.220)	-.088 (.601)	-.031 (.852)	-.196 (.238)
VGEQ1	-.052 (.764)	-.038 (.824)	-.204 (.220)	-	.658 (<.001)	.669 (<.001)**	.622 (<.001)**
VGEQ2	.169 (.325)	-.042 (.805)	-.088 (.601)	.658 (<.001)**	-	.723 (<.001)**	.662 (<.001)**
VGEQ3	.056 (.745)	.026 (.879)	-.031 (.852)	.669 (<.001)**	.723 (<.001)**	-	.762 (<.001)**
VGEQ4	.139 (.420)	-.154 (.362)	-.196 (.238)	.622 (<.001)**	.662 (<.001)**	.762 (<.001)**	-

All values are reported as Spearman's rho (*p*-value) (* indicates, $p < 0.05$, **indicates $p < 0.01$).

Table 4-4: The Relationship Between Several Subjective Presence Measures/Questionnaires

Condition	Variable	PQ (N = 36)	ITQ (N = 37)	SSQ (N = 38)	VGEQ1 (N = 38)	VGEQ2 (N = 38)	VGEQ3 (N = 38)	VGEQ4 (N = 38)	Age (N = 38)
Day	Time to evacuation	-.095 (.582)	-.117 (.491)	-.009 (.957)	-.461 (.004) **	-.750 (<.001)**	-.577 (<.001)**	-.576 (<.001)**	.171 (.305)
	Distance travelled during evacuation	-.046 (.788)	-.067 (.693)	.010 (.953)	-.363 (.025)*	-.625 (<.001)**	-.482 (.002)**	-.526 (.001)**	.166 (.318)
	Backtracking time	-.284 (.093)	.016 (.927)	-.054 (.747)	-.406 (.011)*	-.699 (<.001)**	-.467 (.003)**	-.438 (.006)**	.153 (.358)
	Backtracking distance travelled	-.290 (.086)	-.019 (.913)	-.062 (.712)	-.337 (.038)*	-.652 (<.001)**	-.421 (.008)**	-.372 (.021)**	.187 (.260)
Night	Time to evacuation	-.208 (.225)	-.189 (.262)	.044 (.794)	-.457 (.004)**	-.748 (<.001)**	-.625 (<.001)**	-.598 (<.001)**	.187 (.260)
	Distance travelled during evacuation	-.189 (.271)	-.244 (.145)	.037 (.824)	-.278 (.091)	-.541 (<.001)**	-.448 (.005)**	-.425 (.008)**	.251 (.129)
	Backtracking time	-.138 (.421)	-.091 (.591)	.138 (.409)	-.488 (.002)**	-.718 (<.001)**	-.568 (<.001)**	-.605 (<.001)**	.121 (.468)
	Backtracking distance travelled	-.134 (.435)	-.119 (.483)	.106 (.528)	-.464 (.003)**	-.690 (<.001)**	-.536 (.001)**	-.578 (<.001)**	.124 (.457)
Hazard	Time to evacuation	-.221 (.196)	.068 (.690)	.082 (.626)	-.505 (.001)**	-.648 (<.001)**	-.544 (<.001)**	-.559 (<.001)**	.096 (.567)
	Distance travelled during evacuation	-.240 (.159)	.096 (.571)	.066 (.694)	-.468 (.003) **	-.586 (<.001)**	-.488 (.002)**	-.486 (.002)**	.097 (.563)
	Backtracking time	-.278 (.100)	.075 (.657)	.157 (.345)	-.481 (.002)**	-.614 (<.001)**	-.492 (.002)**	-.519 (.001)**	.045 (.788)
	Backtracking distance travelled	-.273 (.107)	.075 (.658)	.132 (.428)	-.439 (.006)**	-.539 (<.001)**	-.433 (.007)**	-.421 (.009)**	.098 (.558)

All values are reported as 5pearman's rho (p - value) (* indicates $p < 0.05$, **indicates $p < 0.01$).

Night values for GSR, ST, RR, and HR represent percent changes from the Day condition to the Night Condition.

Hazard values for GSR, ST, RR, and HR represent percent changes from the Day condition to the Hazard Condition.

Table 4-5: The Relationship Between Subjective Presence Measures, Questionnaires and Task Performance

