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The Impact of Extreme Virtual Elevation above Grade on Construction Workers' Physiological Responses, Physical Responses, and Task Performance

Mahmoud Habibnezhad
University of Nebraska - Lincoln, mahmoud@huskers.unl.edu

THE IMPACT OF EXTREME VIRTUAL ELEVATION ABOVE GRADE ON CONSTRUCTION WORKERS' PHYSIOLOGICAL RESPONSES, PHYSICAL RESPONSES, AND TASK PERFORMANCE

by

Mahmoud Habibnezhad

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THE IMPACT OF EXTREME VIRTUAL ELEVATION ABOVE GRADE ON CONSTRUCTION WORKERS' PHYSIOLOGICAL RESPONSES, PHYSICAL RESPONSES, AND TASK PERFORMANCE

Mahmoud Habibnezhad, Ph.D.

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Advisors: Jay Puckett and Terry Stentz

On average, in every two work hours, one person dies from work-related injuries at construction sites. Most incidents are due to falling from elevated surfaces. Slips, trips, and loss of balance are the main causes. Studies suggest that instigating visual mismatch and physiological changes are among the most important reasons behind falling from narrow elevated surfaces. By using advanced virtual reality models, this dissertation aims to highlight some of the possible effects of a destabilizing environment (i.e., elevation above grade) on workers' physiological responses and task performance. More specifically, this dissertation strives to find potential effects of elevation above grade and a moving structural beam as destabilizing environments on construction workers' postural sway, gait pattern, and task performance accuracy. To that end, a series of virtual reality experiments was conducted on thirty volunteers, all students from the University of Nebraska - Lincoln. There were three required VR tasks asked from the subjects once on the ground and again on the 20^{th} floor of an unfinished building: walking on virtual structural beams, standing still on the virtual platform (force plate in reality), and performing hand-steadiness and pursuit tests (physiological battery tests). In addition, to study the plausible relationship between self-perceived fear (and acrophobia) and physiological responses, all subjects were instructed to complete

the electronic James Geer's fear and Cohen's acrophobia questionnaires. The result of this study showed that elevation above grade has a substantial effect on the gait pattern. More specifically, exposure to elevation increases gait stride height variability and decreases gait stride length. As a result, subjects spend more time on gait tasks executed on narrow elevated surfaces. Also, the findings indicated that the presence of the virtual avatar significantly affects gait parameters. The presence of synchronized virtual legs caused subjects to increase their stride height and spend more time on similar virtual tasks on the ground. However, the subjects did not exhibit similar differences once exposed to virtual elevation. Furthermore, the moving structural beam significantly increased the heart rate of the subjects. As part of the steel erection simulation, the experimental results implied that construction workers could show noticeable physiological responses in the vicinity of large moving objects. In terms of task performance, working at height affects the result of the posturography and battery tests. This finding suggests that dual-tasks performed in a static position, and in the presence of elevation-related visual stimuli, can cause a reduction in postural sway. In contrast, in the absence of visual depth, fear of height can positively influence the outcome of the construction tasks performed on elevated platforms.

DEDICATION

This dissertation is for you, Dad.

As you look down from heaven, I hope you're proud of your son.

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Author

Mahmoud Habibnezhad

Table of contents

List of Figures

List of Tables

Chapter 1

INTRODUCTION

Based on the Bureau of Labor Statistics, in 2016 more than 10 percent of all fatal injuries took place at construction sites (Bureau of Labor Statistics, 2016). More precisely, in 2016, 887 construction workers died from job-related accidents. Considering that these losses have reached their highest level in the past 26 years, it would seem that current safety procedures, training, and precautions have not adequately limited injuries and fatalities at construction sites. To mitigate the number of injuries in the construction industry, numerous research studies have been conducted in the past decades. One specific area that needs great consideration is falling incidents, especially those that happen on elevated surfaces. It is alarming because fall-related fatal injuries account for over one-third of fatalities at the construction job sites. Basically, there are two approaches in searching for the root causes of falling: 1. a passive approach in which the risk perception of the worker accounts for his/her unsafe behavior and subsequently might lead to incidents (Abdelhamid & Everett, 2000; Habibnezhad & Esmaeili, 2016; Habibnezhad et al., 2016), and 2. an active approach in which the physiological responses of the worker to the destabilizing environment leads to accidents (Hsiao & Simeonov, 2001). From an active point of view, based on a general consensus among past research, slips, trips, and loss of balance are among the main causes of falling

(Hsiao & Simeonov, 2001). Therefore, many researchers strive to find influential factors affecting the instability and loss of balance. Two of the main dependent factors on which these studies concentrated are postural stability and gait pattern. Considering the prominence of postural stability in falling, the balance mechanism of the human body needs to be studied in detail. There are three main sensory cues involved in human postural stability: visual, vestibular, and somatosensory systems. The resultant association of these sensory systems should maintain the stability of the center of mass of the body against various perturbations. From these three sensory cues, visual input is the most important one because it is associated with the proactive mechanism of balance while the other two cues are considered the reactive mechanisms of balance actuated after the external exposure. Also, based on the study conducted by Hsiao and Simeonov, moving visual scenes and depth perception are among the key elements in provoking instability and negatively affecting balance (Hsiao & Simeonov, 2001). The fact that both of these perturbations are present in activities performed at height highlights the significant role of elevation above grade in affecting the static and dynamic postural stability of construction laborers executing tasks on narrow elevated surfaces. Alternatively, these provoking visual factors also deliver anxiety about the unsafe nature of these perturbations. Numerous studies investigated the effect of anxiety on postural stability and demonstrated that the manifestation of fear could adversely influence postural stability (Boffino et al., 2009; Regenbrecht et al., 1998). Some of these studies used fear and acrophobia questionnaires to measure the self-judged level of fear while others used more advanced and accurate measurement approaches such as measuring variations in the facial temperature (Pavlidis et al., 2002), the level of salivary cortisol (Vreeburg et al., 2010), and heart rate (Schmitz et al., 2012). Due to the ubiquity of smartwatches such as Fitbit and simplicity of collecting heart rate data, this study chose heart rate as one of the physiological responses of construction workers subjected to extreme height. Fall-related experiments can be expensive and dangerous, especially those pertaining to fear of height and flight (Boffino et al., 2009). To overcome these barriers, recent studies explored virtual reality (VR) as an alternative experiment tool. Virtual reality "offers the opportunity to bring the complexity of the physical world into the controlled environment of the laboratory (Keshner, 2004)." According to Burdea and Coiffet, VR is basically "a simulation in which computer graphics are used to create a realistic-looking world" (Burdea & Coiffet, 2003). Due to the intuitive interaction capabilities, and immersion feeling, virtual reality is one of the most rapidly growing technologies in recent years. There are considerable areas of VR applications such as manufacturing design, product design, planning, simulation (Mujber et al., 2004), training, and rehabilitation (Keshner, 2004). Immersion, a wide range of view and haptic feedback provide researchers with a firm ground for safe and cheap experiment designs. Therefore, this evolving technology has been utilized in numerous gait and posture studies (Cleworth et al., 2012; Greffou et al., 2008; Mirelman et al., 2011; Tossavainen et al., 2002; Wallach & Bar-Zvi, 2007). While the design of a dynamic job site can be fairly straight-forward, the user-interaction with the virtual environment (VE), especially user movement in VE, can be challenging. There are two main problems for users to move in a virtual environment: 1. Generally, the VR tracking areas are limited in size and do not have adequate space for natural gait locomotion experiments, and 2. Experiments related to narrow elevated surfaces cannot be performed without the user's ability to see her/his legs in VR. Therefore, many of these studies attempt to utilize VR systems without considering natural ground walking locomotion as a part of their experiments. Their main study concentrations were on the stationary postural sway as the dependent factor or walking on a treadmill in VR caves. For instance, Cleworth et al. (Cleworth et al., 2012) studied the effect of virtual height on the subjects' postural sway standing next to the edge of an elevated surface. While these types of fall-related studies are original and profound, there is still a need for more dynamic VR experiments that can shed lights on deriving factors of fall. These conservative approaches towards gait stability in VR have hindered analysis of fall-related experiments to a great extent. This important gap in the literature lies behind the fact that one cannot walk on a virtual narrow path without looking at her/his foot. To address these gaps in the literature, this dissertation attempts to analyze possible changes in the construction workers' natural walking locomotion at height. More specifically, this study strives to find the relationship between elevation above grade and gait pattern, task performance, postural sway, and physiological responses of construction workers. To the best of our knowledge, no study has investigated the impact of virtual elevation above grade on natural walking locomotion of construction workers at height. Interestingly, by integrating virtual legs to the VR first-person character model, we aim to overcome this obstacle and open a new door to VR fall-related studies.

1.1 Research Questions and Hypothesis

As explained above, the influential factors affecting gait and postural balance are of utmost importance. The role of elevation above grade on the instability of construction workers, especially those exposed to height for the first time, should be investigated thoroughly. Standing, walking, and manual work executed on narrow elevated surfaces such as steel erection are among the most dangerous construction tasks that might lead to the fatal falling event. To study the impact of the destabilizing environments such as elevation above grade and large moving objects as some of the most salient visual stimuli at construction sites, an integrated VR model enhanced with virtual legs was designed and developed using an in-house C# (Studio, 2015) code for Unity3d (Unity3D, 2017). To simulate steel erection, a moving structural beam hung from a crane was designed and added in our VR experiments. As for the task performance of construction workers possibly affected by virtual elevation above grade, a hand-steadiness test and the compensatory circle tracking test was designed specifically for VR. All the experiment setups and procedures aimed to answer these four important research questions:

- Does elevation above grade have any relationship with gait stride length and height?
- Does elevation above grade has an impact on postural stability during a quiet stance?
- Does a moving structural beam, slowly approaching a construction worker, affect her/his postural sway metrics? How about heart rate?
- Can subjects' level of fear be an influential factor in construction workers' postural balance, gait pattern, and task performance? What about the level of acrophobia?
- How does elevation above grade influence the results of neurophysiological battery tests such as compensatory circle tracking and hand-steadiness tests?
- Does elevation above grade affect heart rate during a quiet stance?

While the combination of induced anxiety and instigating visual mismatch affect person working at height, the extent to which each of these factors contributes to physiological response can be quite challenging to measure. Therefore, in this dissertation, whenever the term "elevation above grade" is used, it describes a provoking visual factor accompanied by anxiety and fear of height.

1.2 Objectives

As stated in the problem statement section, the high number of injuries and fatalities at construction sites is alarming. Because the most prevailing cause of construction-related death and injuries is falling, one of the main objectives of this study is to find influential factors affecting the instability of construction workers and subsequent fall-related (fatal) injuries. Another objective of the current study is to present a new VR framework that can simulate gait locomotion on a virtual structural beam by examining new advanced VR models (with synchronized virtual legs). This approach can provide researchers with new insights into VR gait analysis and postural stability. Moreover, this research study strives to discover the influence of elevation above grade and the accompanying fear of height on the task performance of construction workers executing tasks at height. Finally, by simulating a part of the steel erection procedure, the current dissertation aims to find the impact of big moving objects on the postural stability and physiological responses of construction workers. Upon prominent results, this dissertation can open new doors to advanced fall-related simulations and development of innovative virtual models. Also, the findings of this study can be crucial in safety training design and hazard prevention techniques.

Chapter 2

BACKGROUND CONCEPTS AND RELATED WORKS

2.1 Fall

2.1.1 Construction Safety and Falling

With 38 percent of all fatal injuries at construction sites, falling is the leading cause of death and injuries in the construction industry (Bureau of Labor Statistics, 2016). Not only the number of fall-related fatal injuries at construction sites are unacceptable and alarming, but in the past 26 years, the overall trend is ascending, suggesting the need for more profound safety research studies. In addition to the direct cost of life and compensations, these accidents create a bad reputation for construction job sites, presenting them as the most dangerous workplaces in the US. To mitigate the disproportional rate of death and injuries due to falling, numerous fall-related studies have been conducted in the past decades. These studies have striven to shed light on some of the most common and influential factors affecting falling. While some of these studies explored the human's decision-making strategies in executing an unsafe action (Choudhry & Fang, 2008), others investigated more fall-related 'dynamic' elements (Ayoubi et al., 2014; Mirelman et al., 2011). The decision-making approach takes into account the risk perception of construction workers as the main influential factor impacting

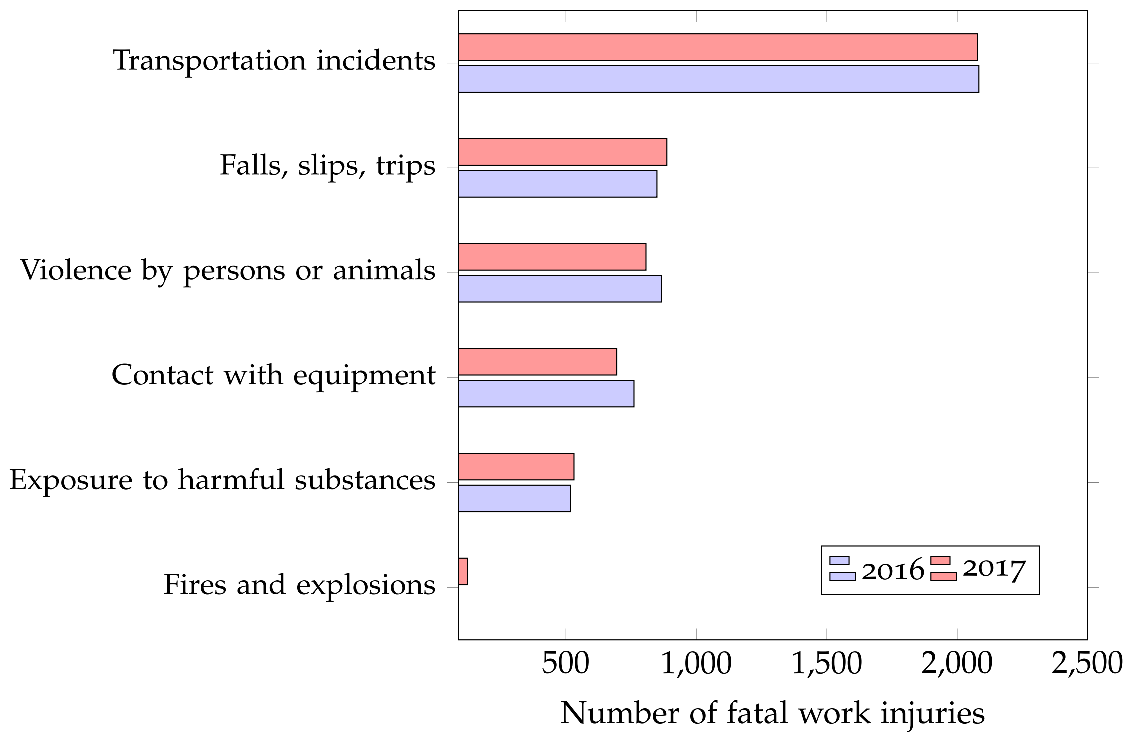


Figure 2.1: Fatal Occupational Injuries by Major Event, 2016-17

falls in the first place. More specifically, these types of studies attempt to find the relationship between construction workers' decision-making strategy and their risk perception, national culture, eye tracking metrics, and other independent factors. On the other hand, there are plenty of studies that have focused on the other factors of falling, such as loss of balance. In the study conducted by Hsiao and Simeonov, slips, trips, and loss of balance were the main reasons behind falling, especially from elevated surfaces (Hsiao & Simeonov, 2001). As intuitive as it can be, postural stability is one of the main causes of falling. Therefore, to study the driving factors of falling, one needs to study the instrumental factors affecting postural stability and instability.

2.1.2 Falling and Postural Stability

Postural stability is dependent on the balance mechanism of the human body and defined as "the ability to maintain and control the body center of mass within the base of support to prevent fall and complete desired movements" (Greffou et al., 2008). Postural regulation is the result of three main sensory cues: visual, vestibular, and somatosensory inputs. From these three sensory cues, only visual input is considered as a proactive afferent, compared to the other two cues triggered after the external exposure (Hsiao & Simeonov, 2001). This point highlights the paramount role of visual input in the stability mechanism of the human body. The unique contribution of visual input in postural stability has been studied exhaustively (Paulus et al., 1984; Sundermier et al., 1996). These studies suggest that the differences between the visually perceived self-motion and the external-motion are the cause of instability commonly induced by visual stimuli (Clement et al., 1985). Schieppati et al. showed that eyes being closed reduces postural stability (Schieppati et al., 1999). In addition, Van Asten demonstrated that moving visual scenes adversely influence postural stability during the quiet stance (van Asten et al., 1988; Lestienne et al., 1977). Interestingly, visual sensory afferent plays a crucial role in postural balance when the proprioception is reduced, or both of the other two cues are deficient (Lacour et al., 1997). As stated by many scholars, due to the instigating visual mismatch and depth perception, elevation above grade can affect postural regulation and lead to falling. In the critical review of Hsiao and Simeonov (Hsiao & Simeonov, 2001), elevation above grade, depth perception, moving a visual scene, visual ambiguity, and obstacle detection are among the most significant environmental and visual factors that cause instability and subsequently result in falling. In the current study, two of these five perturbations are selected for further revision. In other words, subjects' physiological responses will be investigated in these two situations: 1. In the presence of elevation above grade (extreme height) and 2. moving structural beam slowly approaching the subjects. There is another important factor accompanied by elevation above grade, and that is fear of height. The next section addresses the association of fear of height with elevation and its impact on postural stability (and task performance).

2.1.3 Elevation and Fear of Height

Past research showed that threatening environments in VR such as standing on the edge of a simulated building evoke anxiety and physiological arousal similar to those reported under real height conditions (Cleworth et al., 2012; Meehan et al., 2005; Simeonov et al., 2005; Wilhelm et al., 2005). The amount of fear induced by virtual elevation has a direct relationship to the extent to which the person perceives height (Simeonov et al., 2005) and the associated risk (Menzies & Clarke, 1995). The induced anxiety from fear of height provokes physiological responses, including an increase in heart rate (Emmelkamp & Felten, 1985). Also, fear of falling influences postural stability and intensifies postural sway (Cleworth et al., 2012).

2.2 Virtual Reality

2.2.1 Virtual Reality and Postural Stability

Virtual reality (VR) technology provides a firm basis for the simulation of immersive environments by which the user can perceive 'close to reality' insights. VR is capable of replacing users' real-world experience with a computer-generated 3D environment. This enhancement is crucial in many safety research studies and helps users perform ‘dangerous’ tasks that were not possible otherwise. Therefore, relying on the versatilities of VR systems in generating various (destabilizing) environments, numerous safety research studies have been widely conducted in the past 20 years (Horlings et al., 2009; G. Li et al., 2018; Tossavainen et al., 2002; Cleworth et al., 2012; Akizuki et al., 2005). Because induced anxiety and perceived fear is highly correlated with postural sway, in many safety research studies, VR has become the key equipment for experimental design and virtual environment (VE) development. Although VR is a promising tool in inducing the feeling of presence, some studies suggested that the body sway found in the eyes-closed condition is similar to that of VR (Horlings et al., 2009). Alternatively, recent studies reported that not only are the eyes-open and eyes-closed conditions not different in terms of body sway, but the static VE does not increase postural sway. Li et al. extensively investigated the effect of visual stimuli on the stability and complexity of postural control (H. Li & Trocan, 2018). They concluded that dynamic virtual environments could evoke active postural instability, especially in the anterior-posterior direction (AP).

2.2.2 Virtual Reality and Fall

Anxiety-related behavioral and psychological studies have considerably employed VR technologies in their experiment design procedures (Boffino et al., 2009; Cleworth et al., 2012; Regenbrecht et al., 1998; Rothbaum et al., 1995; Wallach & Bar-Zvi, 2007). A higher level of anxiety perceived due to elevation above grade is directly related to a higher feeling of presence and immersion. By following this rationale, literature used VR systems to convey the fear of height to the subjects, and consequently, investigate the impact of anxiety-related accidents or rehabilitate people who have acrophobia (Regenbrecht et al., 1998; Wallach & Bar-Zvi, 2007).

Researchers applied VR technologies to study the impact of elevation above grade on the subjects' anxiety level in real and virtual experiment conditions (Cleworth et al., 2012). As reported by many studies, by using VR-based rehabilitation tools, there was a substantial difference between the result of the self-reported fear and acrophobia questionnaires before and after treatments (Rothbaum et al., 1995). These studies showed that VR could closely simulate the anxiety provoked by being on a narrow elevated surface, and be a valuable research and rehabilitation tool for people with balance regulation deficits associated with fear or height (Habibnezhad, Puckett, Fardhosseini, Jebelli, et al., 2019).

2.3 Task Performance

2.3.1 Measuring Task Performance

While task performance is regarded as the essential determinant of the time and accuracy of finishing designated job, various aspects of task performance can be utilized to quantify this term. More specifically, in the context of construction, task performance can be mainly related to the neuromuscular speed, strength, arm-hand steadiness, and fine motor performance (Rigal, 1992). The experimental quantification methods are mostly revolved around certain famous neurophysiological performance batteries such as placing a dot in various sized circles or holding a stylus in various sized holes for certain amount of time (Kakehbaraei et al., 2017; Kaur et al., 2007; Rigal, 1992; Smith et al., 1977). Although most of these methods are considered to be robust and effective in measuring neurophysiological performance, due to each trial's limitation of time, and virtual space, their impact on the realism of the virtual environment was questionable. This concern is relevant because the context of these tests were not in line with a real construction

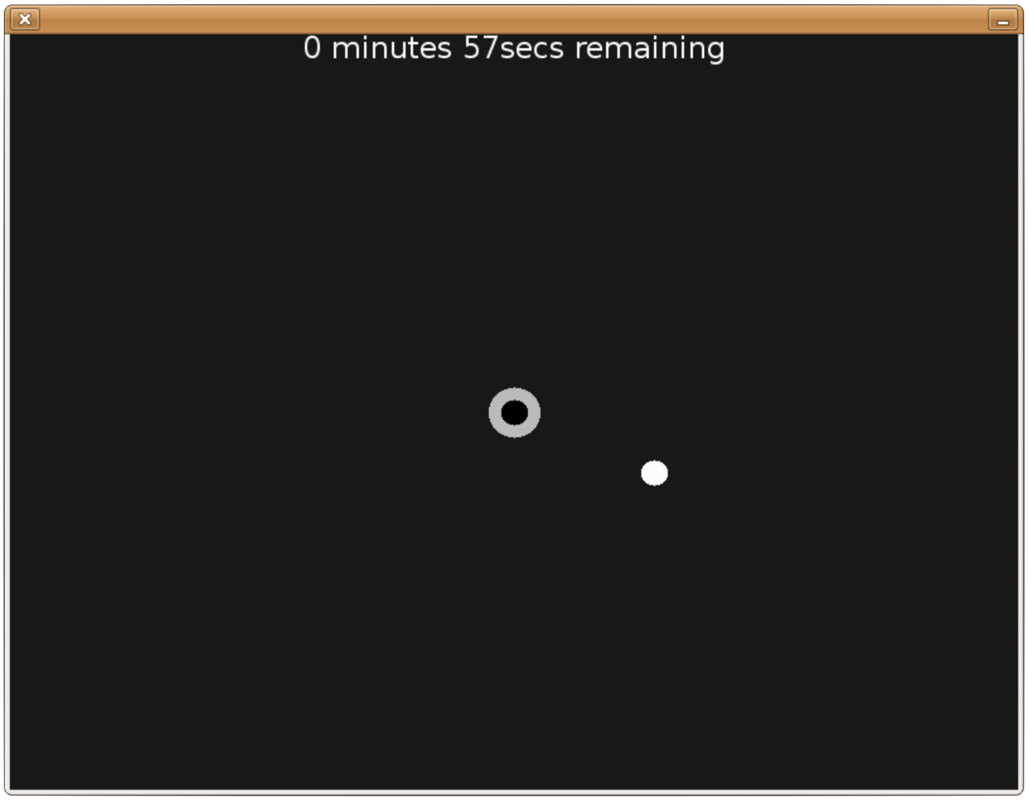


Figure 2.2: An Screenshot of the PEBL Compensatory Tracking Task.

scenario. Alternatively, subjects' induced anxieties should be as close to reality as possible. Therefore, the task performance tests were designed to measure the hand-steadiness and tracking capability of the subjects in the VR environment. As such, these test will impose minimum interference to the subjects' VR experience and provide a suitable technique in measuring subjects' postural metrics. We believe that these two tasks can strengthen each other in extracting the neurophysiological responses of the subjects exposed to destabilizing environments such as narrow elevated surfaces.

2.3.2 Task Performance and Height

While neurophysiological battery tests can assess the performance of the subjects at elevation, due to our specific (and intentional) experiment design, their results should be more associated with the fear of height rather than depth perception or visual stimuli. The reason lies behind the fact that in both tasks, subjects are not looking down during the tests and are focusing on the whiteboards placed in front of them. Although the subjects will be asked to look at their feet once before the start of the test, during the battery tests all their attention is concentrated on the boards. On the other hand, the natural walking task can be a great example of a task executed while the subjects are subjected to visually perceived height. The extent to which one is looking at her/his feet is correlated with the wideness of the path. For example, when one is instructed to walk on a narrow-elevated surface such as a structural beam, the completion of the task is not possible without sufficient attention to the path and the exact location of his/her foot placement on that path. This rationale ensures that subjects need to look at their feet when they want to walk on a structural beam. Therefore, any changes in the gait pattern of the subjects or their postural sway are directly affected by the influence of elevation above grade as a visual stimulus (and fear of height). While the amount to which postural stability and gait pattern are influenced is unknown, it is certain that neurophysiological battery of tests will be less affected by visual input compared to tasks involving gait locomotion on narrow elevated surfaces.

Chapter 3

METHODOLOGY

3.1 Subjects

3.1.1 Human Subject's Consideration and Clearance from IRB

The study protocol, along with the fliers and consent forms, were approved by the Institute Review Board (IRB). Prior to the experiments, all the subjects were informed of the experiment procedures and related IRB protocols, including the freedom to withdrawal at any time during the study. Also, all of them signed the written consent form, which explained all the experiment procedures and possible side effects of VR experiments such as dizziness and nausea.

3.1.2 General Information about Subjects

Two groups of subjects were recruited from the University of Nebraska - Lincoln (UNL) for three different VR experiments: 1. gait locomotion, 2. postural stability during a quiet stance, and 3. task performance. The first group consisted of 12 healthy subjects (5 females, mean age: 32 years, seven males, mean age: 28) and the second group consisted of 18 healthy subjects (8 females, mean age: 30 years, ten males, mean age: 32) and had not had any VR experiments before participating in this study. In Group 1, the subjects' average height and weight were respectively 5′ 8″ and 157 lbs, and in group 2 were 5′ 8″ and 148 lbs. All the subjects had a normal or corrected-to-normal vision and stated no ocular or neuromuscular disorder that can influence their stability.

3.1.3 Subject Attrition

From the 14 subjects recruited for the first VR experiment (Group 1), one female subject was not able to continue the experiment procedures in the initial phases of data collection. The subject attrition was due to her extreme level of acrophobia. Accordingly, the collected data were not adequate for further analysis and usage.

3.1.4 Missing Data

From the first group of subjects, two subjects were removed from further data analysis, subject #1 and #2. subject #1 was not instructed to perform some gait analysis due to some technical problems during the data collection. Also, data collected from the trackers mounted on the back torso, and both ankles of subject #2 were not correctly triggered for collecting data during the experiments. Although later, all the technical problems were resolved, the missing data forced the researcher not to include these subjects' data information in the analysis.

In experiment #3, five subjects had missing data in their third trial, "randomized pursuit task on the ground". All the text files associated with the force plate's stored data were empty. Therefore, these subjects were omitted from all the paired two-tail T-tests performed on the postural metrics concerning the third and fourth trial of experiment #3.

3.2 Apparatus

The main experimental devices utilized included:

- An HMD device (HTC Vive pro headset): This VR headset has an OLD display and 1440 by 1600 pixels per eye. The device refresh rate is 90 HZ and has 110° field of view. The tracking capability of the headset is 33 by 33 feet, which makes this VR headset one of the best VR devices for VR safety studies.

Figure 3.1: A Picture of the HTC Vive Pro VR Headset (on the Left) and HTC Vive Tracker (on the Right)

- Three HTC Vive Tracker: With 6 degrees of freedom for tracking, these trackers can accurately send their coordinate information 90 times per second.

- AMTI Force Plate: The AMTI AccuSway Force Plate is highly capable of calculating and storing the trajectory of the center of pressure (COP) mapped on its surface. Based on the company specifications for AccuSway, the accuracy of the force plate for measuring COP_x and COP_y is less than 0.5mm.

Therefore, all the resultant values for the postural sway parameters is rounded to comply with the accuracy standards of the force plate.

Figure 3.2: An AMTI Force Plate (on the Left) and the Sensor Collector Fitbit App (on the Right)

- Dell Alienware: With Intel® Core ™ i7-6950x CPU @ 3.00 GHz, installed memory (RAM) of 64.0 GB, and two NVIDIA GeForce GTX 1080, this workstation can leniently provide the rendering power for the HTC Vive Pro headsets.

- Fitbit Versa (to measure heart rate): by using an in-house JavaScript code, this smartwatch can collect the heart rate of the subjects and send them to an online database. To improve the synchronization procedures, the start and stop events for each trial on the Fitbit Versa can be triggered remotely from the companion smartphone.

All the VEs have been designed and developed by Unity3D Game Engine (version 5.3, Unity Technologies, CA, USA).

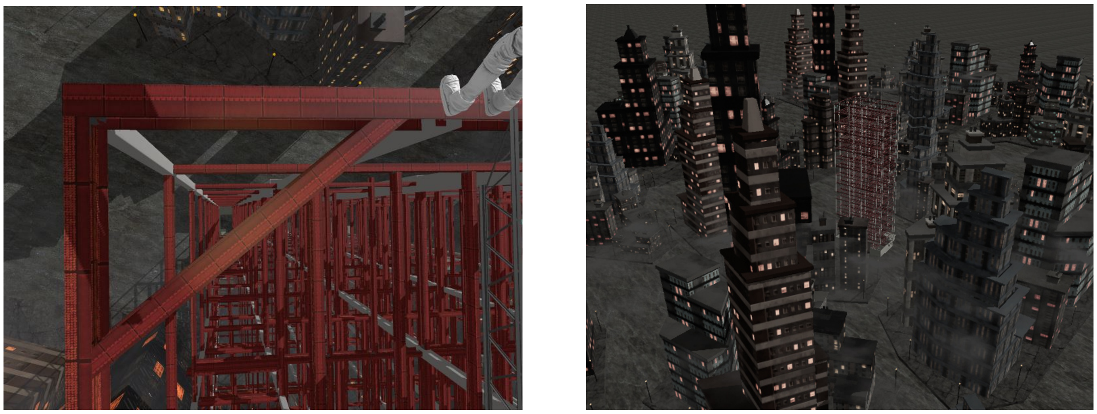


Figure 3.3: The Experiment VE Design Including a Twenty-story Unfinished Building

3.3 Measures

3.3.1 Fear Questionnaire

The famous James Geer Fear Questionnaire was used for measuring the self-judgmental level of fear in the subjects (Geer, 1965). The questionnaire consists of 50 questions regarding frightening objects or situations. For each item, by using a Likert-scale multiple-choice (none, very little, a little, some, much, very much, terror), the subjects were asked to select the choice that most closely described the amount of fear they felt toward the object or situation.

3.3.2 Acrophobia Questionnaire

To measure the level of acrophobia in the volunteers, Cohen Acrophobia Survey was selected for this study (Cohen, 1977). The Cohen Questionnaire was designed to measure the extent to which a person feels anxious towards a list of situations that can cause fear of heights (e.g., driving over a bridge, walking over a sidewalk grating, or sitting in an airplane). More specifically, in each item, the volunteer rated from 0: not at all anxious to 5: terror anxious, to express her/his anxiety level corresponding to that situation. In addition, for each question, the subject was asked to report the selected avoidance level for the pertinent situation (would not avoid doing it, would try to avoid doing it, and would not do it under any circumstances). Cohen's survey consists of twenty items.

3.3.3 Heart rate

Subjects' physiological recordings were performed using a Fitbit Versa smartwatch. The in-house script was written and developed in Fitbit Studio with which complete control over the execution and halt of the sensor data collector app was possible remotely (API, 2019). For initializing the data collection, the subject number was set in the data collector app. As stated above, to ensure a smooth and synced data collection procedure, the start and stop event of the HR data collection were triggered remotely. With this technique, all the data collector devices such as AMTI Force Plate, HTC Vive Trackers, and Fitbit Versa were started and stopped within an acceptable one-second delay. Once the data were collected from the volunteer, the relevant file containing all the HR data were sent to the companion (synched Pixel 3 XL smartphone), and subsequently, from the companion to the cloud database. Later, all the HR data were retrieved from the server, and then analyzed by MATLAB software (MATLAB, 2017).

3.3.4 Postural Metrics

3.3.4.1 Total Excursion of the COP

Total excursion (TE) of the COP can be defined as the sum of all distances traveled by COP during the course of a trial. Simply stated, the length of a path generated by connecting all the successive COP locations is the total excursion of the COP. Figure 3.4 demonstrates the path of the COP generated in a single trial. As suggested by the literature, increase in TE is associated with a decrease in postural ability to maintain balance (Ekdahl et al., 1989; Holme et al., 2007; Uimonen et al., 1992). However, the use of the TE index for stability inferences should be approached with cautions. Several small postural excursions pertaining to a stable posture can produce a large TE, or inversely, a few big displacements of COP in an unstable postural balance trial can generate a small TE. To overcome these misinterpretations, many researchers use COP velocity, which is expressed as TE over the trial duration (Baloh et al., 1998; Magnusson et al., 1990; Norré, 1993). A steady, upright stance is associated with lower COP velocity, whereas an unstable postural balance is correlated with higher COP velocity. Because the TE and COP represent a combination of anterior-posterior (AP) and mediolateral (ML) directions, a solo usage of TE and COP velocity cannot be a good indicator of stability in postural stability trials.

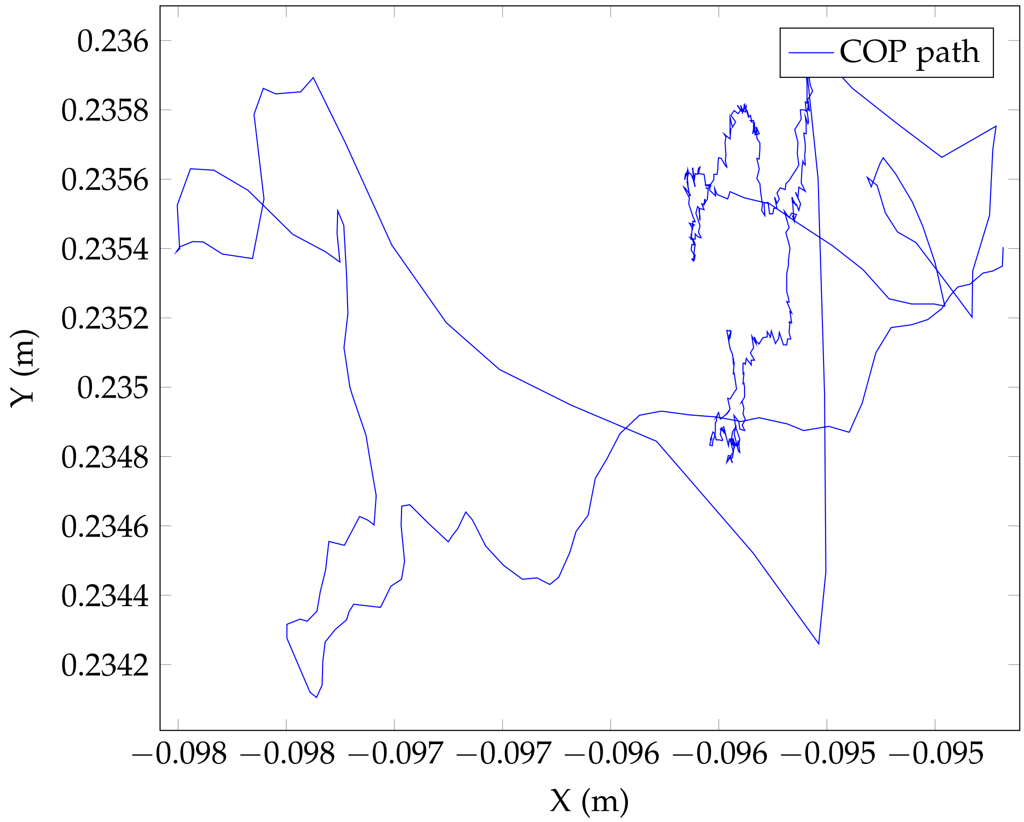


Figure 3.4: A sample path of COP during the course of a trial

3.3.4.2 Root-mean-square Amplitude of the COP

Root-mean-square (RMS) amplitude denotes the standard deviation of the translation of the COP. As reported by many scholars, RMS amplitude is a reliable measure for evaluating postural balance (Geurts et al., 1993; Le Clair & Riach, 1996). Another powerful, and yet different, postural metric is RMS velocity defined as the average COP translations divided by time. Similar to TE, a decrease in RMS amplitude and velocity suggests a higher upright postural stability. Interestingly, both of the postural metrics are sensitive to proprioception alternation and visual deprivation.