Condition	Variable	GSR - Day (N = 38	GSR - Night (N = 38)	GSR - Hazard (N = 37	ST - Day (N = 37)	ST - Night (N = 37)	ST - Hazard (N = 37)	RR - Day (N = 38)	RR - Night (N = 38)	RR - Hazard (N = 38)	HR - Day (N = 38)	HR - Night (N = 38)	HR - Hazard (N = 38)
Day	Time to evacuation	.110 (.510)	-.032 (.849)	.094 (.579)	.102 (.549)	-.098 (.562)	.022 (.897)	-.324 (.047)*	-.300 (.067)	-.248 (.133)	.003 (.986)	.152 (.362)	.259 (.117)
	Distance travelled during evacuation	.138 (.410)	.023 (.892)	.100 (.556)	.057 (.737)	-.030 (.858)	.118 (.487)	-.318 (.053)	-.179 (.283)	-.266 (.106)	-.047 (.782)	.126 (.450)	.164 (.326)
	Backtracking time	.232 (.162)	.060 (.719)	.090 (.595)	-.051 (.766)	-.188 (.264)	-.111 (.511)	-.296 (.072)	-.282 (.087)	-.251 (.128)	.009 (.956)	.221 (.182)	.232 (.161)
	Backtracking distance travelled	.275 (.094)	.108 (.517)	.115 (.499)	-.017 (.919)	-.144 (.396)	-.069 (.687)	-.319 (.051)	-.240 (.147)	-.294 (.074)	.003 (.984)	.196 (.237)	.183 (.271)
Night	Time to evacuation	.109 (.515)	-.024 (.884)	.022 (.899)	.069 (.687)	-.089 (.599)	.046 (.786)	-.267 (.105)	-.285 (.083)	-.176 (.292)	.113 (.501)	.309 (.059)	.315 (.054)
	Distance travelled during evacuation	.055 (.745)	-.013 (.938)	-.025 (.883)	.033 (.848)	.003 (.987)	.191 (.257)	-.143 (.393)	-.092 (.583)	-.014 (.935)	.172 (.301)	.366 (.024)*	.257 (.119)
	Backtracking time	.092 (.582)	-.022 (.895)	.062 (.717)	-.015 (.929)	-.203 (.227)	-.091 (.592)	-.300 (.067)	-.315 (.054)	-.231 (.162)	.155 (.352)	.317 (.053)	.271 (.099)
	Backtracking distance travelled	.096 (.568)	-.016 (.923)	.079 (.644)	-.046 (.785)	-.196 (.244)	-.077 (.650)	-.234 (.157)	-.251 (.129)	-.154 (.357)	.167 (.316)	.303 (.065)	.305 (.063)
Hazard	Time to evacuation	-.050 (.767)	-.80 (.634)	-.054 (.752)	-.037 (.830)	-.080 (.636)	-.089 (.600)	-.256 (.121)	-.281 (.087)	-.216 (.193)	-.092 (.584)	.072 (.668)	.116 (.489)
	Distance travelled during evacuation	-.034 (.839)	-.080 (.632)	-.041 (.811)	-.050 (.769)	-.084 (.621)	-.115 (.498)	-.192 (.247)	-.222 (.180)	-.161 (.335)	-.127 (.448)	.010 (.951)	.092 (.583)
	Backtracking time	-.069 (.680)	-.114 (.497)	-.073 (.667)	-.001 (.994)	-.073 (.667)	-.106 (.532)	-.279 (.089)	-.275 (.095)	-.258 (.117)	-.121 (.470)	.031 (.853)	.053 (.751)
	Backtracking distance travelled	-.061 (.716)	-.093 (.577)	-.055 (.748)	-.027 (.876)	-.063 (.711)	-.114 (.503)	-.205 (.216)	-.242 (.143)	-.201 (.225)	-.131 (.432)	-.009 (.958)	.019 (.909)

All values are reported as Spearman's rho (p-value) (* indicates, $p < 0.05$, **indicates $p < 0.01$).
Day values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Day Condition.
Night values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Night Condition.
Hazard values for GSR, ST, RR, and HR represent percent changes from the resting baseline to the Hazard Condition.

Table 4-6: The Relationship Between Objective Presence Measures and Task Performance

Chapter 5 : Discussion

5.1: Introduction

The most important findings of this study were as follows: 1) the A Group demonstrated superior task performance as compared to the AP Group, 2) irrespective of group, males demonstrated superior task performance as compared to females, 3) subjective and objective measures of presence were generally not correlated with task performance, and 4) the amount of video game experience consistently correlated with task performance.

5.2: Spatial Learning as Measured by Task Performance

5.2.1: Active Learning Resulted in Better Task Performance Compared to Combined Active and Passive Learning

Analysis of the task performance measures indicate that the Day and Night conditions were relatively equal in difficulty, whereas the Hazard condition was much more difficult as indicated by the decline in task performance during the Hazard condition. Although the Night condition was supposed to present a relatively moderate challenge (with the Day and Hazard condition representing easy and difficult, respectively) it appears that decreasing visibility does not substantially impact task performance in a multi-task VE. The Hazard condition imposed task performance decrements, and thus could be replicated in future VEs as a criterion measure for benchmark performance. To determine an appropriate "moderate" difficulty condition, future studies should decrease visibility further (or not allow for use of the flashlight) to determine if decreasing visibility affects task performance in the absence of other changes.

To effectively implement VEs during ST, spatial learning (the process of encoding and retrieving information about one's environment and orientation within that environment [14]) must occur. Consistent with the first hypothesis, the A Group demonstrated superior (35-103% better) task performance compared to the AP Group in all four task performance measures during the most challenging (Hazard) condition. Since the A group was exposed to 58% more active exploration time compared to the AP group, it appears that active exploration facilitated greater spatial learning than combined active and passive learning.

The time to evacuation and distance travelled during evacuation tasks can be considered as surrogates for a wayfinding task. The task performance results of this study are in agreement with similar studies which found that active explorers demonstrated better wayfinding task performance and greater spatial knowledge on subjective route analysis and route drawings [34, 35]. However, the task performance results contrast with other studies which found no active-passive differences in the following tasks: pointing towards the origin [37, 41], scene recognition [40, 41], route drawings [41], time to locate/number of errors made while locating a target [37], and making distance estimates [14].