3.3.4.3 Maximum Absolute Amplitude Distance of COP

The absolute maximum amplitude represents the absolute maximum translation of the COP from its average. Similarly, the absolute minimum amplitude denotes the absolute minimum distance of COP from the mean. A decrease in the maximum or minimum amplitudes suggests an increase in postural stability and sustainable balance. However, since these two parameters are obtained from only two data points, they vaguely, or sometimes even incorrectly, describe the upright regulation of subjects.

3.3.4.4 Peak-to-peak Amplitude of the COP

The difference between the maximum and minimum amplitudes of COP is called peak-to-peak amplitude. Although the peak-to-peak amplitude can be an informative parameter in postural stability data analysis, however, this representing variable can misinterpret the changes in postural balance. Therefore, for postural control evaluation, the peak-to-peak amplitude should not be employed (Palmieri et al. 2002).

3.3.5 Gait Characteristics

Human gait is defined as the "the motion of a complex mechanical system with a large degree of freedom and several driving forces" (Bazkiewicz et al., 2014). One of the techniques used in clinical gait analysis is the spatial and temporal measurements of gait cycles. To address the differences between two gait measurements, researchers commonly use kinematic parameters such as walking speed, gait stride length, and gait stride height (McGinley et al., 2009). Not only can the average speed and length of these parameters be beneficial, but a careful study on their variabilities can present valuable insights about the role of influential independent factors. For example, in the presence of fear of height, a higher level of walking disorder parameters has been reported (Ayoubi et al., 2014; Habibnezhad, Puckett, Fardhosseini, & Pratama, 2019).

3.3.6 Task Performance

3.3.6.1 Hand-shake Steadiness

There are various approaches in assessing individuals' neurophysiological responses (Rigal, 1992; Kakehbaraei et al., 2017; Kaur et al., 2007; Smith et al., 1977). The experimental quantification methods for these types of tests mostly revolve around certain famous neurophysiological performance batteries such as placing a dot in various sized circles or holding a stylus in various sized holes for a specific amount of time. However, the situation might be different when subjects are in construction VE. The quality of the test cannot be guaranteed using virtual stylus and holes. Also, the virtual replica of these tests can reduce the level of realism which is essential for this study. Therefore, to preserve the feeling of immersion and realism, a hand-steadiness battery test was developed similar to the construction welding tasks. This measurement technique consisted of two objects, one of the HTC Vive Controllers presented as a welding device in VE, and virtual plate on which the subjects perform the test. Because the controller appears as a welding device in VE, there is a virtual metal stick ("electrode") attached at the end of the controller. There are two patterns on the virtual plate, a horizontal line and a half-circle facing upward with a negative curvature. First, for accuracy measurement, from each path the corresponding C# script selects 100 points equally distributed. Then once the user completes the hand-steadiness battery test for each of the selected points from the previous procedure, the program calculates the perpendicular distance of the closest welding point created by the user. Finally, the application will report the average of all the computed distances and present an accuracy index for each pattern. In addition, the application reports the average and standard deviation of all distances computed from the tip of the electrode to the metal plate.

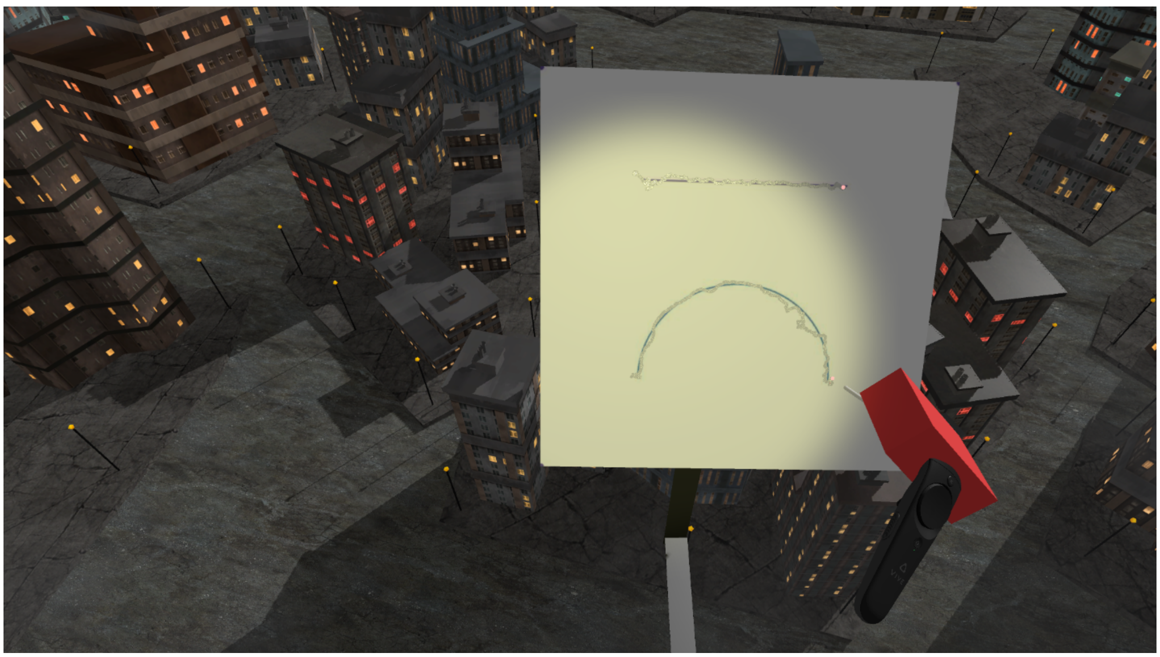


Figure 3.5: The Hand-steadiness Test with the Virtual Metal Plate and HTC Vive Controller Appeared As a Welding Device in VE

3.3.6.2 Randomized Pursuit Task

As discussed in chapter #2, another method for measuring the performance of the subjects is to use compensatory circle tracking and pursuit tasks. By assessing eye-hand coordination, these battery tests are some of the best techniques for computing tracking and compensatory performance. However, there is a difference between pursuit tasks and compensatory tasks. In pursuit tasks, an operator needs to follow a moving 'target' affected by outside forces, while in compensatory tasks, the operator is asked to place a moving indicator back into the reference points. As Senders pointed out, "Pursuit tracking of the sort reported" in his study "is more accurate than compensatory tracking by a large factor" (Senders, 1952). In his study, Senders stated that the compensatory tasks have a more stochastic nature compared to pursuit tasks.

Following this rationale, the current study developed a pursuit task in which the randomized movement of the target (circle) is not predictable. In other words, the target does not have a smooth path and the whole movement of the circle is on various-length line segments. In addition, to increase the unpredictability of the movement of the target, there is a minor pause between each segment paths that makes it harder for the subjects to predict the next direction of the target. Accordingly, in various situations, this approach can differentiate the battery test scores better and highlights the latent changes in subjects' task performance.

For each successful data collection, the randomized pursuit test provides time series data associated with the location of the indicator controlled by the user and the location of the target controlled by the script (invariant with regards to the subjects). By using appropriate mathematical procedures, much useful information can be derived from these time series data. For example, the accuracy index can be computed by adding all the distances between the location of the target and indicator during the course of the trial. Another valuable piece of information concerning how the subject tracked the target can be calculated by following the 'smoothness' of the path generated by the subject while performing the task. More accurately, the average sum of all the angles between the two consecutive line segments on the indicator's path can represent the steadiness of the hand in generating a smooth path.

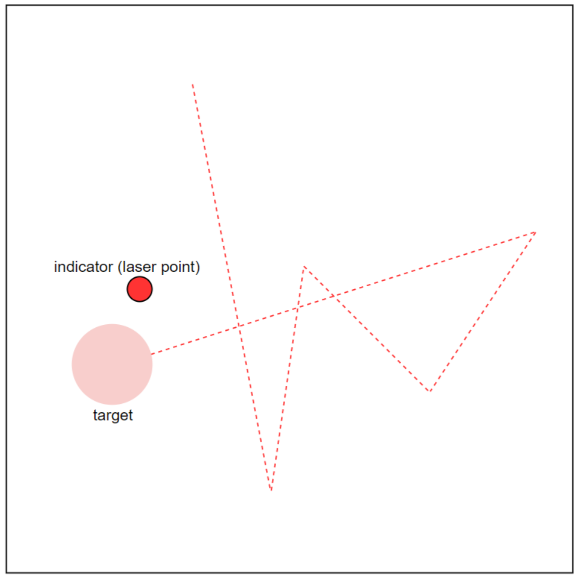


Figure 3.6: This Figure Shows a Target Moving on a Segment Line-based Path and an Indicator Following It

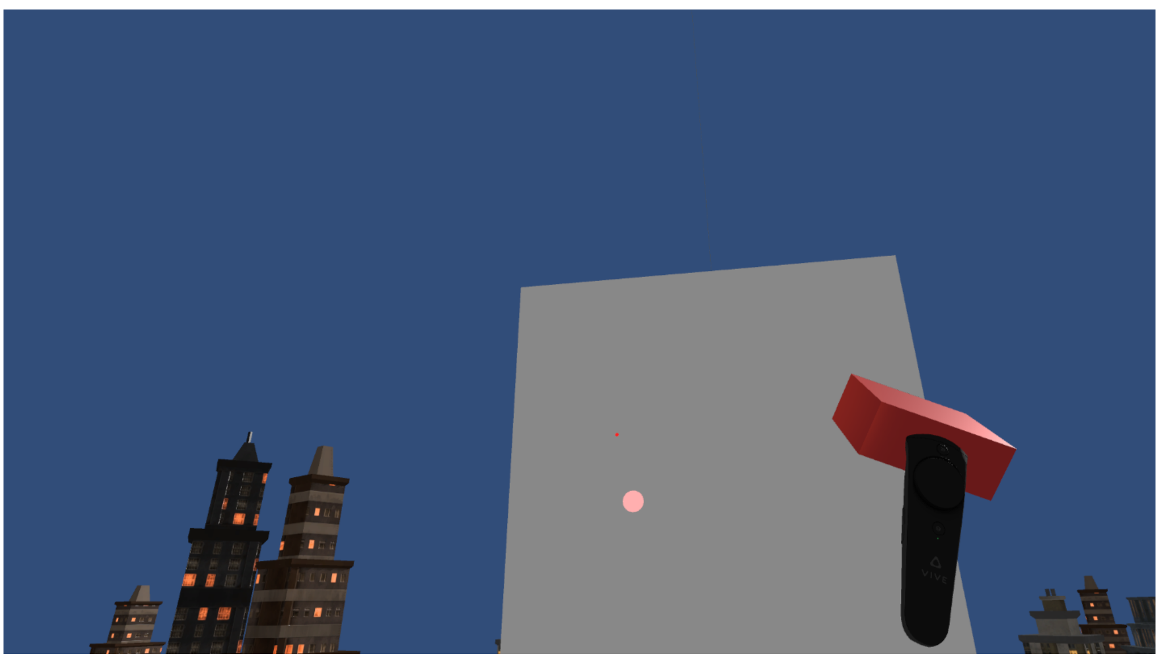


Figure 3.7: The Randomized Pursuit Task Performed in VE

3.4 Research Design

3.4.1 Dependent and Independent Variables

A short recall of the dependent and independent variables...

3.4.2 Graph of the Research Design

3.5 Interactive Virtual Reality Models

3.5.1 Driving Reasons for Developing the Advanced VR Model

The idea of walking on a narrow path (i.e. structural beam) in a virtual environment was the main motive for designing the current advanced first-person VR model. Since walking on a narrow path requires person to look down and follow the path, the absence of virtual legs can lower the immersion feeling. On the other hand, if the narrow path is elevated, the feeling of presence will be dramatically improved by synchronized virtual legs. The synchronized virtual body parts are computer-generated 3D objects that can simulate the geometry and movement of the user's corresponding body parts. In Unity3D (Unity3D, 2017), this synchronization is fast and seamless and provides a higher immersion experience for the user. Therefore, the addition of synchronized virtual legs to the first-person virtual model can improve the feeling of realism and immersion in VE and even make it possible to walk on a real structural beam (future work) virtually. Not only has this dissertation employed these advanced synchronized VR legs for more precise results and conclusions, but the impact of virtual legs on the subjects' gait pattern has been investigated as well.

3.5.2 Design procedures of the models

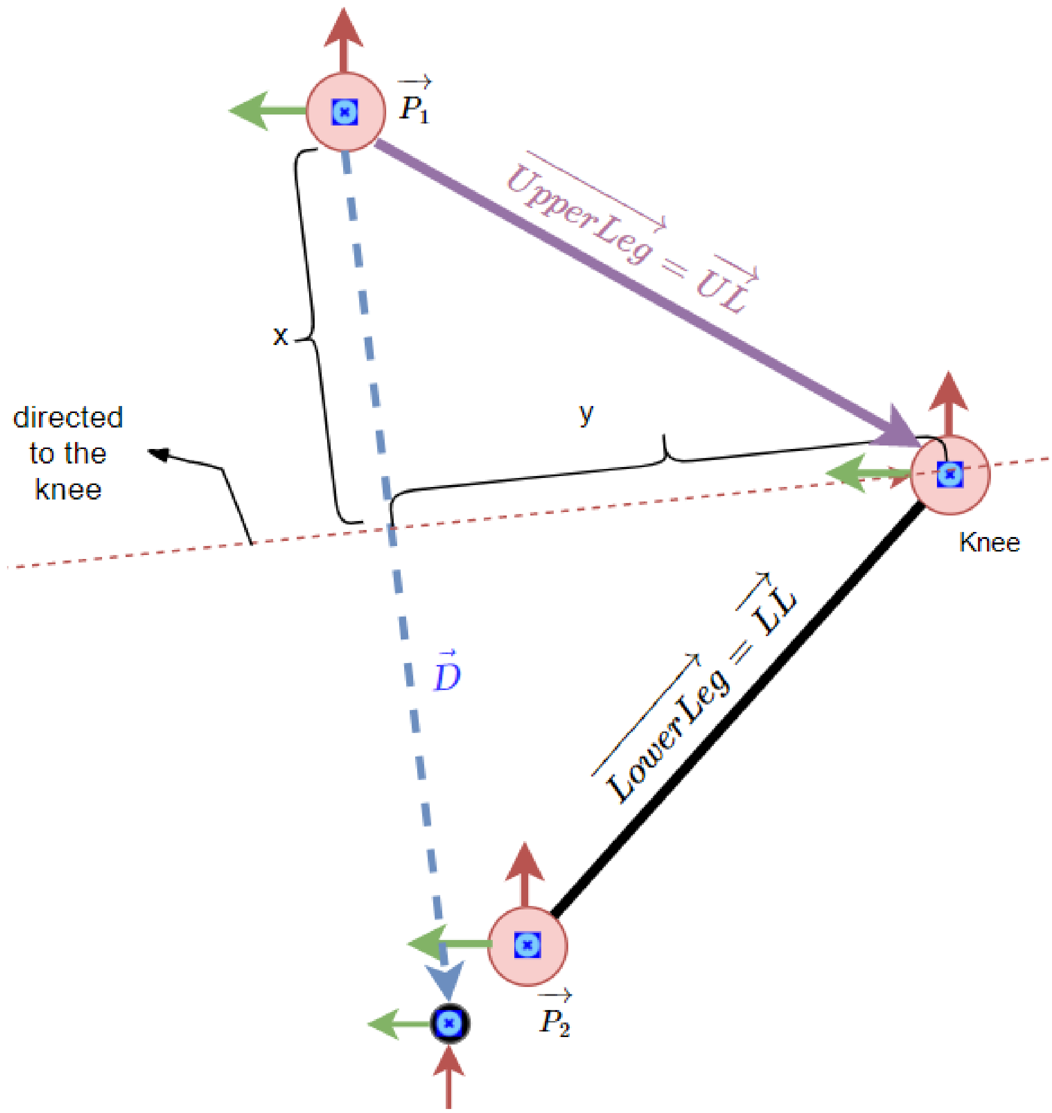


Figure 3.8: This Figure Demonstrates a Vector Representation of a Human Leg with Which the Location of the VR Knee Can Be Calculated.

The first step towards designing synchronized virtual legs is to find the least number of trackers necessary for simulating the movement of the legs. This step is fairly easy because the lower and upper parts of the leg are assumed to be rigid and will not bend or change size. Therefore, if the position of the ankle and Coxal is known, then the position of the knee can be calculated by using trigonometric relationships. Therefore, by mounting two trackers on the feet and one tracker on the waist, the modeling of the legs can be performed. Formula 3.1 determines the position of the knee and consequently the necessary rotations in the root of the leg. Here, $\overrightarrow{P_1}$ represents the location of the root of the leg, $\overrightarrow{P_2}$ represents the location of the ankle, and $\overrightarrow{D}$ represents the direction vector with $\overrightarrow{P_1}$ as the origin and $\overrightarrow{P_2}$ as the destination. x is the horizontal distance between $\overrightarrow{P_1}$ and the location of the knee and y is the vertical distance between $\overrightarrow{P_1}$ and the location of the knee. The vector representation of human leg can be found in Figure 3.8.

$$\begin{cases} \overrightarrow{D} = \overrightarrow{P_1} - \overrightarrow{P_2} \\ (\overline{D} - x)^2 + y^2 = \overline{LL}^2 \\ x^2 + y^2 = \overline{UL}^2 \end{cases} \tag{3.1}$$

$$x = \frac{\overline{UL}^2 - \overline{LL}^2 + \overline{D}^2}{2\overline{D}} \tag{3.2}$$

$$y = \sqrt{\overline{UL}^2 - x^2} \tag{3.3}$$

Here, the height of the person will be calculated automatically by using the location of the trackers and the headset. By using this information, the length of the upper and lower legs can be estimated. However, an important caveat is that the estimated length of the upper and lower legs leads to an estimated value for the location of the knee. While this procedure might not affect the level of immersion during gait locomotion, further study is required to assess the accuracy of such a technique. Another caveat is that the motion simulation of the legs is dependent on the z-axis direction (by which the knee's bending plane is defined). In this simulation, $\overrightarrow{Z}$ is the result of the cross product of $\overrightarrow{D}$ and $\overrightarrow{Y}$. The direction of the foot determines the direction of $\overrightarrow{Y}$. In other words, the knee's bending plane is specified by the direction of $\overrightarrow{Y}$. Although in a normal walking task, $\overrightarrow{Y}$'s direction is in line with the walking direction, higher-level simulations are required for more complex leg movements and accurate leg modeling.

3.6 Experimental Procedures

There were three main experiments in this study, attempting to collect data about postural stability during a quiet stance, natural gait locomotion, and task performance, respectively. The virtual environment was simulated by using Unity3D (Unity3D, 2017). In all of the experiments, subjects were exposed to two main virtual scenes: a small city with no traffic and pedestrians, and an unfinished 20-story building. The unobtrusive design of the virtual environment helps to reduce unintended visual distractions. To improve the feeling of presence and realism in the VE, the first-person VR model was equipped with synchronized virtual legs. As stated in Chapter Three, also, to minimize the postural perturbations induced by the VR headsets (Horlings et al., 2009), subjects were asked to walk or perform tasks in VE physically. Finally, in an attempt to reduce the habituation effect, all the subjects were asked to perform relevant experiment tasks on an unelevated virtual ground for one minute. At the end of each experiment, all subjects were asked to fill out the fear and acrophobia questionnaires.

3.6.1 Experiment #1

The experiment consisted of three trials, namely no VR, no height VR, and height VR. During each trial, subjects were instructed to stand on the center of a force plate in a quiet stance mode and open their legs to the extent to which they are comfortable and most stable. In every trial, the heart rates of the subjects were collected by using the Fitbit smartwatch, and their COP was retrieved by using the force plate. In the first 20-second trial, while standing, subjects were asked to look at their feet for two seconds and then return to their initial posture. Because any movement on the force plate will influence the postural sway of a person and, to preserve consistency, they were instructed to execute the same task in the same manner performed in other trials. They were not allowed to bend their knees or bend to their left or right. In the second part of the experiment, all subjects were exposed to VE. Again, they were asked to look at their feet in the most convenient natural way, but not to bend their knees or bend to their left or right. At the end of the 20 seconds, the subjects were informed that a virtual structural beam hung from a crane wire will slowly approach them. They were also informed that the moving structural beam will not 'hit' them and will stop one feet away from their bodies. The total duration of the second trial was thirty seconds. The last trial was identical to the second trial with the difference that subjects were exposed to elevation in VR. Accordingly, once they looked down to their feet, they noticed that they were placed on the edge of the 20^{th} floor of the unfinished building. Figure 3.9 depicts a schematic presentation of the setup for the first experiment.

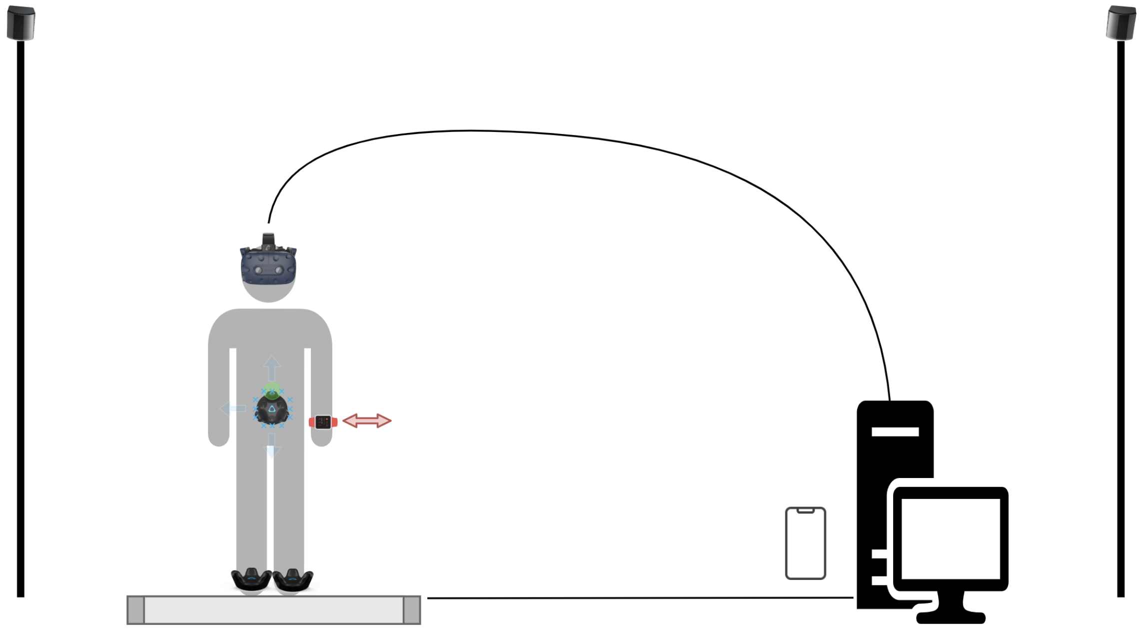


Figure 3.9: A Schematic Figure of the Experiment Room Along with the Experimental Devices Used to Simulate VR and Capture Subjects' Postural Sway and HR

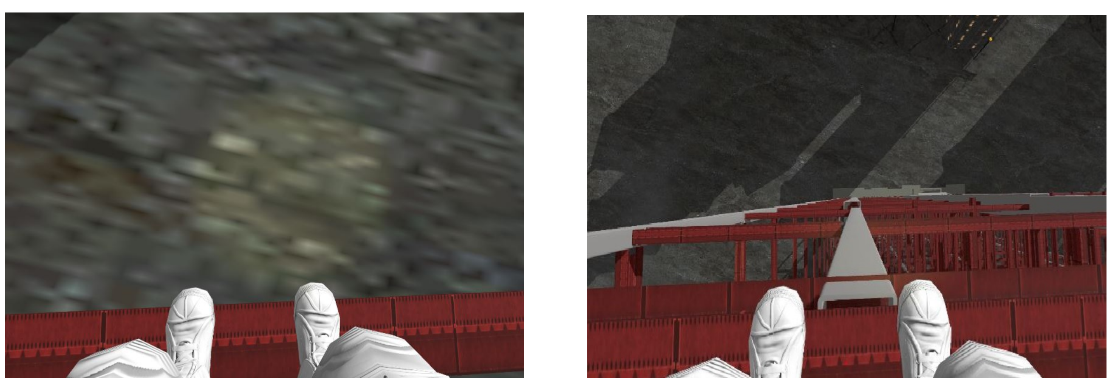


Figure 3.10: A Comparison between the Influence of Elevation Above Grade on Subjects' Postural Sway Measured by Force Plate during a Quiet Stance

Figure 3.11: A Comparison between the Effect of a Moving Structural Beam on the Postural Sway (and Physiological Responses) of a Subject Computed Once on the Ground and Once at Height

3.6.2 Experiment #2

The second experiment was mainly designed for collecting gait data. Twelve subjects, five females and seven males, were randomly selected for this gait experiment. As can be seen in table 3.1, two different scenarios were designed for the gait experiment, each with two settings: one with no VR leg enhancement and the other one with VR leg enhancement. Prior to the start of the experiment, all the subjects were equipped with the three HTC Vive Trackers and the HTC Vive headset. During the first trial, subjects were asked to walk on the unelevated 'immersed' beam path (Figure 3.13) at a comfortable speed, while they could see their virtual legs dynamically superimposed on their real legs. As stated by the subjects after the experiment, the use of synchronized virtual legs dramatically improved their feeling of presence and immersion. In the second trial, all of the subjects were instructed to walk on the same path, but this time, on the 20^{th} and last story of the unfinished building. Moreover, the virtual legs were still visible to the subjects. The last trial was similar to the second trial except that the virtual legs were excluded from the first-person VR model.

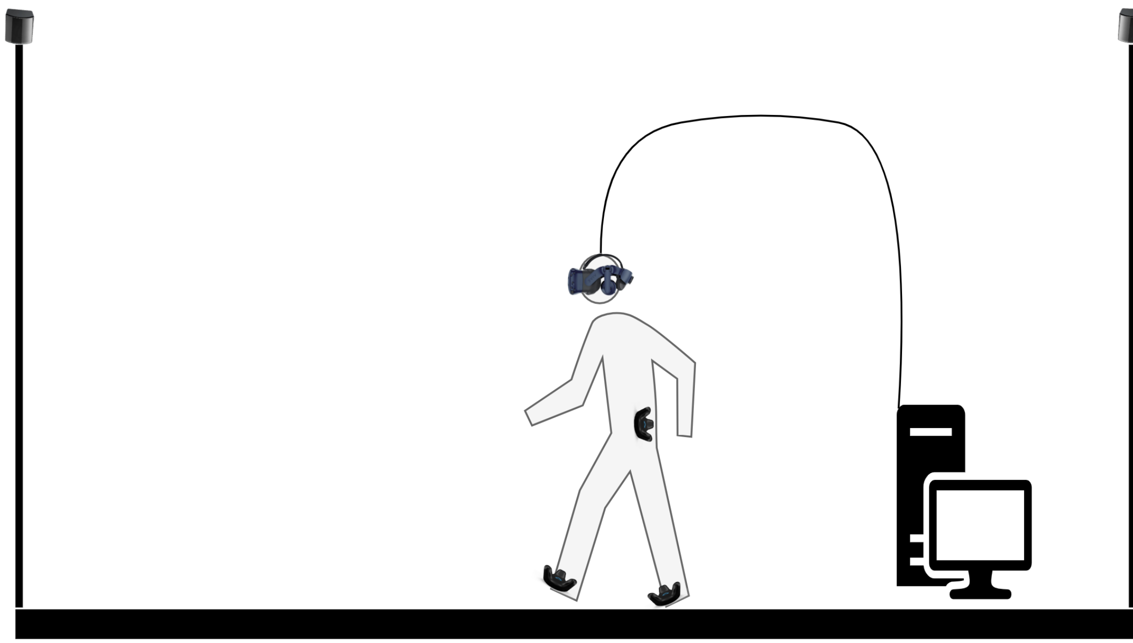


Figure 3.12: A Schematic Figure of the Experiment Room Along with the Experimental Devices Used to Simulate VR and Capture Subjects' Gait Patterns

Table 3.1: Experiment Configuration for Gait Data Collection

Setting	Scenarios	
No virtual legs	VR path on the ground	Elevated VR path
Virtual legs		

Figure 3.13: Subjects Were Asked to Walk on the Same Path Once on the Ground and Once at Height

3.6.3 Experiment #3

This experiment was devised to collect the neurophysiological battery test results from the subjects. The experiment consisted of four trials and one visual exposure for a trial. Overall, two different virtual conditions were employed for each battery of tests, namely, exposure to an unelevated and elevated virtual platform (structural beam). Whenever the subjects were exposed to the elevated virtual platform, before performing the battery tests, the subjects were asked to look at their feet in the same way instructed in Experiment #1. In the first two trials, the volunteers were asked to perform the hand-steadiness battery test once on the ground and once on the 20^{th} floor of the building frame. As shown in Figure 3.15, a whiteboard was presented to the subjects on which a line and circle pattern were drawn. The subjects were required to use the virtual 'welding' tool and 'weld' the patterns as accurately as they could. To preserve consistency through all the trials, all subjects were instructed not to bend their knees during the trial, use two hands to perform the welding task and to contact the tip of the virtual electrode to the virtual whiteboard (or the welding would automatically stop). The third and fourth trials enclosed pursuit tasks were designed for measuring the task performance of the subjects. In each trial, a large white plane was presented to the subjects. The plane was located 30 feet away from the subjects' standing position. Each subject was asked to follow the purple circle (target) located on the plane (Figure 3.6), which moved on an invisible path constructed with multiple various-length line segments. In between each transition of the target from one line segment to another segment, there was a short pause aimed to improve the unpredictability of the target movements. The total duration of the pursuit task was one minute.

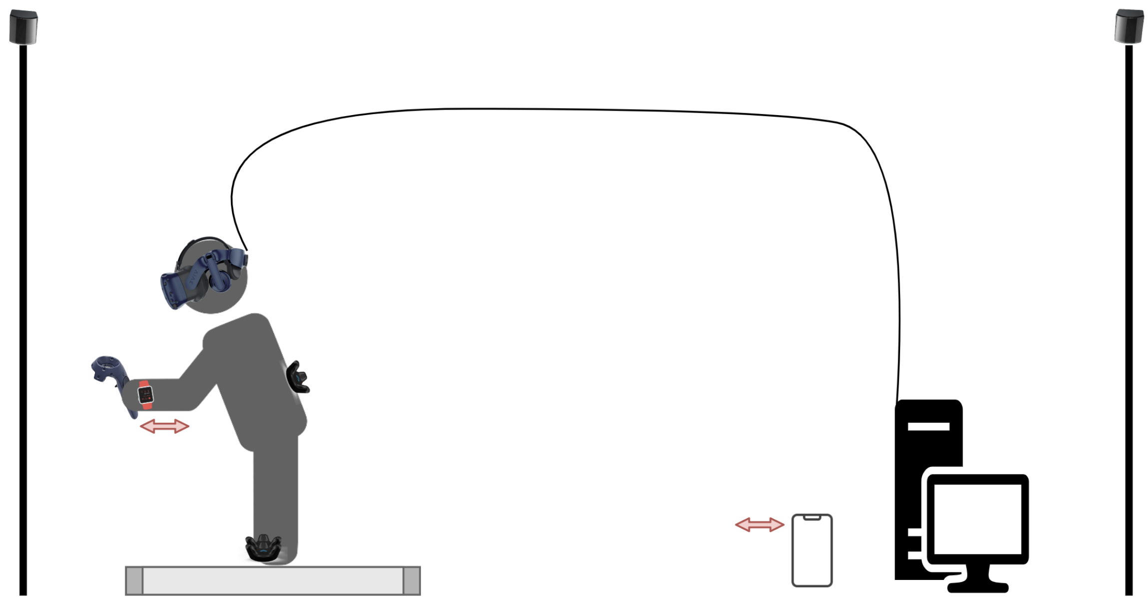


Figure 3.14: A Schematic Figure of the Experiment Room Along with the Experimental Devices Used to Simulate Welding and Capture Subjects' Hand-shake Steadiness Index, Postural Sway, and HR

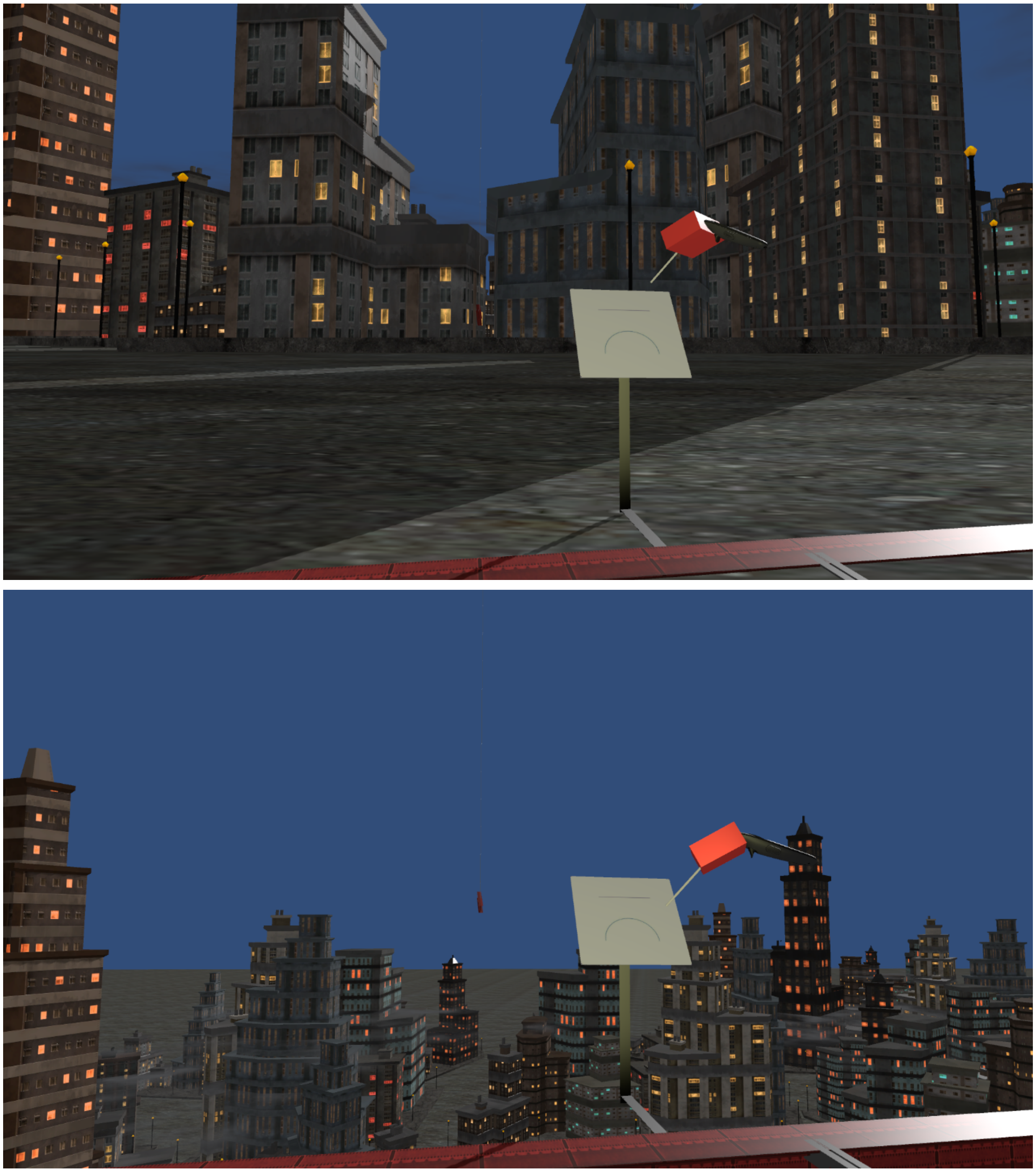


Figure 3.15: Hand-shake steadiness test performed once on the ground and once on a narrow elevated surface

3.7 Data Analysis

For each subject, all the corresponding collected data was stored in multiple text files, each with a proper name. Later, these data files were read by an in-house MATLAB code and tabulated in the form of a matrix. Subsequently, this matrix was used as the input data for many statistical analysis tests such as the non-parametric Mann Whitney U Test or the standard two-tail T-test. Whenever the normality of the data were violated, the Mann Whitney U test was performed on the input data. Otherwise, the standard T-test was applied to the data. Fortunately, all the results of the Leven's tests for testing the equality of variances were statistically insignificant in this study. Therefore, the hypotheses were not rejected in the Leven's tests which means the population variances were equal. Also, the results of Anderson-Darling tests showed that all the samples of data are drawn from a normal distribution.

Additionally, for the within-subject design case in which the same subjects operate in all the levels of independent variables, the standard paired T-test was employed for data analysis. As for the between-subject design case in which different subjects performed in all the levels of independent variables, the unpaired T-test was utilized for data analysis. In the next chapter, the statistical results are presented and reviewed in great detail.

Chapter 4

RESULTS

4.1 Nomothetic Studies

4.1.1 Descriptive Statistics

Table 4.1 summarizes the descriptive statistical results of the subjects for age, height, and weight, along with their level of fear, and acrophobia. As can be seen in table 4.1, the same subjects performed experiment number 1 and 2 whereas for experiment number 3, new subjects were recruited. While the nature of the first two experiments were different, due to the habituation effect, parallel data collection procedures might have a negative impact on the results of Experiments 1 and 2. The concurrent data collection is addressed as one of the limitations of this dissertation in Chapter 6.