In studies where an active learning advantage is found, it was hypothesized that active exploration results in a more survey-type representation [34, 35]. When no active-passive difference is found, the results are generally attributed to task-specific differences and similar attention levels between groups. It appears that for wayfinding/time to completion tasks (such as the time to evacuation task used in this study) active exploration results in better performance than passive exploration. The study by Wilson [37] was the only study using a wayfinding task that found no active-passive difference, however the active group in that particular study was not truly "active" since they were guided by an experimenter. To efficiently complete the Hazard condition, it would appear that a survey-type representation would be most beneficial since novel routes may need to be navigated to evacuate. The environment used in the present study had 8 and 7 more floors and was 1492 and 1627% larger in area compared to similar studies by Wilson [37] and Caressa [35], respectively. If active exploration created a more survey-type representation as hypothesized by the current study and others ([42] as read in [43], [34, 35, 45]), then perhaps the advantages of survey representation (such as the ability to link together distant places to create a global overview [35]) are more pronounced in larger, more complex environments. Thus, not only may there be a task-specific (wayfinding/time to completion) advantage of active exploration, then there may also be an environment-specific advantage, as suggested by Peruch [14].

It has been hypothesized that attention to the spatial environment is more important than mode of exploration for spatial learning in a VE [14], and that no active-passive exploration differences exist if both groups equally attend to the spatial properties of the environment [14, 43]. However, it may be more difficult to sustain attention during passive learning compared to active learning. Increased autonomy over exploration allows active explorers to plan and subsequently test the consequences of their decisions during exploration, affecting their resulting view of the environment [43] and potentially facilitating a survey-type representation. Although attention was not directly measured in the present or the above mentioned studies, the A group may have had greater attentional allocation to relevant (i.e. routes, landmarks, relationships between landmarks, etc.) features of the VE during ST. This greater attentional allocation may have resulted in a more survey-type representation, allowing the A group to more efficiently navigate the complex Hazard condition. Therefore, more time spent in active exploration results in better task performance. However, the mode of learning my interact with video game experience or gender effects.

5.2.2: Males Demonstrated Better Task Performance than Females

An interesting finding was that irrespective of group, males generally demonstrated better task performance than females. The results possibly under predict this effect, as four females were removed as outliers compared to one male. Although Slater [19] found that males performed better than females in a VE chess game and VE navigation of a small room, this effect can be chiefly be attributed to video game experience. According to the VGEQ (Appendix D), although not always significant, females reported playing video games for a fewer number of years (VGEQ1), less hours currently (VGEQ2), and indicated less experience with the controller/interface used (VGEQ3) in the study and with first-person vantage point VEs in general (VGEQ4) (Table 4-1). The effects of gender are likely associated with general VE and interface proficiency, since gender differences in real-world spatial knowledge-based tasks are much smaller than in VEs. Although most spatial tasks show a slight to moderate male advantage, gender differences may be attenuated with additional training aimed to increase interface experience and proficiency [56]. Thus, gender may only be related to task performance if associated to other variables.

5.3: Presence Correlations

5.3.1: Subjective Presence Measures Seldom Correlated with Objective Presence Measures

Inconsistent with the second hypothesis, subjective presence measures were not correlated with objective presence measures (Table 4-3). The results of this study contrast with the current literature. This may be due to procedural differences (such as using different questionnaires) or a difference in the type of VEs used.

The absence of correlation between subjective and objective measures of presence may be due to the different types of questionnaires used. Wiederhold [33], Meehan [22] and the present study all use different questionnaires to measure subjective presence. This makes comparison across studies difficult, since the relationships of presence scores between questionnaires is unknown. Since there is no consensus amongst researchers about how to quantify presence, each questionnaire may measure slightly different aspects of presence. These factors could potentially affect the associations between subjective and objective measures of presence.

The different types of VEs used may have also impacted the correlations between subjective and objective presence measures. Wiederhold [33] and Meehan [22] both used a full-mission simulator, whereas a multi-task simulator was used in the present study. Wiederhold [31] measured HR, GSR, and RR during exposure to a VE of an airplane flight using either a full-mission simulator or a multi-task simulator. Participants felt more immersed, had a greater experience of subjective presence, and had heightened GSR responses with the full-mission simulator compared to the multi-task simulator. The authors hypothesized that using a full-mission simulator increases immersion and therefore presence, since the visual and auditory stimulation are inescapable. Similarly, Meehan [22] found that HR and GSR were positively correlated with questionnaire (modified UCL) scores in a series of experiments using a full-mission simulator. However, similar to the present study Meehan [22] found no relationship between PST and presence, likely due to the slow response time of PST measures. Meehan [22] also suggested that stereo portrayal of a VE (which can be accomplished using a full-mission simulator) is necessary to evoke high levels of presence. Thus, the degree of presence evoked by multi-task VEs may not have been high enough to evoke physiological responses.

5.3.2: Presence Measures Did Not Correlate with Task Performance

This is the first study that has investigated the relationship between presence and task performance in a multi-level, complex VE. Inconsistent with the third hypothesis, presence measures did not correlate with spatial learning as quantified by task performance (Tables 4-5 and 4-6). The relationship between presence and task performance is unclear, as 51% of the literature included in a review by Youngblut [18] did not find a correlation. Despite considerable face validity, a relationship between presence and task performance is unsupported by the present study. It is possible that the use of a full-mission simulator may yield a relationship between presence and task performance, as the use of a multi-task VE may not have evoked enough presence.