Table 4.1: Descriptive Statistic for Gender, Age, Height, Weight, Level of Fear, and Level of Acrophobia

	Experiment					
	Postural sway (#1) & Gait (#2)			Task performance (#3)		
	female	male	total	female	male	total
Number	5	7	12	8	10	18
Age	30.6 ± 2.9	28.4 ± 6.7	29.3 ± 5.4	30.4 ± 5.0	31.8 ± 2.8	31.2 ± 3.9
Height (feet inch)	$5' 4'' \pm 1''$	$5' 10'' \pm 3''$	$5' 8'' \pm 4''$	$5' 5'' \pm 2''$	$5' 11'' \pm 3''$	$5' 8'' \pm 4''$
Height (cm)	163 ± 3.3	173 ± 6.7	171 ± 9.7	164 ± 5.3	179 ± 7.0	173 ± 9.8
Weight (lbs)	131.4 ± 9.4	174.6 ± 31.9	156.6 ± 9.4	123.3 ± 12.8	167.7 ± 26.8	148.0 ± 13.0
Weight (Kg)	59.6 ± 4.3	79.2 ± 14.5	71.0 ± 4.3	56.0 ± 5.8	76.1 ± 12.2	67.1 ± 5.9
Fear (1-7)	4.0 ± 0.6	3.5 ± 0.8	3.7 ± 0.7	3.7 ± 0.8	3.5 ± 0.8	3.6 ± 0.8
Acrophobia (1-7)	2.7 ± 0.8	2.5 ± 1.1	2.6 ± 0.9	2.3 ± 0.9	2.4 ± 0.8	2.3 ± 0.8
Acrop. Avoidance (1-3)	1.4 ± 0.1	1.3 ± 0.3	1.3 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.3 ± 0.2

4.2 Statistical Analysis Results

4.2.1 Results of Experiment #1

Table 4.2 shows the P-values of all the T-tests performed for pairs of comparisons of HR and postural metrics on the independent factors: VR, elevation (EL), MB on EL, MB on the ground (homoscedasticity is valid) . As demonstrated, TE and Bound was significantly affected by the presence of VR (P-values of 0.004 and 0.17 respectively). The TE and Bound T-test results were achieved by comparing subjects' stance parameters with and without the VR headsets. In addition, Figure 4.1 demonstrates each subject's TE of COP in the presence and absence of VR. Interestingly, almost all subjects had higher TE of COPs once they were exposed to VE. Moreover, the virtual legs slightly increased their TE of COPs compared to when the VR legs were invisible. As for the Bound of COP, the same trend can be observed in Figure 4.2. Notably, more spikes are visible in the plot suggesting more subtle changes in the Bound of COPs.

Other statistically significant results were the differences between the subjects' HR with and without exposure to MB. As reported in table 4.2, with

P-values less than 0.0001, MB has a significant effect on the HR increase. Figure 4.4 depicts a comparison between subjects' HR collected while they were standing on the virtual ground with and without exposure to MB. Similarly, Figure 4.5 demonstrates subjects' HR at height in the presence and absence of MB. In both figures, the heartrate dramatically increased once the subjects were confronted by MB.

Table 4.2: The Reported T-Test P-values for the Mean Differences between each Pair of Groups

	P-values			
	VR	EL	MB (no EL)	MB (EL)
Heart rate	0.19	0.554	.00005**	.00005**
Postural sway (TE)	0.004**	0.052*	0.497	0.890
Postural sway (RMS)	0.066	0.174	0.095	0.584
Postural sway (MAX)	0.057	0.156	0.112	0.694
Postural sway (PP)	0.017*	0.084	0.123	0.670

* Sig. at 0.05 level.
** Sig. at 0.01 level

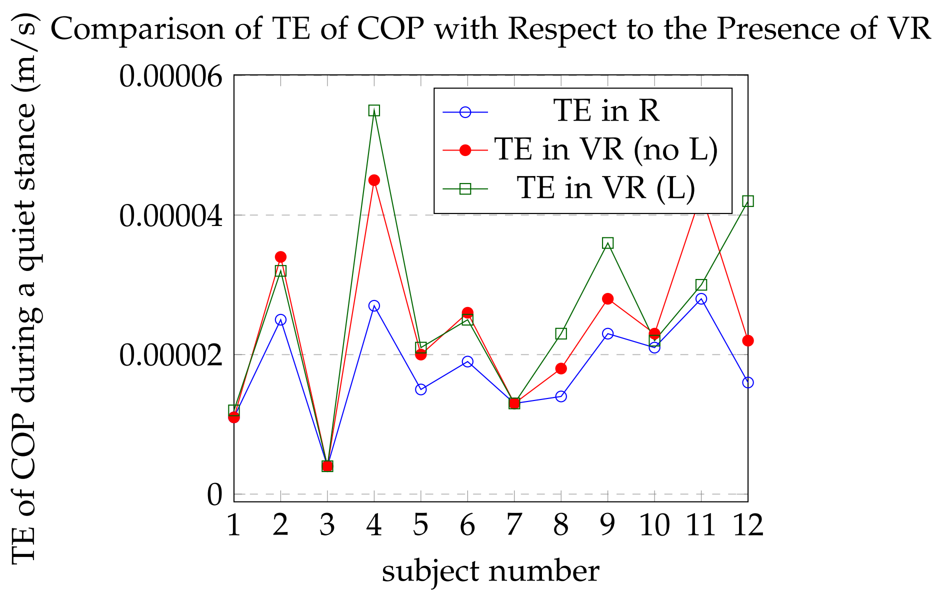


Figure 4.1: Comparison between TEs in the Presence and Absence of VR and Virtual Legs during a Quiet Stance

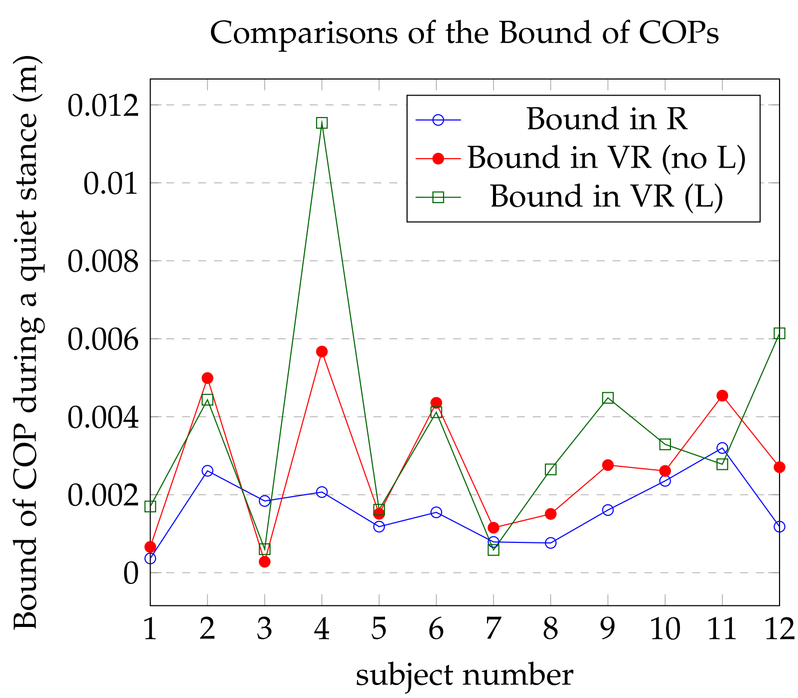


Figure 4.2: Comparisons between the Bound of COPs in Three Different Scenarios: Real Environment (RE), Virtual Environment (VE) without VR Legs, and VE with VR Legs

A closer look at the time-series COP data reveals some notable points regarding the effect of VR, elevation above grade, and MB. As can be seen in Figure 4.3, the bounding box of the COP path expands when the subject is exposed to VR. Table 4.2 also indicates that TE and bound of COP are highly affected by the presence of VR. Another interesting observation is the appearance of the two spikes in the two red-colored mediolateral graphs pertaining to MB. The formation of these spikes might be due to the natural physiological responses of the subjects confronted to the large structural beam (although they knew the beam would not "hit" them). Although all the subjects were familiarized with VE, this subject had an increase variability in her COP, in both medial lateral and anterior posterior directions, when she observed her virtual legs in both elevation conditions.

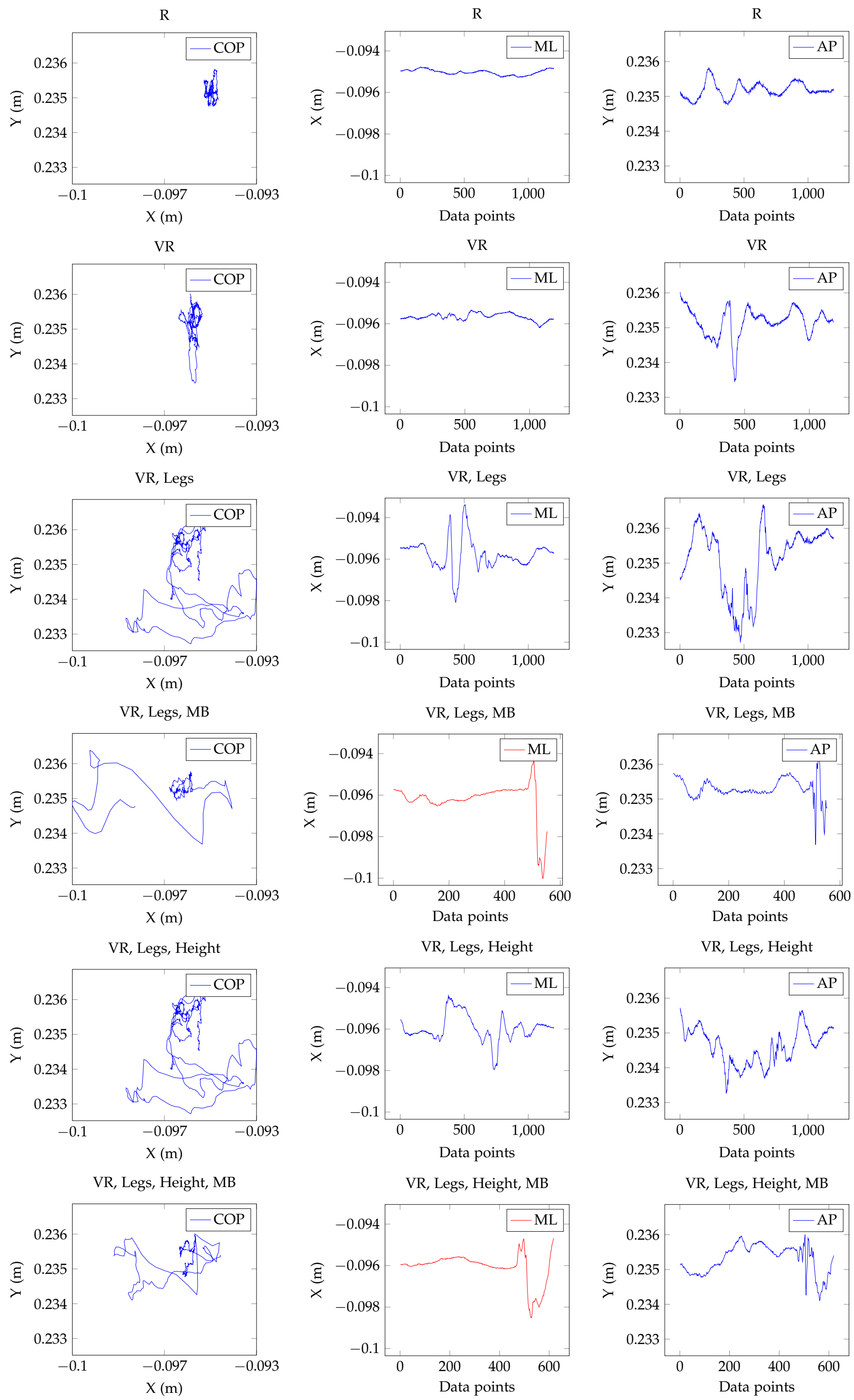


Figure 4.3: An Example of the Findings in One Representative Subject

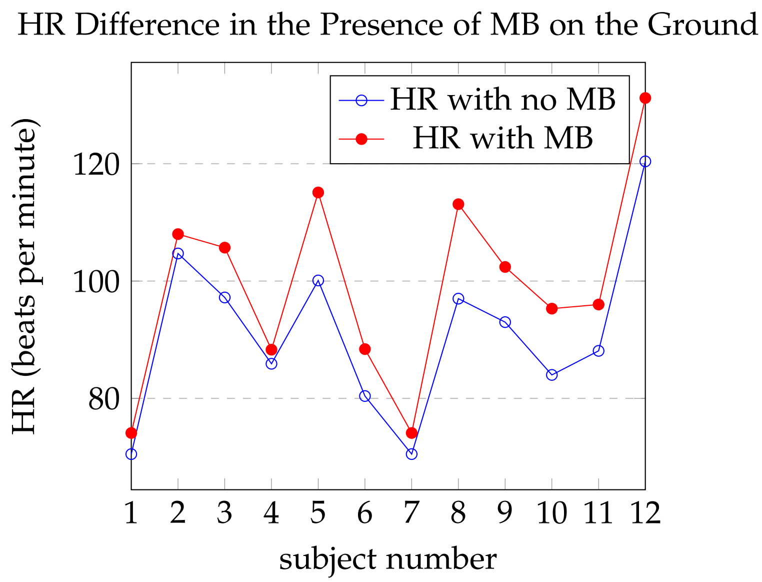


Figure 4.4: A Noticeable Increase in the Heart Rate (HR) of the Subjects in the Presence of the Moving Structural Beam (MB) on the Ground

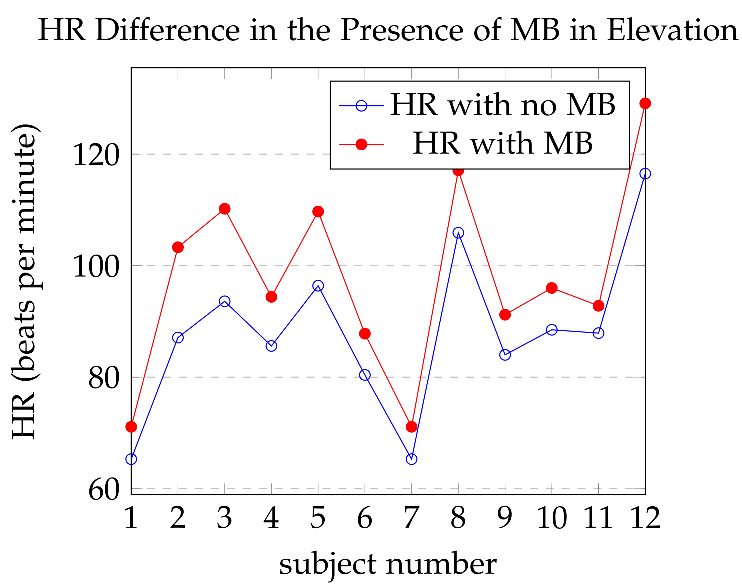


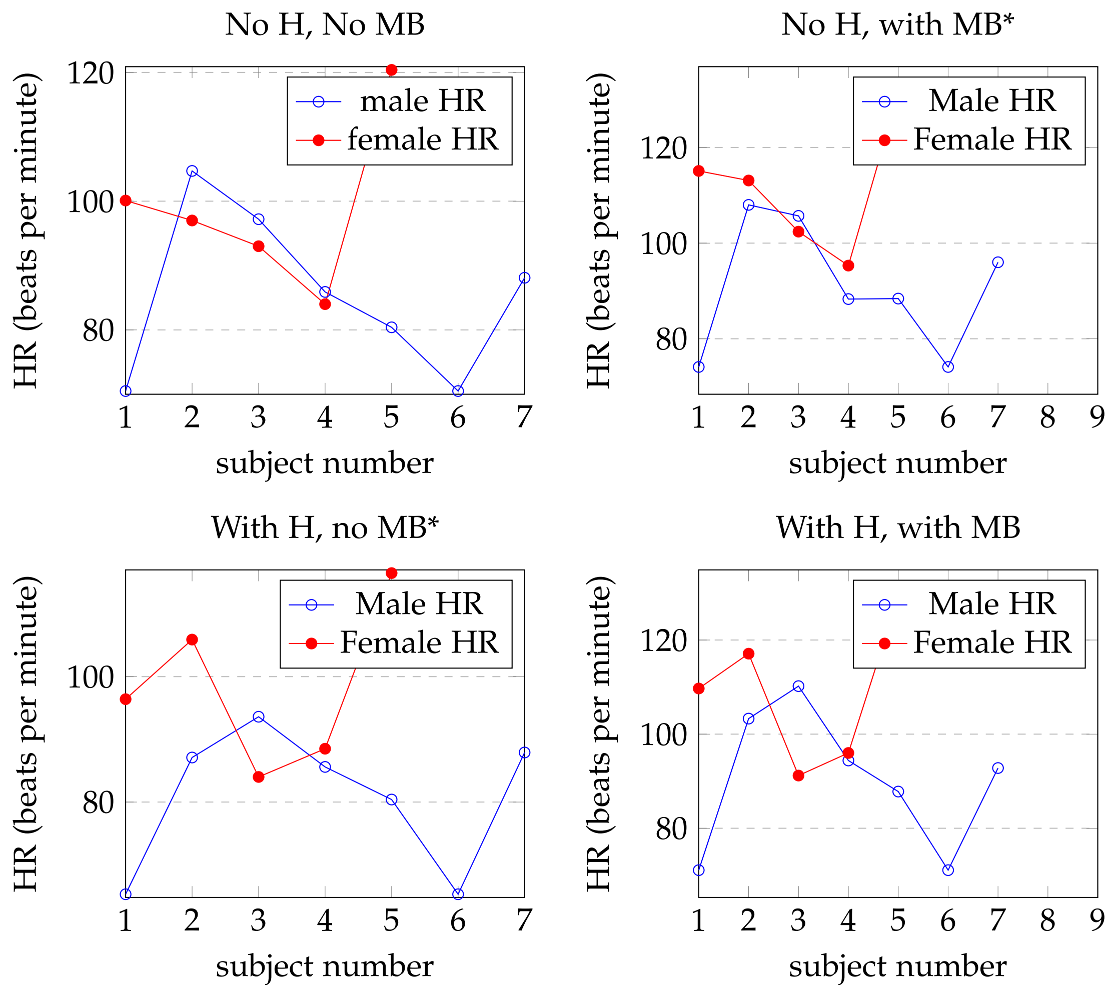
Figure 4.5: A Noticeable Increase in the Heart Rate (HR) of the Subjects in the Presence of the Moving Structural Beam (MB) in Elevation

Table 4.3: Standard Two-tail Unpaired T-test Mean Results for HR and RMS Based on the Subjects' Sex, Fear (selective Questions) and AQ

		No height			Height	
	Groups	No VR	VR-No MB	VR-MB	VR-No MB	VR-MB
Sex (HR in beats/minute)	Male	83.2	82.3*	90.6*	80.7*	89.6
	Female	86.7	99.2*	111.4*	98.2*	106.0
Fear1 (HR in beats/minute)	Low2	86.0	87.7	98.7	87.8	98.1
	High	84.0	90.9	99.9	88.2	97.5
AQ (HR in beats/minute)	Low	85.1	88.0	98.2	89.4	94.9
	High	84.9	90.7	100.4	86.6	100.7
Sex (RMS in meters)	Female	.0002	.0003	.0003*	.0004	.0003*
	Male	.0003	.0005	.0013*	.0006	.0008*
Fear (RMS in meters)	Low	.0002	.0003	.0007	.0003*	.0004
	High	.0003	.0006	.0011	.0008*	.0008
AQ (RMS in meters)	Low	.0002	.0004	.0006	.0003	.0003
	High	.0003	.0005	.0012	.0007	.0009

All the reported P-values of the Leven's tests were above 0.05.
*Sig. at 0.05 level

To identify the role of gender, fear of height, and acrophobia (AQ) in the subjects' physiological responses (HR) and postural sway (RMS), all the subjects were polarized into low and high roups based on AQ, fear, and gender. The findings indicate (table 4.3) the effect of gender is evident in the presence of MB (P-value<0.05). Also, exposure to VE (with or without elevation) caused statistically significant difference in the average heartrate of male and female groups. Another thought-provoking finding was the influence of gender in the presence of MB (both on the ground and at height). According to table 4.3, the male group had a higher RMS compared to the female group (P-value<0.05). Moreover, fear of height had a negative impact on RMS in the presence of virtual elevation (P-value<0.05).



* Sig. at 0.05 level.

Figure 4.6: Differences between the Collected Hear Rate of Male and Female Subjects in Four Different Scenarios

4.2.2 Results of Experiment #2

Table 4.4: Reported P-Values for the Paired-sample T-Tests

			average	variability (sd)	
	Exp. Duration	stride length	stride height	stride length	stride height
no L[1] (EL vs. no EL)	.0052*	.0145	.7609	.6631	.0678
L (EL vs. no EL)	.0305*	.0000**	.6554	.4850	.0281*
no EL (L vs. no L)	.0004**	.4464	.0227*	.2518	.7381
EL (L vs. no L)	.2912	.2968	.2634	.0884	.7290

1 L: VR legs, EL: elevation
* Sig. at 0.05 level.
** Sig. at 0.01 level

Table 4.4 tabulates the results of the paired-sampled T-tests on various gait parameters. Notably, all the reported P-values for the Leven's test was above 0.05 indicating the homoscedasticity or homogeneity of variances. The two most notable differences are between the average gait stride length under two elevation conditions (P-value=0.00001) and between the total duration of the trial with and without virtual leg enhancement (P-value=0.0004). Irrelevant of virtual leg enhancement, elevation noticeably increased the duration of the trials. While virtual elevation did not increase average stride height, the stride height variability significantly increased instead (P-value=0.0227). Finally, once the virtual model was equipped with virtual legs, the average stride height increased substantially during the VR ground-walking tasks (P-value=0.0227).

4.2.3 Results of Experiment #3

Table 4.5: Standard Two-tail Paired T-test Results and Mean Values for the Postural Sway Metrics Obtained from Experiment #3

Metrics	Direction	Randomized pursuit test[1]		Hand-steadiness test[2]	
		No elevation	Elevation	No elevation	Elevation
TE (m/s)	Total	0.000046	0.000047	0.000040	0.000041
	X	0.000026	0.000025	0.000021	0.000021
	Y	0.000026	0.000025	0.000021	0.000021
RMS (m)	Total	0.0011	0.0009	0.0005	0.0005
	X	0.0010	0.0009	0.0004	0.0003
	Y	0.0007*	0.0006*	0.0004	0.0004
Max (m)	Total	0.0063*	0.0046*	0.0033	0.0028
	X	0.0059*	0.0040*	0.0023*	0.0016*
	Y	0.0036*	0.0030*	0.0026	0.0025
Mean (m)	Total	0.0016	0.00140	0.0009	0.0008
	X	0.0012	0.0010	0.0005*	0.0004*
	Y	0.0008	0.0008	0.0006	0.0006
Bound (m)	Total	0.0107*	0.0085*	0.0061	0.0054
	X	0.0087*	0.0065*	0.0037*	0.0028*
	Y	0.0058*	0.0052*	0.0046	0.0045

[1] Number of subjects:18
[2] Number of subjects:13
* Sig. at 0.05 level

Table 4.6: A Comparison between the Results of the Two Task Performance Tests Executed in the Two Elevation Conditions

Test	Parameter	No elevation	Elevation
RPT	Sum of distances[1] (m)	234.66*	227.61*
	Sum of angles[2] (deg.)	30.12	29.74
	HR (bits/minute)	88.93	89.42
HST	Error-line (m)	0.234*	0.319*
	Error-circle (m)	0.276	0.351
	Avr. distance[3] (m)	0.079*	0.092*
	STD distance[4] (m)	0.015	0.015
	HR (bits/minute)	91.0	91.7

[1] The sum of the collected distances between the target and laser point during the trial
[2] The mean of all computed angles between each consecutive path lines during the trial
[3] The average distance of the tip of the electrode to the whiteboard in VE
[4] The standard deviation of the distance of the tip of the electrode to the whiteboard in VE
* Sig. at 0.05 level

Table 4.7: The Results for the Average Hand-steadiness Test (HST) and Randomized Pursuit Task (RPT) Based on the Subjects' Gender, Fear (selective Questions) and AQ

	Groups	Unelevated platform	Elevated platform
Sex (HST[1] duration in seconds)	Male	1155.6	1038.4
	Female	1126.9	1117.1
Fear (HST duration in seconds)	Low	1043.5	965.1
	High	1242.1	1181.7
AQ (HST duration in seconds)	Low	1398.2**	1326.7*
	High	887.4**	820.1*
Sex (HST Distance-SD[2] in meters)	Male	.0133	.0138
	Female	.0164	.0162
Fear (HST Distance-SD in meters)	Low	.0186**	.0169
	High	.0108**	.0128
AQ (HST Distance-SD in meters)	Low	.0137	.0140
	High	.0156	.0157

1 HST: Hand-Steadiness Test
2 SD: Standard Deviation
*Sig. at 0.05 level **Sig. at 0.01 level

Table 4.7 demonstrates the effect of gender, fear of height, and AQ on the comparison results for the two dependent factors: 1. hand-steadiness test (HST) duration, 2. standard deviation (SD) of all distances between the electrode and the plate. Based on these findings, subjects with a higher level of acrophobia spend more time performing HST. Additionally, the low fear-group had a higher SD for the HST distance score compared to the high-fear group under the elevation condition. However, the same statistically significant difference was not observed at height.

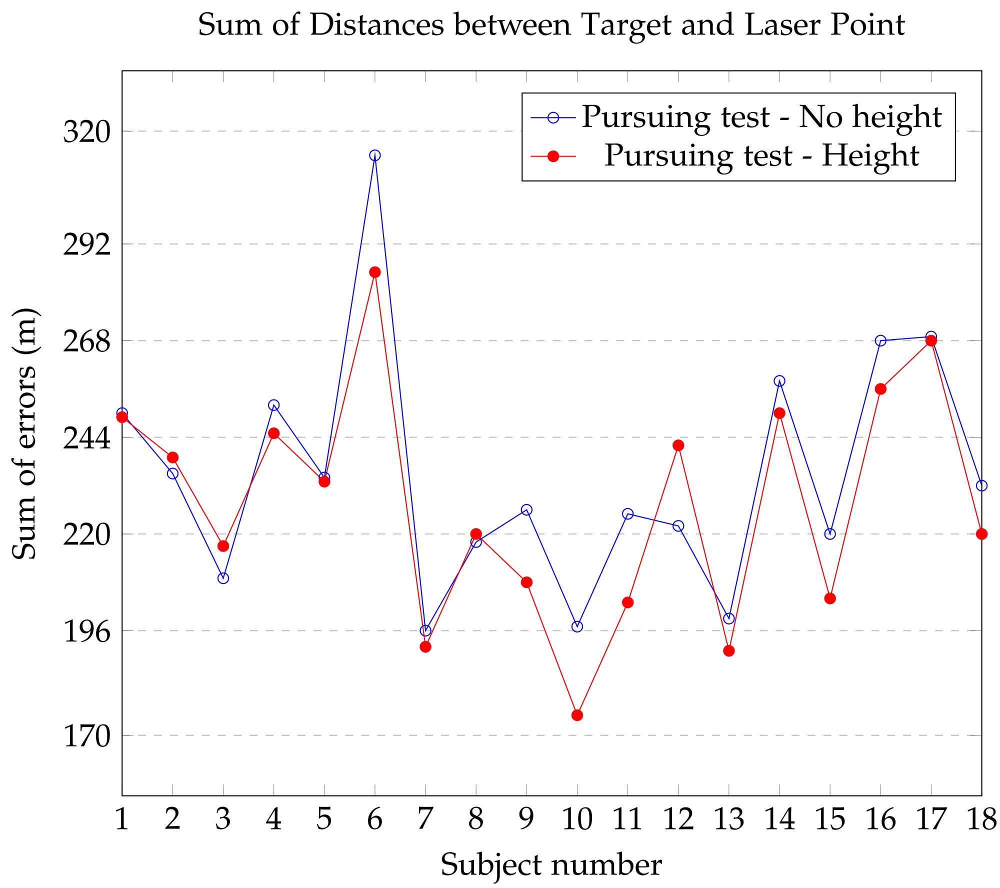


Figure 4.7: A Comparison between the RPT Sum of Errors in the Presence and Absence of Elevation (EL)

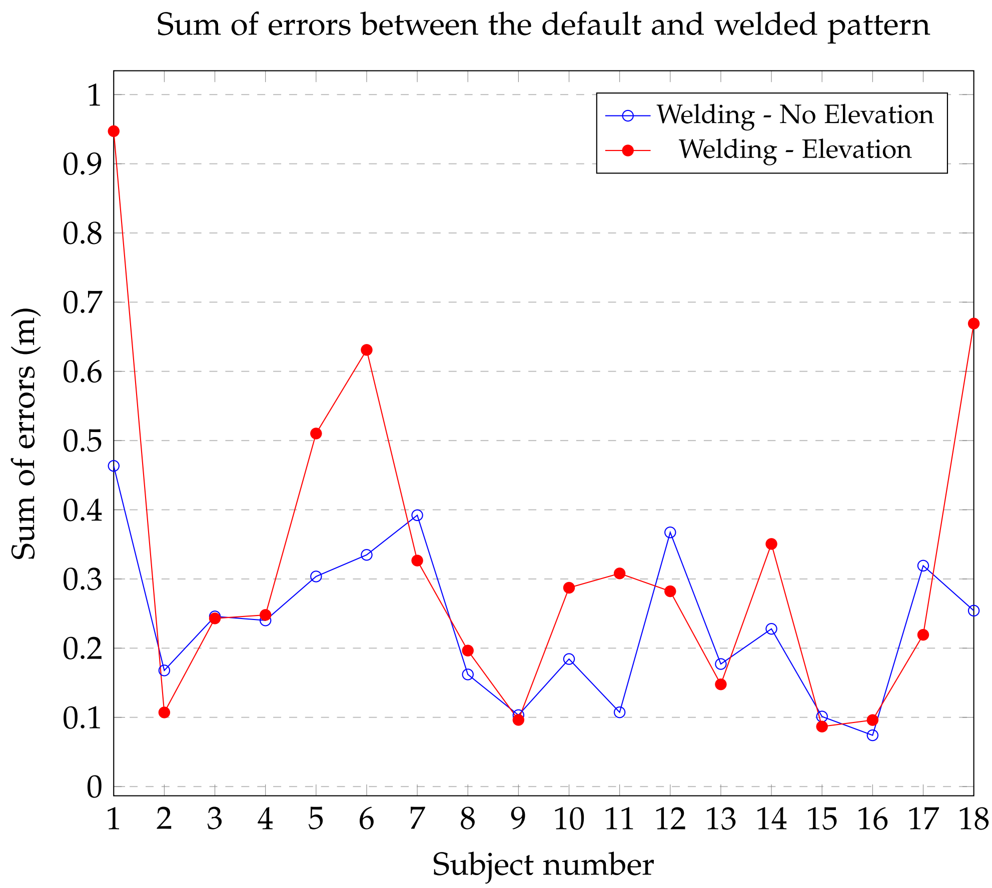


Figure 4.8: This Graph Shows the Resultant Straight-line Accuracy of the Participants in the Hand-steadiness Test with and without the Presence of Elevation

As can be seen in Figure 4.7, most of the subjects performed better in RPT once exposed to elevation (P-value<0.5). More specifically, at height, the sum of distances between target and laser point through out the one-minute RPT statistically reduced. The same decrease can be observed for the subjects' RMS of COP (Figure 4.9, P-value<0.05).

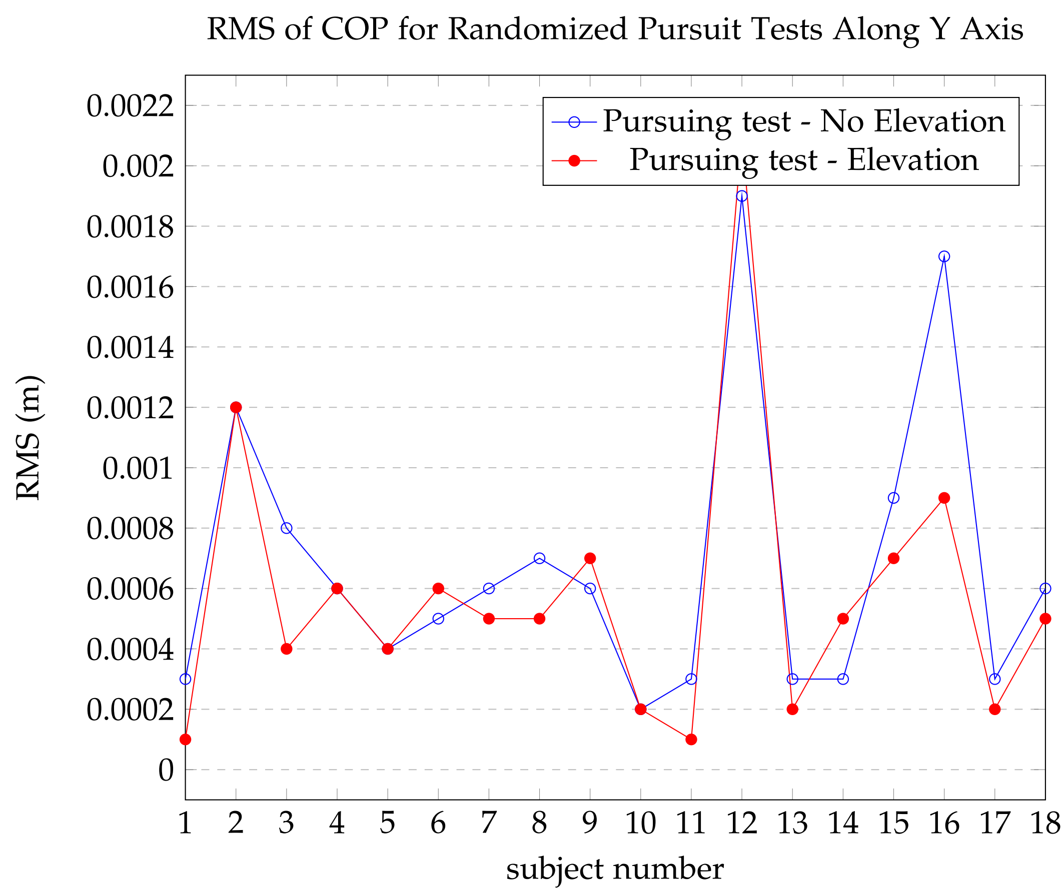


Figure 4.9: RMS of COP Along the Anterior-Posterior Direction Reported for the Two Pursuit Tests Performed in the Two Elevation (EL) Conditions

One of the important parameters in measuring task performance is the steadiness of the hand in the x, y, and z directions. As for the HST, x and y are the two axes on the 'welding' plate, and z is the axis perpendicular to the plate. Therefore, the operator can observe her welding performance along the x and y axis. In contrast, she is not aware of her HST score in the z direction so that she can compensate (a latent factor to the operator). Therefore, finding any information regarding this variable is valuable because the subject is not aware of her performance for this parameter. As can be seen in the Figure 4.10, the average distance of the electrode from the welding board has increased by height

(P-value<0.5). The apparent increase in the distance can imply that the subjects tend to lean less for welding on elevated platforms compared to non-elevated ones.

Figure 4.11 demonstrates the average and SD of hand-steadiness scores along the z-axis (perpendicular to the welding plate) for the two low and high-fear groups in the absence of elevation. The score results were different across the two groups (P-values < 0.05). However, no statement can be made regarding the impact of elevation on the task performance because the similar differences did not exhibit at height.