Another plausible hypothesis is that presence and task performance are not related. Slater [19] argued that no such relationship exists as presence is concerned with the similarities between behavior in a VE and a real-world environment and not with task performance in an environment. Although presence may not be related to task performance in a VE, it may be crucial for the transfer of skills learned in VEs to real-world environments [19].

5.4: Video Game Experience, and not Presence, was Highly Correlated with Task Performance

Virtually every task performance measure in each condition correlated with scores on each question for the VGEQ (Table 4-5). The strongest relationship between task performance and video game experience appears to be with those who play videogames currently, as Spearman's ρ correlation coefficients indicate moderate (0.5-0.6.9) and strong (0.7-0.89) relationships. The results of the present study are in agreement with Waller [56], who found that the amount of interface experience is the most important predictor of an individual's ability to interact with a VE task effectively.

Experience with VEs may lead to increased task performance in a VE for several reasons. Mental representations of computer functions and tasks may change as people gain more interface experience ([57] as read in [56]). Furthermore, a person's attitude towards computers may influence how they interact with VEs, however this has not been proven empirically [56]. The most likely hypothesis is that those who have experience using VEs do not have to pay attention to mastering interface interaction. Individuals who do not have experience using VEs may have to pay increased attention to interacting with the interface. This increased cognitive load may interfere with subsequent task performance in the VE [58]. Therefore, novice individuals may be attempting a dual-task situation by manipulating the controller and navigating the VE. Although all individuals indicated that they received adequate training in the pre-training period before the first training session, the task may not have truly become "automatic" as it was for those who had a great deal of experience. Thus, those who are experienced with VEs may have spent more of their training attending to learning spatial aspects of the VE, instead of having to attend to the interface.

5.5: Conclusion

As task performance is a measure of spatial learning in VEs, the results suggest that the A group demonstrated increased spatial learning as compared to the AP group. Active exploration may result in a more survey-type representation, potentially due to greater attentional allocation to spatial properties of the VE. Regardless of group, males demonstrated increased spatial learning as compared to females. This gender difference is likely associated with VE and interface proficiency, as females reported less video game experience compared to males. Subjective presence measures were generally not correlated with objective presence measures, possibly due to the types of questionnaires or VE used. These presence measures did not correlate with spatial learning, likely because of the type of VE used. Finally, video game experience was consistently related to spatial learning in a VE. Participants who had experience using VEs may have had to pay less attention to interacting with the interface, and thus may have spent more of their training attending to the spatial properties of the VE.

5.5: Limitations and Future Research

As many researchers use different questionnaires to measure subjective presence, future research should investigate correlations between different subjective questionnaires (such as the PQ, the UCL, the SUS and QPR) and objective measures of presence. Determining which questionnaire most accurately reflects the experience of presence would allow for easier comparison across studies.

Although all participants indicated adequate familiarity with the controller interface after the pre-training period in the first training session, future research should quantify the level of familiarization needed to navigate a VE. Also, potential differences in how experienced and novice individuals learn to utilize controller interfaces should be investigated.

To the author's knowledge, this is the first time that active learning was compared to a combination of active and passive learning. Future studies should examine the combination of active and passive learning compared to both modes of learning separately to determine if there is an optimal combination of each.

The A and AP groups were not gender-matched, which may have impacted between-group differences in task performance. To determine how gender impacts task performance in VEs, future research should investigate how individual differences in VE experience and proficiency interact with factors such as gender and mode of learning. Although the active exploration group exhibited better task performance in the VE, it is outside the scope of this research to discuss how these results can be generalized to task performance in a similar real-world environment. Although presence did not correlate with VE task performance, future research should investigate how a high degree of presence during ST (possibly using a full-mission simulator) transfers to both VE and real-world scenarios [22, 31]. Since a potential relationship between presence and task performance may be task dependent, researchers must adopt a careful, systematic approach for subsequent studies.

Chapter 6 : Conclusion

Even with technological improvements in navigation, processing, safety and evacuation equipment, accidents related to human error still represent a substantial risk to the health and safety of employees on offshore installations [4]. ST using VEs can be used as a complement to traditional training methods by allowing employees to gain experience with dangerous and stressful scenarios which would normally be impossible due to financial, ethical, and logistical concerns [9].

Although the aviation industry has been at the forefront in their use of ST over the past number of years, marine industries are beginning to research and develop similar training protocols. To be effective, ST must train the appropriate skills in suitable environments so that individuals can practice complex tasks in a manner which would transfer to similar tasks in real-world environments [16]. However, before marine industries invest large sums of money and time implementing ST, it is important to determine which mode of learning is most effective.

The current study provides evidence that while using a multi-task VE for ST, active exploration results in increased spatial knowledge within a VE compared to combined active and passive exploration. Subjective and objective measures of presence are rarely correlated with each other and presence is not related to task performance within the VE. Future research should investigate how different modes of learning and different levels of presence transfer to task performance in real-world environments.

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Appendix

Appendix A: Free and Informed Consent Form

Title:

The effect of virtual training systems on participant behavior and learning in emergency response scenarios.

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You are invited to take part in a research project entitled "The effect of virtual training systems on participant behaviour and learning in emergency response scenarios".

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study at any time. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researchers *Dr. Scott MacKinnon or Jennifer Smith* if you have any questions about the study or for more information not included here before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction:

We are an interdisciplinary research team at Memorial University. The research is being conducted as a part of the Virtual Environments for Knowledge Mobilization Project. Disciplines collaborating on this project include engineers of various specialties (naval architecture, mechanical, software, electrical), human factors and ergonomics researchers, coop students from the faculty of engineering and kinesiology, and graduate students with related research interests.

There has recently been increased emphasis placed on ensuring the safety of crew on ships and offshore platforms. This has manifested in the form of improved safety management systems, more stringent regulations governing qualifications of seafarers and offshore crew, and requirements for more comprehensive training programs relating to all aspects of work and personal safety in maritime occupations.

The basic training related to personal safety and emergency response is most commonly delivered in lecture format, and routine drills. On offshore platforms there are weekly muster drills on a specific day and time where the onboard crew is required to proceed to their muster stations. Practically, this is their only opportunity to practice emergency response and muster procedures learned in lecture.

These weekly training drills are performed under optimal conditions. The crew knows to expect the drill at the same day and time, there is no threat of danger, and the route to the muster area will be free of obstacles. With no opportunity to experience an actual hazard or threat of danger, the value of this training may be lost.

This research project is evaluating naive participants training for emergency response and mustering on a virtual offshore oil rig. In this virtual environment there is the capability to implement hazards such as fires, explosions, oil leaks and toxic fumes. When practicing evacuation of an area of the vessel, doors can be barred, stairs can be rendered impassable, and the trainees will have to select alternate routes to avoid hazards, and safely make their way to their muster station or abandonment area.

Purpose of study:

This study will evaluate virtual training systems. Technology is advancing is such a way that training time may be increased without increasing the demand on instructors. In this study, minimal contact with the training facilitator is supplemented with training tools and artificial instruction. The research team is seeking to determine if there is a difference in performance between groups after a self-facilitated training program and an artificial-instructor led training program.

What you will do in this study:

Participants will attend three, thirty minute training sessions in Virtual Environments Lab with no more than two days between sessions. This training will be either self-guided, with no instructor guidance, and the use of the provided floor plans, or supplemented with an on-demand video instruction of each of the three escape routes, where the instructor will point out landmarks, areas where the trainee should not go, and helpful guidance to facilitate the learning of the escape routes. The instructions will be to learn, with the assistance of the familiarization materials, three escape routes which will be denoted on the floor plans.

At the end of the training phase, each participant will perform three measured trials to assess the efficacy of each of the training protocols on learning escape routes. Each participant will perform three of the measured trials in the same order. Hazards such as poor lighting, barriers, fires, or explosions may be present. The task is to navigate from the starting position to the muster station as quickly as possible.

Length of time:

Each participant will be required to attend three, thirty minute training sessions, with no more than 2 days between training sessions. Following the completion of the training sessions, the participant will be required to attend a final session where they will complete their testing trials. The anticipated total time involvement of the participants is expected to be no more than four hours of the four visits to the Virtual Environments Lab.

Withdrawal from the study:

If you decide to withdraw from the study, the information collected up to that time will continue to be used by the research team. It may not be removed. This information will only be used for the purposes of this study

Information collected and used by the research team will be stored by Scott MacKinnon and he is the person responsible for keeping it secure. Withdrawal from the study will not affect your standing with Memorial University, The School of Human Kinetics and Recreation, The School of Engineering and Applied Science, or the Virtual Environments for Knowledge Mobilization Project

Possible benefits:

There are no known direct benefits to the participants of this study.

The knowledge gained from this study will support efforts to improve training in the maritime community.

Possible risks:

- Participants will be equipped with electrodes on several locations on their body. While these self-adhesive electrodes are only applied to the skin, or are worn attached to a head cap, the adhesive gel and tape that is used to secure the wires may irritate sensitive skin.
- Navigation through the virtual space may cause some to experience symptoms of motion (or simulator) sickness.
- Exposure to a computer screen may cause eye strain in some participants. Screen time exposure is minimal, and therefore there is minimal expected discomfort.

Confidentiality vs. Anonymity:

There is a difference between confidentiality and anonymity: Confidentiality is ensuring that identities of participants are accessible only to those authorized to have access. Anonymity is a result of not disclosing participant's identifying characteristics (such as name or description of physical appearance).

Confidentiality and Storage of Data:

Protecting your privacy and maintaining confidentiality is an important goal of the research team. Every effort to protect your privacy will be made. However it cannot be guaranteed. For example we may be required by law to allow access to research records.

When you sign this consent form you give us permission to

- Collect information from you
- Share information with the people conducting the study
- Share information with the people responsible for protecting your safety

The members of the research team will see study records that identify you by name. Other people may need to look at the study records that identify you by name. This might include the research ethics board. You may ask to see the list of these people. They can look at your records only when one of the research team is present.

Use of records:

The research team will collect and use only the information they need for this research study. This information will include your:

- date of birth
- sex
- performance metrics
- physiological data
- subjective assessments

Your name and contact information will be kept in a locked office on a password protected PC by the research team at MUN. It will not be shared with others without your permission. Your name will not appear in any report or article published as a result of this study.

Information collected for this study will be kept for 5 years. Following this period, all electronic records of your participation will be permanently deleted and all paper files will be appropriately destroyed.

Anonymity:

Protecting your privacy and ensuring all personal data recorded during participation remains anonymous is an important goal for the research team. Every reasonable effort will be made to assure your anonymity. You will not be identified in any reports or publications without your explicit written permission.