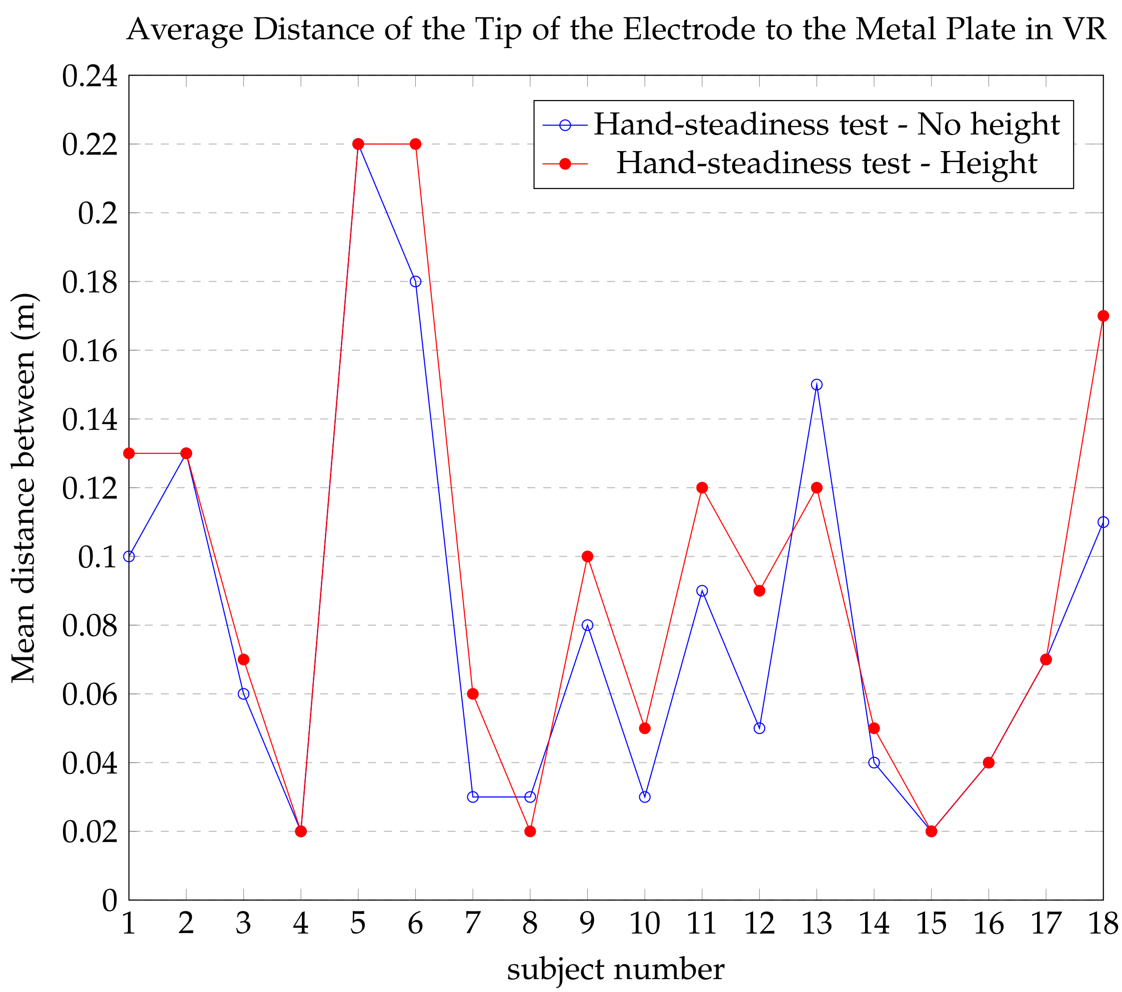


Figure 4.10: A Comparison between the Average Distance of the Electrode to the Plate (in HST) Among Subjects Under Two Elevation Conditions

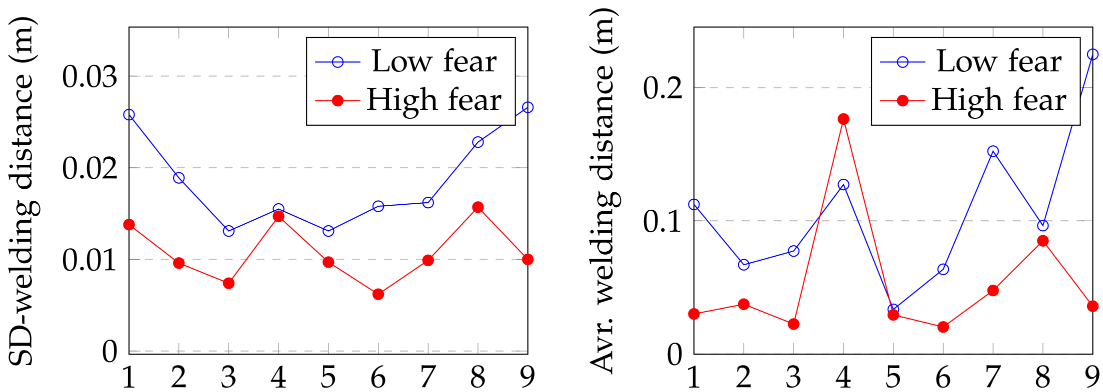


Figure 4.11: The Results of the Hand-steadiness Task (HST) Performed on the Ground for the Two Low and High Fear Groups

Chapter 5

DISCUSSION

The findings of this study answered the research questions regarding the impact of VR and elevation above grade on the postural sway and physiological responses of subjects. Based on the results of Experiment #1, during a quiet stance, subjects' postural sway was affected by elevation. Accordingly, individuals exhibited a higher TE of COP when they were exposed to elevation. However, the outcome of Experiment #3 showed that elevation positively affects postural sway. Accordingly, subjects were able to perform cognitive tasks with less postural sway while maintaining upright stance at height (both in the anterior-posterior and mediolateral directions). More precisely, RMS of COP in AP direction reduced while HST was performed at height compared to when it is performed on the ground (P-value$<$0.5). Likewise, during RPT at height, subjects' maximum COPs were reported lower compared to those stated during RPT on the unelevated platform. This inconsistency between the results of the two experiments indicates the complexity of the postural regulation system during different tasks. As stated by Mitra et al., (Mitra et al., 2013) some cognitive tasks will not trigger competition between tasks due to limited processing resources. In our study, maintaining a quiet stance during neurophysiological battery tests was not challenging for the subjects. In contrast, higher stability was observed during RPT and HST at height.

Many researchers reported a decrease in postural sway during the dual tasks (Andersson et al., 1998) and reaction time task paradigms (Vuillerme et al., 2000). This observation suggests further studies on the impact of height on different construction tasks performed at height.

Moreover, when the subjects experienced VR for the first time, significant responses were observed concerning TE and RMS of COP. The stimulating effect of VR has been reported previously in other gait and posture studies (Horlings et al., 2009). Horling et al. stated that a normal VR experience during a quiet stance could negatively influence postural regulations similar to that of eye-closed condition. Additionally, the field of view of the VR headsets is lower than that of a normal vision (Streepey et al., 2007). Therefore, subjects might exert more effort to look at their feet in VE compared to the real world. As of this study, while this visual limitation can overshadow the influence of elevation on the postural sway matrices, still there is a notable difference between the TE of COP obtained on the two different virtual platforms, narrow elevated and unelevated surfaces.

This study confirmed the statement made by Cleworth (Cleworth et al., 2012) that fear of height negatively influences postural balance. By categorizing subjects based on their gender, level of fear, and acrophobia, into two groups of low and high, the postural stability metrics and heart rate of the subjects were compared across the two groups. Once the low and high-fear groups were compared with respect to the postural metrics data collected on the elevated beam in VE, a noticeable difference was perceived between their RMS. Since no statistically meaningful difference was identified between the RMS data collected on the ground in VE, the critical role of fear of height in predicting the differences of RMS measured on the elevated platform becomes evident. However, the comparison between the two groups of low and high AQ did not result in any significant differences concerning postural metrics. Possibly, the insignificant difference was due to the specific design of AQ for identifying the extreme cases of fear of height. Notably, we were not able to find any of those cases in our successfully collected data (AQ range: 1-6, AQ of subjects=2.6$\pm$0.9). Finally, based on gender grouping, the female subjects had lower RMS concerning the moving structural beam (MB) compared to that of male subjects in both elevation conditions. No other remarkable differences were observed similar in comparisons between the two gender groups. Two important points can be regarded from the above statement: 1. MB can influence the RMS of males more than that of females, 2. Other independent factors, such as elevation or VR, were not able to predict changes in RMS for the two gender groups.

Remarkably, MB had a dramatic impact on the increased heart rate of the subjects in both elevation conditions (P-vlaue=0.00005). At the same time, no significant increase was spotted for the subjects' postural sway parameters. Whether the size of MB altered HR or the uncertainty of the situation changed HR, we cannot know for sure. However, it is quite evident that approaching large objects can change the heart rate. As for gender factor, female subjects exhibit a higher heart rate compared to male subjects when the moving structural beam approached them (in the unelevated support condition only). The same alteration was not detected in other trials which suggest female are more susceptible to increased anxiety (HR) in the presence of large moving objects (for the first time) compared to men. In addition to the remarkable difference in HR, as stated above, the RMS of the female group was lower than that of the male group independent of the elevation conditions. These outcomes are thought-provoking and highlight the importance of large moving objects (MO), and perhaps machinery and equipment, as provoking factors in the context of construction safety. Therefore, more investigations are required to strictly study the impact of these moving objects on the physiological responses of construction workers.

As explained in the previous chapter, there is a strong relationship between gait stride length and narrow elevated surfaces. Our study determined that the average gait stride length decreased once the walking path became elevated. This noticeable stride length difference across different scenarios implies a more "careful" walk during the course of the trials. Sheik Nainar and Kaber's findings suggest a similar conclusion with respect to walking at height (Sheik_Nainar & Kaber B., 2007). By recruiting 19 young subjects from NCSU, they showed a decreased gait stride length and an increased cadence during overground walking at height. Notably, these findings match with Schniepp et al.'s experimental result of the overground walking on the real elevated surfaces.

On a narrow elevated path, one of the most pivotal elements of a successful walking experience is the ability to follow the foot positions on that path, especially close to the edges. Several studies seem to use wider paths (Sheik_Nainar & Kaber B., 2007) or use CAVEs (Cruz-Neira et al., 1993) to address this caveat (Antley & Slater, 2011). The current approach towards gait experiment on narrow virtual surfaces was to use HTC Vive Trackers to simulate the shape and movement of the subject's legs. The experimental results revealed that the average gait stride height increased once subjects were able to see their virtual legs for the ground walking trials. Other important observations in these ground walking trials were the reduction in the average stride length, coupled with an increase in the duration of the trials once the subjects had access to the enhanced VR model. These findings suggest that the use of responsive and real-time tracking virtual legs can increase the level of realism and immersion. However, once elevation was appended to these walking trials, the same increase in the subjects' stride length was not spotted.

Possibly, the effect of elevation above grade, as an influential independent factor, overshadows the effect of VR legs on the increase of the average gait stride length.

As described in the literature, variability in the stride height is a higher level of walking disorder that is influenced by fear of height (Ayoubi et al., 2014). Our analysis of the collected information for gait stride height confirmed this statement. Overall, in the presence of VR legs, subjects had more variability in their stride height (P-value=0.0281) once they were exposed to elevation. Interestingly, once subjects were prevented from seeing their VR legs, a similar difference was not detected across the two elevation conditions. Apparently, the visual and vestibular systems work differently in the absence of virtual legs. Further studies need to investigate the impact of virtual legs on gait locomotion more in-depth.

The final result of this study was the manifestation of the significant changes in the HST and RPT error indices of the subjects once they performed the neurophysiological battery tests on the elevated platform. More specifically, the HST error index for the line pattern increased at height (P-value=0.02), and the RPT error index decreased at height (P-value=0.03). While the decreased HST accuracy due to elevation was in line with the study's hypothesis, the increased RPT accuracy was a surprising result. Sorted based on their influential level, here are some of the driving factors for this controversial elevation effect on HST:

- The position of the boards: the position of the boards on which tasks are being performed can strongly influence the outcome of the relevant tests. Visual stimuli are effective once an individual is exposed to them. In this dissertation, the welding board was placed at the chest-level height. Accordingly, the subjects needed to lean forward to execute the battery tasks, thus resulting in continuous exposure to elevation. Therefore, during the entire trial, subjects were being provoked by elevation above grade. Whereas in the RPT tests, the board was placed 30 feet away from the subjects and in front of them. The placement design of the RPT board did not cause any height exposure, thus resulting in less visual perturbations concerning height. However, since the subjects were asked to look at their feet before the start of RPT, they were probably subjected to the induced anxiety of elevation, and not the visual provocations, through the entire task. The author believes that the placement of the boards is the leading cause of different accuracy outcomes for RPT and HST.

- Task complexity: based on the nature of each task, different processing resources are required for task completion. In our study, RPT required more 'responsive' actions accompanied by tracking ability while HST required more hand steadiness and less responsive and dynamic actions. These inherent differences might have led to different accuracy outcomes across the two tests. As such, it seems plausible that higher concentration for HST due to its higher complexity resulted in less distraction concerning elevation and the threatening situation. Also, elevation-related anxiety could act positively and trigger more processing resources for the completion of the task. The positive effect of fear of height can be seen in the result of the comparison between the low and high-fear groups in terms of HST accuracy score at height. Accordingly, the high-fear group performed better compared to the low-fear group. Therefore, although due to the lower task complexity of HST and elevation-related visual stimuli during the course of the test, subjects performed worse at height, the fear of height (as a reactive factor) acts as a positive component in the HST accuracy outcome.

- Stance posture: in PST, fewer muscles are involved in controlling body balance, and the postural stability was close to that of the quiet stance. However, in HST, more advanced stance posture control was needed for postural balance regulation. In addition, all subjects were instructed to lean forward and not to bend their knees. Consequently, during the HST trial at height, subjects focused more on maintaining their postural balance due to the continuous exposure to visual perturbation and their required stance posture for the task.

Chapter 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusion

Based on numerous construction safety studies, postural instability is the leading cause of death and injuries in dynamic job sites. This dissertation strove to shed light on the effect of elevation-related visual stimuli on the postural balance, gait pattern, and task performance of construction workers. To that end, a series of virtual reality experiments were conducted. The result of these tests showed that postural balance is affected by elevation above grade, large moving objects, and the presence of virtual body parts. In terms of postural steadiness, during quiet stance, subjects performed worse at height. However, postural balance increased once subjects executed tasks at height.

Furthermore, the average gait stride length increased at height. On the narrow elevated surfaces, the variation of gait stride height increased as well. The presence of virtual legs seemed to increase the level of immersion and realism for the subjects and influence their gait patterns.

Interestingly, task performance was altered at height. However, elevation acted positively on the outcome of a more complex task with less exposure to visual perturbation and negatively on the result of a less complicated task with more exposure to visual stimuli. Therefore, it can be concluded that the accompanying stance posture and task complexity could significantly alter the outcomes of the tasks performed at height.

Finally, the bodily responses of the subjects (HR) were significantly increased by the moving structural beam. In addition, the HR of female subjects raised more compared to males' HR. There were no statistically prominent HR differences between the two elevation conditions. However, gender was a crucial element in predicting the HR differences induced by VR headsets. Accordingly, female HR increased more compared to male HR in the presence of VR.

6.2 Limitation and Future work

These are limitations of this study that could to be addressed in future research projects:

- Number of subjects: for the first two experiments, the number of subjects was relatively low. A larger sample size can lead to more robust conclusions.
- Order of the trials and the effect of habituation: due to the small sample size, the order of trials was not randomized. This is an important limitation that needs to be addressed in future research projects.
- Different shoe types: another important caveat is the use of different types of shoes during different experimental procedures. Each type of shoe can have an impact on the postural balance and gait pattern of the subjects. The same statement can be made for the type of clothes and their relevant weights. At construction sites, workers wear helmets and carry heavy construction tools.

These objects can influence balance and need to be considered for relevant future studies.

- Verbally explaining task procedures during the course of the trial: to improve the feeling of immersion and realism, instruction procedures should be explained to the subjects only before the trials. Any outside voice can reduce the feeling of presence for the subjects.

- The need for a more advanced fear of height measurement: although the survey employed in this study consisted of famous fear and acrophobia questionnaires, more accurate fear measurements should be utilized for assessing the level of anxiety and fear in the subjects such as cortisol and skin temperature tests.

- Walking (and standing) on office floors: the type of the surface is another important factor in increasing the immersive feeling during VR experiments. Similar surfaces should be used in both virtual and real environments.

- The use of a specific sign for height exposure (look at a specific point instead of just looking down): to have the subjects look down at their feet, they were instructed to look at their feet. However, due to the presence and absence of VR legs, this approach can result in different postures during the task. Accordingly, the use of a specific sign (i.e., a colorful dot on the virtual and real platform) can create more consistency through various trials.

Because the simulation of construction tasks at height has not been thoroughly performed in the context of construction safety, numerous research projects can be conducted in the future. Below are some of the suggested topics for future VR studies in the area of construction safety and construction task performance:

1. A comparison of elevation and task performance among novices and experienced construction workers.

2. The use of the same type of shoes equipped with HTC Vive trackers for consistent data collection.

3. Investigate the influence of elevation-related visual perturbations on task performance and postural stability by changing the positions of the virtual boards used in each task.

4. Examine the steel erection simulation by using virtual hands (leap motion).

5. Observe the gait locomotion on a real structural beam (with the same type of shoes and the fixed positions of the trackers)

6. Investigate the light and fear variables on task performance and postural stability (during gait and quiet stance).

7. Study the effect of elevation above grade on short and long-term memory.

8. Study changes in the visual search patterns of construction workers at virtual height by using eye tracking technology.

9. Investigate the impact of elevation-related visual perturbations on one's attention.

References

Abdelhamid, T., & Everett, J. (2000). Identify Root Causes of Construction Accidents. *Journal of Construction Engineering and Management*, *126*(1), 52–60. Retrieved from http://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9364(1998)124:1(67) doi: 10.1061/(ASCE)0733-9364(2000)126:1(52)

Akizuki, H., Uno, A., Arai, K., Morioka, S., Ohyama, S., Nishiike, S., ... Takeda, N. (2005). Effects of immersion in virtual reality on postural control. *Neuroscience Letters*, *379*(1), 23–26. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0304394004015757 doi: 10.1016/j.neulet.2004.12.041

Andersson, G., Yardley, L., & Luxon, L. (1998). A dual-task study of interference between mental activity and control of balance. *The American journal of otology*, *19*(5), 632–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9752972

Antley, A., & Slater, M. (2011). The effect on lower spine muscle activation of walking on a narrow beam in virtual reality. *IEEE Transactions on Visualization and Computer Graphics*, *17*(2), 255–259. doi: 10.1109/TVCG.2010.26

API, F. (2019). *Fitbit Document API.* Retrieved 2019-06-24, from https://dev.fitbit.com/build/reference/device-api/document/

Ayoubi, F., Launay, C. P., Kabeshova, A., Fantino, B., Annweiler, C., & Beauchet, O. (2014). The influence of fear of falling on gait variability: results from a large elderly population-based cross-sectional study. *Journal of neuroengineering and rehabilitation*, *11*, 128. doi: 10.1186/1743-0003-11-128

Baloh, R. W., Jacobson, K. M., Beykirch, K., & Honrubia, V. (1998). Static and Dynamic Posturography in Patients With Vestibular and Cerebellar Lesions. *Archives of Neurology*, *55*(5), 649. Retrieved from http://archneur

.jamanetwork.com/article.aspx?doi=10.1001/archneur.55.5.649 doi: 10.1001/archneur.55.5.649

Bazkiewicz, M., Wiszomirska, I., & Wit, A. (2014). Comparison of four methods of calculating the symmetry of spatial-temporal parameters of gait. *Acta of Bioengineering and Biomechanics*, *16*(1), 29–35. Retrieved from http://www.actabio.pwr.wroc.pl/Vol16No1/4.pdf doi: 10.5277/abb140104

Boffino, C. C., Cardoso de Sa, C. S., Gorenstein, C., Brown, R. G., Basile, L. F. H., & Ramos, R. T. (2009). Fear of heights: Cognitive performance and postural control. *European Archives of Psychiatry and Clinical Neuroscience*, *259*(2), 114–119. doi: 10.1007/s00406-008-0843-6

Burdea, G., & Coiffet, P. (2003). *Virtual reality technology*. J. Wiley-Interscience. Retrieved from https://books.google.com/books?hl=en{&}lr={&}id=0xWgPZbcz4AC{&}oi=fnd{&}pg=PR13{&}dq=Wht+is+virtual+realtiy{&}ots=LDdsfRXQ9q{&}sig=uIMDTqM20ajz6oemXZfmVOQiUkw{#}v=onepage{&}q=Whtisvirtualrealtiy{&}f=false

Bureau of Labor Statistics. (2016). Bureau of Labor Statistics. , 1–22.

Choudhry, R. M., & Fang, D. (2008). Why operatives engage in unsafe work behavior: Investigating factors on construction sites. *Safety Science*, *46*(4), 566–584. Retrieved from https://www.sciencedirect.com/science/article/pii/S0925753507001087 doi: 10.1016/j.ssci.2007.06.027

Clement, G., Jacquin, T., & Berthoz, A. (1985). Habituation of Postural Readjustments Induced by Motion of Visual Scenes. In *Vestibular and visual control on posture and locomotor equilibrium* (pp. 99–104). S. Karger AG. doi: 10.1159/000410310

Cleworth, T. W., Horslen, B. C., & Carpenter, M. G. (2012). Influence of real and virtual heights on standing balance. *Gait and Posture*, *36*(2), 172–176.

Retrieved from http://dx.doi.org/10.1016/j.gaitpost.2012.02.010 doi: 10.1016/j.gaitpost.2012.02.010

Cohen, D. C. (1977). Comparison of self-report and overt-behavioral procedures for assessing acrophobia. *Behavior Therapy*, *8*(1), 17–23. doi: 10.1016/S0005-7894(77)80116-0

Cruz-Neira, C., Sandin, D. J., & Defanti, T. A. (1993). Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. In *Proceedings of the 20th annual conference on computer graphics and interactive techniques.* ACM. Retrieved from http://delivery.acm.org/10.1145/170000/166134/p135-cruz-neira.pdf?ip=129.93.184.33{&}id=166134{&}acc=ACTIVESERVICE{&}key=B63ACEF81C6334F5.EE2BA0AAC6332229.4D4702B0C3E38B35.4D4702B0C3E38B35{&}{_}{_}acm{_}{_}=1562169982{_}cfec1ad62dba08edc572116d87b5876c

Ekdahl, C., Jarnlo, G. B., & Andersson, S. I. (1989). Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. *Scandinavian journal of rehabilitation medicine*, *21*(4), 187–95. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2631193

Emmelkamp, P. M., & Felten, M. (1985). The process of exposure in vivo : cognitive and physiological changes during treatment of acrophobia. *Behaviour Research and Therapy*, *23*(2), 219–223. doi: 10.1016/0005-7967(85)90034-8

Geer, J. H. (1965). The Development Of A Scale To Measure Fear. *Behavior Research and Therapy*, *3*(1), 45–53.

Geurts, A. C., Nienhuis, B., & Mulder, T. W. (1993). Intrasubject variability of selected force-platform parameters in the quantification of postural control. *Archives of physical medicine and rehabilitation*, *74*(11), 1144–50. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8239951

Greffou, S., Bertone, A., Hanssens, J.-M., & Faubert, J. (2008). Development of visually driven postural reactivity: a fully immersive virtual reality study. *Journal of vision*, *8*(11), 15.1–10. doi: 10.1167/8.6.426

Habibnezhad, M., & Esmaeili, B. (2016). The Influence of Individual Cultural Values on Construction Workers' Risk Perception. *52nd ASC Annual International Conference Proceedings*. Retrieved from `http://ascpro.ascweb.org/chair/paper/CPRT211002016.pdf`

Habibnezhad, M., Fardhosseini, S., Moghaddam, A., Esmaeili, B., & Michael, D. (2016). The Relationship between Construction Workers' Risk Perception and Eye Movement in Hazard Identification. In *Construction research congress 2016*. Retrieved from `https://doi.org/10.1061/9780784479827.297` doi: 10.1061/9780784479827.297

Habibnezhad, M., Puckett, J., Fardhosseini, M., Jebelli, H., Stentz, T., & Pratama, L. (2019). Experiencing Extreme Height for The First Time: The Influence of Height, Self-Judgment of Fear and a Moving Structural Beam on the Heart Rate and Postural Sway During the Quiet Stance. In *36th international symposium on automation and robotics in construction (isarc 2019).* Retrieved from `https://pdfs.semanticscholar.org/4530/c3b8330686ec38127a4c09db80ab40c2898a.pdf`

Habibnezhad, M., Puckett, J., Fardhosseini, M., & Pratama, L. (2019). A Mixed VR and Physical Framework to Evaluate Impacts of Virtual Legs and Elevated Narrow Working Space on Construction Workers' Gait Pattern. In *36th international symposium on automation and robotics in construction (isarc 2019).* Retrieved from `https://arxiv.org/pdf/1906.08670.pdf`

Holme, E., Magnusson, S. P., Becher, K., Bieler, T., Aagaard, P., & Kjaer, M. (2007). The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scandinavian Journal of Medicine & Science in Sports*, *9*(2), 104–109. Retrieved from http://doi.wiley.com/10.1111/j.1600-0838.1999.tb00217.x doi: 10.1111/j.1600-0838.1999.tb00217.x

Horlings, C. G. C., Carpenter, M. G., Küng, U. M., Honegger, F., Wiederhold, B., Allum, J. H. J., ... Allum, J. H. J. (2009). Influence of virtual reality on postural stability during movements of quiet stance. *Neuroscience Letters*, *451*(3), 227–231. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0304394008017436http://www.ncbi.nlm.nih.gov/pubmed/19146921 doi: 10.1016/j.neulet.2008.12.057

Hsiao, H., & Simeonov, P. (2001). Preventing falls from roofs: a critical review. *Ergonomics*, *44*(October 2012), 537–561. doi: 10.1080/00140130117338

Kakehbaraei, S., Seyedarabi, H., & Zenouz, A. T. (2017). Dental segmentation in cone-beam computed tomography images using watershed and morphology operators. *Journal of medical signals and sensors*, *8*(2), 119–124. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/29928637{%}0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC5992906 doi: 10.4103/jmss.JMSS

Kaur, G., Sandhu, S. S., & Sandhu, J. S. (2007). *Comparison of Arm-Hand Steadiness for Shooting Perfection in Armed Forces and Punjab Police* (Vol. 9; Tech. Rep. No. 4). Retrieved from https://pdfs.semanticscholar.org/fa60/6e92118df59ee756c74a0a80db9aa67f64c4.pdf

Keshner, E. (2004). Virtual reality and physical rehabilitation: a new toy or a new research and rehabilitation tool? *Journal of NeuroEngineering and Rehabilitation*, *1*(1), 8. Retrieved from http://www.jneuroengrehab.com/content/1/1/8 doi: 10.1186/1743-0003-1-8

Lacour, M., Barthelemy, J., Borel, L., Magnan, J., Xerri, C., Chays, A., & Ouaknine, M. (1997). Sensory strategies in human postural control before and after unilateral vestibular neurotomy. *Experimental brain research*, *115*(2), 300–10.

Le Clair, K., & Riach, C. (1996). Postural stability measures: What to measure and for how long. *Clinical Biomechanics*, *11*(3), 176–178. Retrieved from https://www.sciencedirect.com/science/article/pii/0268003395000275?via{%}3Dihub doi: 10.1016/0268-0033(95)00027-5

Lestienne, F., Soechting, J., & Berthoz, A. (1977). Postural readjustments induced by linear motion of visual scenes. *Experimental Brain Research*, *28-28*(3-4), 363–384. doi: 10.1007/BF00235717

Li, G., Hu, X., Luo, J., Luo, H., Wang, X., Fan, M., ... Wei, M. (2018). The Effect of Visual Stimuli on Stability and Complexity of Postural Control. *Front. Neurol*, *9*, 48. doi: 10.3389/fneur.2018.00048

Li, H., & Trocan, M. (2018). Deep learning of smartphone sensor data for personal health assistance. *Microelectronics Journal*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0026269217302525 doi: 10.1016/J.MEJO.2018.01.015

Magnusson, M., Enbom, H., Johansson, R., & Wiklund, J. (1990). Significance of pressor input from the human feet in lateral postural control. The effect of hypothermia on galvanically induced body-sway. *Acta oto-laryngologica*, *110*(5-6), 321–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2284906

MATLAB. (2017). *MATLAB.* Mathworks. Retrieved from https://www.mathworks.com/products/matlab.html

McGinley, J. L., Baker, R., Wolfe, R., & Morris, M. E. (2009). The reliability of three-dimensional kinematic gait measurements: A systematic review. *Gait & Posture*, *29*(3), 360–369. Retrieved from https://www.sciencedirect.com/

science/article/pii/S0966636208002646 doi: 10.1016/J.GAITPOST.2008.09.003

Meehan, M., Razzaque, S., Insko, B., Whitton, M., & Brooks, F. P. (2005). Review of Four Studies on the Use of Physiological Reaction as a Measure of Presence in Stressful Virtual Environments. *Applied Psychophysiology and Biofeedback*, *30*(3). doi: 10.1007/s10484-005-6381-3

Menzies, R. G., & Clarke, J. (1995). Danger expectancies and insight in acrophobia. *Behaviour Research and Therapy*, *33*(2), 215–221. doi: 10.1016/0005-7967(94)P4443-X

Mirelman, A., Maidan, I., Herman, T., Deutsch, J. E., Giladi, N., & Hausdorff, J. M. (2011). Virtual reality for gait training: Can it induce motor learning to enhance complex walking and reduce fall risk in patients with Parkinson's disease? *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *66 A*(2), 234–240. doi: 10.1093/gerona/glq201

Mitra, S., Knight, A., & Munn, A. (2013). Divergent effects of cognitive load on quiet stance and task-linked postural coordination. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 323–328. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23127476 doi: 10.1037/a0030588

Mujber, T. S., Szecsi, T., & Hashmi, M. S. J. (2004). Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Technology*, *155-156*(1-3), 1834–1838. doi: 10.1016/j.jmatprotec.2004.04.401

Norré, M. E. (1993). Sensory interaction testing in platform posturography. *The Journal of laryngology and otology*, *107*(6), 496–501. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8345297

Paulus, W. M., Straube, A., & Brandt, T. (1984). VISUAL STABILIZATION OF POSTURE. *Brain*, *107*(4), 1143–1163. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6509312https://academic.oup.com/brain/article-lookup/doi/10.1093/brain/107.4.1143 doi: 10.1093/brain/107.4.1143

Pavlidis, I., Levine, J. a., & Baukol, P. (2002). Ioannis Pavlidis Honeywell Laboratories Minneapolis , MN ioannis . pavlidis @ i), honeywell . com James Levine Mayo Clinic Mayo Clinic. *IEEE Transactions on Biomedical Engineering*(6), 315–318.

Regenbrecht, H. T., Schubert, T. W., & Firedmann, F. (1998). Measuring the Sense of Presence and its Relations to Fear of Heights in Virtual Environments. *International Journal of Human- Computer Interaction*, *10*(3), 265–282. doi: 10.1207/s15327590ijhc1003

Rigal, R. A. (1992). *Which Handedness Preference or Performance?'* (Vol. 75; Tech. Rep.). Retrieved from https://journals.sagepub.com/doi/pdf/10.2466/pms.1992.75.3.851

Rothbaum, B. O., Hodges, L. F., Kooper, R., Opdyke, D., Williford, J. S., & North, N. (1995). Effectiveness of computer generated (virtual reality) graded exposure in the treatment of acrophobia. *the American Journal of Psychiatry*, *152*(4), 626–628. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7694917 doi: 10.1176/ajp.152.4.626

Schieppati, M., Tacchini, E., Nardone, A., Tarantola, J., & Corna, S. (1999). Subjective perception of body sway. , *66*, 313–322.

Schmitz, C., Drake, L., Laake, M., Yin, P., & Pradarelli, R. (2012). Physiological Response to Fear in Expected and Unexpected Situations on Heart Rate, Respiration Rate and Horizontal Eye Movements. *Journal of Advanced Student Science*, *1*. Retrieved from http://jass.neuro.wisc.edu/2012/01/Lab602Group10FinalSubmission.pdf

Senders, J. W. (1952). *TRACKING PERFORMANCE ON COMBINED COMPENSATORY AND PURSUIT TASKS* (Tech. Rep.). Retrieved from https://apps.dtic.mil/dtic/tr/fulltext/u2/a076045.pdf

Sheik_Nainar, M. A. C. S. U., & Kaber B., D. C. S. U. (2007). The Utility of a Virtual Reality Locomotion Interface for Studying Gait Behavior. *Human factors*, *4*, 696–709. Retrieved from http://journals.sagepub.com/doi/pdf/10.1518/001872007X215773 doi: 10.1518/001872007X215773

Simeonov, P. I., Hsiao, H., Dotson, B. W., & Ammons, D. E. (2005). HEIGHT IN REAL AND VIRTUAL ENVIRONMENTS. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *6*(2), 430–438. Retrieved from https://journals.sagepub.com/doi/pdf/10.1518/0018720054679506

Smith, D. L., Tong, J. E., & Leigh, G. (1977). *Combined Effects of Tobacco and Caffeine on the Components of Choice, Reaction-Time, Heart rate, and Hand Steadiness* (Vol. 45; Tech. Rep.). Retrieved from https://journals.sagepub.com/doi/pdf/10.2466/pms.1977.45.2.635

Streepey, J. W., Kenyon, R. V., & Keshner, E. A. (2007). Field of view and base of support width influence postural responses to visual stimuli during quiet stance. *Gait and Posture*, *25*(1), 49–55. doi: 10.1016/j.gaitpost.2005.12.013

Studio, V. (2015). *Visual Studio.* Microsoft. Retrieved from https://visualstudio.microsoft.com/downloads/

Sundermier, L., Woollacott, M. H., Jensen, J. L., & Moore, S. (1996). Postural sensitivity to visual flow in aging adults with and without balance problems. *The journals of gerontology. Series A, Biological sciences and medical sciences*, *51*(2), M45–52. doi: 10.1093/gerona/51a.2.m45

Tossavainen, T., Juhola, M., Pyykkö, I., Aalto, H., & Toppila, E. (2002). Virtual reality stimuli for force platform posturography. *Studies in Health Technology* *and Informatics*, *90*, 78–82. doi: 10.3233/978-1-60750-934-9-78

Uimonen, S., Laitakari, K., Sorri, M., Bloigu, R., & Palva, A. (1992). Effect of positioning of the feet in posturography. *Journal of vestibular research : equilibrium & orientation*, *2*(4), 349–56. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1342407

Unity3D. (2017). *Unity - Game Engine.* Unity Technologies ApS. Retrieved from https://unity3d.com/

van Asten, W. N., Gielen, C. C., & Denier van der Gon, J. J. (1988). Postural adjustments induced by simulated motion of differently structured environments. *Experimental brain research*, *73*(2), 371–83.

Vreeburg, S. A., Zitman, F. G., Van Pelt, J., Derijk, R. H., Verhagen, J. C., Van Dyck, R., . . . Penninx, B. W. (2010). Salivary cortisol levels in persons with and without different anxiety disorders. *Psychosomatic Medicine*, *72*(4), 340–347. doi: 10.1097/PSY.0b013e3181d2f0c8

Vuillerme, N., Nougier, V., & Teasdale, N. (2000). Effects of a reaction time task on postural control in humans. *Neuroscience Letters*, *291*(2), 77–80. Retrieved from https://www.sciencedirect.com/science/article/pii/S0304394000013744?via{%}3Dihub doi: 10.1016/S0304-3940(00)01374-4

Wallach, H. S., & Bar-Zvi, M. (2007). Virtual-reality-assisted treatment of flight phobia. *Israel Journal of Psychiatry and Related Sciences*, *44*(1), 29–32.

Wilhelm, F. H., Pfaltz, M. C., Gross, J. J., Mauss, I. B., Kim, S. I., Wiederhold, B. K., & Gray, J. A. (2005). Mechanisms of Virtual Reality Exposure Therapy: The Role of the Behavioral Activation and Behavioral Inhibition Systems. *Applied Psychophysiology and Biofeedback*, *30*(3). doi: 10.1007/s10484-005-6383-1

Appendix A

MEASURING UNPLEASANT EMOTIONAL STATE (James Geer questionnaire)

Please circle for each item the number that most closely described the amount of fear you felt toward the object or situation noted in the item.

- **Sharp objects:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being a passenger in a car:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Suffocating:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Failing a test:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Looking foolish:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being a passenger in an:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Worms:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Arguing with parents:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Rats and mice:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Life after death:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror

- **Hypodermic needles:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being criticized:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Meeting someone for the first time:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Roller coasters :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being alone:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Making mistakes:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being misunderstood:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Death:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being in a fight:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Crowded places:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Blood:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Heights:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being a leader:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Swimming alone:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Illness:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being with drunks:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Illness or injury to loved ones:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being self-conscious:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror

- **Driving a car :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Meeting authority:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Mental illness:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Closed places:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Boating :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Spiders :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Thunderstorms:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Not being a success :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **God :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Snakes:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Cemeteries:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Speaking before a group:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Seeing a fight:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Death of a loved one:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Dark places :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Strange dogs:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Deep water:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Being with a member of the opposite sex:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror

- **Stinging insects:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Untimely or early death :** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Losing a job:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror
- **Auto accidents:** 1. None 2. Very Little 3. A little 4. Some 5. Much 6. Very much 7. Terror

Appendix B

MEASURING ACROPHOBIA (Cohen questionnaire)

Below, we have compiled a list of situations involving height. We are interested in knowing how anxious (tense, uncomfortable) you would feel in each situation. Please indicate how you would feel by filling the box relative to the title of that column. In the same row, we would like you to rate them as to avoidance. Please indicate, by filling the relevant box, how much you would avoid the situation if it arose.

Table B.1: Cohen Acrophobia Questionnaire

	Not at all Anxious	Little Anxious	Some Anxious	Much Anxious	Extremely Anxious	Terror Anxious	Would not avoid doing it	Would try to avoid doing it	Would not do it under any circumstances
Driving off the low board at a swimming poo	☐	☐	☐	☐	☐	☐	☐	☐	☐
Stepping over rocks crossing a stream	☐	☐	☐	☐	☐	☐	☐	☐	☐
Stepping over rocks crossing a stream	☐	☐	☐	☐	☐	☐	☐	☐	☐

Standing on a ladder leaning against a house, second story	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Sitting in the front row of an upper balcony of a theater	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Riding a Ferris wheel	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Walking up a steep incline in country hiking	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Airplane trip (to San Francisco)	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Standing next to an open window on the third floor	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Walking on a footbridge over a highway	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Driving over a large bridge (Golden Gate, George Washington)	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Being away from a window in an office on the 15^{th} floor of a building	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Seeing window washers 10 flights up on a scaffold	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Walking over a sidewalk grating	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Standing on the edge of a subway platform	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Climbing a fire escape to the 3rd floor landing	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐

Standing on the roof of a 10-story apartment building	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Riding the elevator to the 50th floor	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Standing on a chair to get something off a shelf	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐
Walking up the gangplank of an ocean liner	☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