Recording of Data:

As part of this study, we will be collecting various types of data. Performance metrics will be recorded electronically during computer-based activities: time, speed, and errors; physiological parameters will be collected to assess stress experienced during the test trials: heart rate (EKG), galvanic skin response, respiration rate, skin temperature, and electroencephalogram (EEG). Afterwards, you will also be asked to fill out a questionnaire to report perception of "presence" during the simulation, and a questionnaire reporting symptoms of simulator sickness
Reporting of Results:

The research team intends to publish the findings of this study in peer reviewed journals and academic conferences. Formal reports will be made available to funding agencies and industry partners. The data will be reported in statistical and descriptive form. Individual information or data will not be reported without your exclusive written consent.

Sharing of Results with Participants:

☐ On completion of data analysis a report will be prepared for dissemination. Participants who wish to be informed of the results will have the opportunity to receive a copy of the final report.

Questions:

You are welcome to ask questions at any time during your participation in this research. If you would like more information about this study, please contact:

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ICEHR Statement:

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:

Your signature on this form means that:

☐ You have read the information about the research.
☐ You have been able to ask questions about this study.
☐ You are satisfied with the answers to all your questions.
☐ You understand what the study is about and what you will be doing.
☐ You understand that you are free to withdraw from the study at any time, without having to give a reason, and that doing so will not affect you now or in the future.
☐ You understand that any data collected from you up to the point of your withdrawal will be destroyed (OR retained by the researcher for use in the research study).

If you sign this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your signature:

I have read and understood what this study is about and appreciate the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation at any time.
☐ I agree to the use of quotations and that my name may be identified in any publications resulting from this study.
☐ I agree to the use of quotations but do not want my name to be identified in any publications resulting from this study.
☐ I agree to having all of the following physiological parameters recorded during my participation in this study.

- ☐ Heart Rate (EKG)
- ☐ Galvanic Skin Response
- ☐ Skin Temperature
- ☐ Respiration
- ☐ Electroencephalogram (EEG)

☐ I agree to the use of my responses to all questionnaires completed during my participation in this study

A copy of this Informed Consent Form has been given to me for my records.

____________________________ ____________________________

Signature of participant Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

______________________________ ______________________________

Signature of Principal Investigator Date

Appendix B: Call for Participant's Recruitment

Are you interested in taking part in a research study?

Volunteers are needed to study the effect of virtual training systems on behaviour and learning in emergency response scenarios.

Contribute to our understanding of how training protocols affects people's ability to train their memory and emergency response behaviors.

Brief Description of Experiment:

Volunteers will attend three, thirty minute training sessions,
There will be not more than two days between sessions.
On a final, fourth, visit to the Virtual Environments Laboratory, participants will be tested on how well their training prepared them for unpredictable scenarios.

Who can participate?:

Anyone between 19-55 years of age. The study will be conducted in a laboratory on the Memorial University of Newfoundland campus. Total time involvement will be approximately four hours over four visits to the lab.

Sources of data being collected:

Performance during simulation scenarios;
Sensors will be applied to each participant to measure:
Heart rate (2-Lead EKG);
Skin conductance (2 finger electrodes);
Peripheral skin temperature (one sensor applied to the hand);
Respiration (a band fixed around the torso), and;
Electroencephalogram (EEG-electrodes applied to the head and held in place by a soft helmet).
Subjective assessment of experience via questionnaires.

Appendix C: Recruitment Poster

Want to Participate in a Research Study?

Volunteers are needed to study the effect of virtual training systems on behavior and learning in emergency response scenarios.

Contribute to our understanding of how training protocols affects people's ability to train their memory and response behaviors.

Brief Description of Experiment:

Volunteers will attend three, thirty minute training sessions,
There will be not more than two days between sessions.
On a final, fourth, visit to the Virtual Environments Laboratory, participants will be tested on how well their training prepared them for unpredictable scenarios.

Who can participate?:

Anyone between 19-55 years of age.

To find out more, contact:

David Bradbury-Squires – **djbs32@mun.ca**
Elizabeth Burton – **e.burton@mun.ca** or (709) 864-6764

Appendix D: Video Game Experience Questionnaire (VGEQ)

Participant Number: ____________________

Gender (circle one): M / F

Age: _______

1) How long have you been playing video games?

Time (in years): ___________

2) How many hours, on average, do you spend playing video games per week?

_________Hours per week

3) How comfortable/experienced are you using the controller/interface employed in this study?

A) Not at all
B) Somewhat proficient
C) Proficient
D) Expert

4) How proficient/experienced would you rate your level of skill in first-person vantage point-style games?

A) Never Played
B) Played but Not Experienced
C) Played With Some Experience
D) I Consider Myself an Expert

5) Which of the following gaming systems do you have experience using?

A) Xbox
B) Nintendo Wii
C)Play Station
D) PC Based
E) Other (Please Specify) ___________________________________
F) Of the systems you have experience using, with which do you have the most experience?

____

Appendix E: Modified Witmer & Singer Immersive Tendencies Questionnaires (ITQ)

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence: Teleoperators & Virtual Environments, 7(3), 225-240.

Participant Number: ____________________

Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Very Often

How easily can you switch your attention from the task in which you are currently involved to a new task?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all easily Very Easily

How frequently do you get emotionally involved (angry, sad, happy) in the news stories that you read or hear?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

Do you easily become deeply involved in movies or TV dramas?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Very Easily

Do you ever become so involved in a television program or book that people have problems getting your attention?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Very Often

How mentally alert do you feel at the present time?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Alert Very Alert

How frequently do you find yourself closely identifying with the characters in a story line?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very frequently

Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick or watching the screen?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

How good are you at blocking out external distractions when you are involved in something?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not good at all Very Good

Do you ever become so involved in a day dream that you are not aware of things happening around you?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

How well do you concentrate on enjoyable activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not well at all Very Well

How well do you concentrate on disagreeable tasks?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not well at all Very well

Have you ever gotten excited during a chase or fight scene on TV or in the movies?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

Have you ever gotten scared by something happening on a TV show or in a movie?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

Have you ever remained apprehensive or fearful long after watching a scary movie?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never Very Often

Do you ever become so involved in something that you lose all track of time?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Very Often

Appendix F: Modified Witmer & Singer Presence Questionnaire (PQ)

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence: Teleoperators & Virtual Environments, 7(3), 225-240.

Participant Number: ______

How responsive was the environment to actions that you initiated (or performed)?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Responsive Very Responsive

How natural did your interactions with the environment seem?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Natural Very Natural

How much did the visual aspects of the environment involve you?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Completely

How much did the auditory aspects of the environment involve you?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Completely

How natural was the mechanism which controlled movement through the environment?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Natural Very Natural

How compelling was your sense of objects moving through space?

□ □ □ □ □ □ □

Not at all compelling Very Compelling

Were you able to anticipate what would happen next in response to the actions that you performed?

□ □ □ □ □ □ □

Not at all Completely

How completely were you able to actively survey or search the environment using vision?

□ □ □ □ □ □ □

Not at all Completely

How well could you identify sounds?

□ □ □ □ □ □ □

Not at all Very well

How compelling was your sense of moving around inside the virtual environment?

□ □ □ □ □ □ □

Not at all compelling Very Compelling

How involved were you in the virtual environment experience?

□ □ □ □ □ □ □

Not at all Involved Very Involved

How much delay did you experience between your actions and expected outcomes?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Very delayed No delay at all

How quickly did you adjust to the virtual environment experience?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not quickly at all Very quickly

How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all proficient Very Proficient

How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Very Distracting Not at all distracting

How much did the control devices interfere with the performance of assigned tasks or with other activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Very Interfering Not interfering at all

How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not at all Very well

Any Comments?

How helpful were the training videos (if applicable)?

1 2 3 4 5 6 7 8 9 10

How helpful were the floor plans?

1 2 3 4 5 6 7 8 9 10

How helpful was the free-roaming around the platform?

1 2 3 4 5 6 7 8 9 10

Appendix G: Modified Witmer & Singer Presence Questionnaire (PQ)

Kennedy, R. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *International Journal Of Aviation Psychology*, *3*(3), 203

Participant Number: ____________________________________

Time: _________________
When: After / Before Testing

Symptom	0 No Symptoms	1 Minimal	2 Moderate	3 Severe
General Discomfort				
Fatigue				
Headache				
Eyestrain				
Difficulty Focusing				
Increased Salivation				
Sweating				
Nausea				
Difficulty Concentrating				
Fullness of Head				
Blurred Vision				
Dizzy (eyes open)				
Dizzy (eyes closed)				

Vertigo				
Stomach Awareness				
Burping				

Appendix H: Experimental Script

Session 1

Complete Forms and Questionnaires

- Consent Form
- Video Game Experience Questionnaire
- Immersive Tendencies Questionnaire

Background and rationale:

This experiment will be using an AVERT, which means All-hands Virtual Emergency Response Trainer, to simulate an oil platform, called "the platform".

Generally, when you are first hired on an oil platform your first 42 days are spent shadowing someone in order to become familiar with the platform.

Presently, the crew on a offshore vessel performs a safety training drill on a weekly basis. However, this is without hazards or risks present. Therefore, this would have very little comparison with a real-life emergency situation.

The purpose of this experiment is to determine if this form of simulation based evacuation training can elicit a learning response. This will potentially improve the safety of offshore workers.
This experiment involves you to begin at the top deck of the craft and safely make your way to the lifeboat platform. Your lifeboat is the **LEFT** lifeboat.

An AVERT is used as a simulator only and thus you should take the simulator very seriously. Do not treat it as a "videogame". React to any hazards or situations as you would in a real life setting.

Data from this project may allow for us to make recommendations to industry partners.

Procedure:

Over 3 separate 30 minute sessions, you will use the simulator to learn emergency routes to the lifeboat platform.
You will come in for a 4th, separate testing session in which we will assess performance measures which include, distance travelled, time to the lifeboat platform, your speed and number of errors. Also, we will assess the following physiological measures:

- EEG

  - Measuring electrical activity of the brain
  - Measured using a cap with electrodes
- ECG
  - Measuring heart rate
  - Measured by placing electrodes on the chest and abdomen
- Respiration
  - Measuring Breathing rate
  - Measured by placing a strap over the ribcage
- Galvanic skin response
  - Measuring skin perspiration
  - Measured by placing two electrodes on the ring finger of each hand
- Skin temperature
  - Measuring peripheral skin temperature
  - By placing a thermocouple between the thumb and the index finger

There will be a minimum of 24 hours and a maximum of 48 hours between your sessions. Prior to the testing session, avoid:

- Exercise, smoking and caffeine for 4 hours prior to testing
- Alcohol for 24 hours prior to testing
- Fasting for greater than 2 hours prior to testing

You must wear pants, socks, shoes and a cotton t-shirt during their testing session. If any of the above is violated, testing cannot occur.

Since your goal is to learn the best escape routes in the virtual environment in such a limited time period, you must use your time wisely and be focused on the task for the entire 30 minute period. We cannot answer any simulator questions during training. Do you have any questions?

Pre-experiment:

- 5 minute familiarization
- Let's begin by giving you a 5 minute pre-training period where you will be placed in a "pre-training scenario"
- Labeled control schematic /Floor Plans/training videos (Show the illustrations to the participant)
- You can try to use all the controls even if you don't need them in this pre-training scenario, for instance, to crouch, to use the flashlight or to run
- You will have 5 minutes to get use to all the controls and to be briefly get familiar with the floor plans
- We cannot answer any questions about the floor plans, controller, or in game play after this, for the remainder of the training after this, so if you have any questions please ask now.

Experiment (Training):

- You are going to soon be instructed to begin the first session and we will stop you when you reach 30 minutes.
- You are reminded that your goal is to learn the escape routes to the **LEFT** lifeboat platform to the best of their ability
- You must use your time wisely and be sure to focus on the task for the entire time period
- Your in-game performance will be tested in the testing scenario

Session 2

Experiment (Training)

- You are going to soon be instructed to begin the second training session and we will stop you when you reach 30 minutes.
- You are reminded that your goal is to learn the escape routes to the **LEFT** lifeboat platform to the best of their ability
- You must use your time wisely and be sure to focus on the task for the entire time period
- Your in-game performance will be tested in the testing scenario

Prior to the testing session, avoid:

- Exercise, smoking and caffeine for 4 hours prior to testing
- Alcohol for 24 hours prior to testing
- Fasting for greater than 2 hours prior to testing

You must wear pants, socks, shoes and a cotton t-shirt during their testing session. If any of the above is violated, testing cannot occur.

Since your goal is to learn the best escape routes in the virtual environment in such a limited time period, you must use your time wisely and be focused on the task for the entire 30 minute period. We cannot answer any simulator questions during training. An AVERT is used as a simulator only and thus you should take the simulator very seriously. Do not treat it as a "videogame". React to any hazards or situations as you would in a real life setting.

Do you have any questions?

Begin session 2.

Session 3

Experiment (Training):

- You are going to soon be instructed to begin the third training session and we will stop you when you reach 30 minutes.
- You are reminded that your goal is to learn the escape routes to the **LEFT** lifeboat platform to the best of their ability
- You must use your time wisely and be sure to focus on the task for the entire time period
- Your in-game performance will be tested in the testing scenario

Prior to the testing session, avoid:

- Exercise, smoking and caffeine for 4 hours prior to testing
- Alcohol for 24 hours prior to testing
- Fasting for greater than 2 hours prior to testing

You must wear pants, socks, shoes and a cotton t-shirt during their testing session. If any of the above is violated, testing cannot occur.

Since your goal is to learn the best escape routes in the virtual environment in such a limited time period, you must use your time wisely and be focused on the task for the entire 30 minute period. We cannot answer any simulator questions during training. An AVERT is used as a simulator only and thus you should take the simulator very seriously. Do not treat it as a "videogame". React to any hazards or situations as you would in a real life setting.

Do you have any questions?

Begin session 3.

REMINDER

Prior to the testing session, avoid:

- Exercise, smoking and caffeine for 4 hours prior to testing
- Alcohol for 24 hours prior to testing
- Fasting for greater than 2 hours prior to testing

You must wear pants, socks, shoes and a cotton t-shirt during their testing session. If any of the above is violated, testing cannot occur.

Testing Session

Pre-test:
We have to check to make sure you have the requirements for testing:

- Have you exercised, smoked, or had caffeine in the last 4 hours?
- Have you had alcohol in the last 24 hours?
- Have you fasted greater than the past 2 hours?
- Are you wearing pants, socks, shoes and a cotton t-shirt?
- Have you had any exposure to sedative drugs?

Complete the Simulator Sickness Questionnaire (SSQ)

Today we will perform 3 different trials. Before each trial, we will have a 5 minute "baseline" period. You need to relax as much as possible and to avoid talking and moving.

We will be measuring your performance in your ability to find the lifeboat platform.

Your lifeboat is the **LEFT** lifeboat. Also, we will be measuring the following physiological measures:

- EEG
  - Measuring electrical activity of the brain
- ECG
  - Measuring heart rate
- Respiration
  - Measuring Breathing rate
- Galvanic skin response
  - Measuring skin perspiration
- Skin temperature
  - Measuring peripheral skin temperature

You are required to reach the lifeboat platform and **LEFT lifeboat** as quickly as possible. The trial will begin as soon as you start moving. We cannot answer questions of any nature during testing.

An AVERT is used as a simulator only and thus you should take the simulator very seriously. Do not treat it as a "videogame". React to any hazards or situations as you would in a real life setting.

Begin testing session.

Post Testing session.

Complete the Presence Questionnaire and a second Simulator Sickness Questionnaire

Please do not discuss specific aspects of training or testing sessions with any other participant under any circumstance.