# THE EFFECTS OF A MOVING ENVIRONMENT ON POSTURAL CONTROL AND PERFORMANCE DURING MANUAL MATERIALS HANDLING, VISUAL TRACKING AND ARITHMETIC TASKS.

by © Craig Hickey

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## Abstract

The purpose of this study was to evaluate the performance of cognitive tasks and manual materials handling in a moving environment. In particular we were interested in how task performance, postural control and lower limb muscle activation changed when tasks were performed in motion compared to no motion conditions. The motion trials were performed on a MOOG 2000E that created a 5-degrees of freedom simulated environment. The tasks examined were a lifting task, a mental arithmetic task and a visual tracking task. Results of this experiment indicated that two outcome measures of a visual tracking task (time to task completion and performance errors) were negatively affected by motion, while arithmetic task performance was unaffected. Additionally, postural control was not affected by the presence of motion in the two cognitive tasks. Lifting was the only task where postural control appeared to be negatively affected as participants exhibited significant increases in lower limb muscle activation and non-significant increases in number of steps taken. The significant increase in time to completion and errors suggest that workers doing these type of tasks in an offshore environment may be more prone to committing human factors errors. Furthermore, the results suggest that the risk of falls and injury due to loss of balance may be highest in workers regularly performing lifting tasks as this was the only task where task performance in a moving environment negatively impacted postural control. These findings were attributed to greater demands placed on the postural control system when lifting during the motion condition. This study provides ergonomists with a resource they

can use to better appreciate the risks associated with performance of job related tasks in a moving environment.

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# Chapter 1: Introduction

## 1.1 Background of study

In Canada, maritime industries consist of container transportation, crude oil transportation, oil platform resupply and the use of ferry services within and between many provinces. These services produce billions in economic activity every year (Transport Canada, 2011). In order for companies to ensure maximum profit, worker safety and productivity must be maximized. Manual materials handling (MMH), exposure to moving and falling objects, inadequate sleep, and slips, trips and falls in the presence of wave motions are some factors that may increase the risk of injury. The combination of labour and unpredictable wave motions requires workers to have to try and maintain their balance in addition to completing their work tasks. This additional balance challenge can increase risk of injury due to slip, trips and falls in addition to potentially increasing risk of performance-related injuries (Duncan, MacKinnon & Albert, 2010). Furthermore, workers in these environments must perform a variety of cognitive-based tasks including radar and sonar tracking, the monitoring of various meters and gauges and quick and frequent problem solving on the job.

Currently, little is known about how individuals maintain balance in 6 degrees of freedom moving environments when performing cognitive-based tasks. Similarly, to the authors' knowledge, there is no literature that explores the difference in postural control between performing a lifting task and cognitive-based tasks.

The purpose of this thesis is to examine the effects that performing lifting and cognitive-based tasks has on task performance, postural control and lower limb muscle activation in 5 degrees-of-freedom (5DOF) simulated moving environments. The author first discusses the literature that exists about postural control and how people respond when exposed to perturbations, followed by a look at what happens when people are required to perform a secondary task. Then it is explained what is known about postural control in moving environments and the limited literature that exists on performing dual-tasks in these environments. Following the review of literature is a discussion of the methods used in the research study and subsequent results. Finally, a discussion about what the results mean to the field of ergonomics is presented, along with applications and limitations of the research study.

The present study looks to address two main research questions:

1) Which type of task performance, cognitive or lifting, will have a bigger effect on postural control and lower limb muscle activation when performed in a moving environment?

2) How does simulated ship motion affect task performance in a cognitive task?

The three proposed hypotheses are:

1) The cognitive task will have a greater impact on postural control than the lifting task.

2) Simulated ship motion will have a negative impact on cognitive task performance.

3) The lifting task in motion will result in the greatest increase in lower limb muscle activation when compared to the control condition.

# Chapter 2: Literature Review

The purpose of this review of literature is to examine and outline what is currently known about how performance of secondary tasks (both MMH task and cognitive tasks) impact postural stability, injury risk and slip, trip and fall risk. Additionally, studies done looking at the theory behind both control of posture and the dual-task approach are discussed.

## 2.1 Postural Control

As stated above, working in a moving environment, compared to doing the same work on solid ground, has the added challenge that the environmental motion creates instability that workers must be able to resist in order to remain stable while working. If the instability is too extreme then workers may lose their balance, resulting in a trip or fall. In 2005, slips, trips and falls accounted for 43% of non-fatal injuries on vessels worldwide which is estimated to be three times more than in shore-based occupations (Jensen et al., 2005). Of those slip, trip and fall related injuries happening on vessels, almost half resulted in a fracture or sprain, while the rest resulted mainly in lower back injuries or lacerations and cuts to the body. Jensen et al. (2005) also found that the majority of those injuries occurred while on deck and less injuries occurred in engine rooms.

Postural control is required to perform any upright physical task effectively. It is a capacity to keep the body from moving from equilibrium (Horak, 1997). There are a number of factors that affect how a person maintains balance First are biomechanical constraints, primarily the size and quality (ie. strength, range of motion, if any pain is present) of a person's base of support (BoS). For a person to remain stable his or her center of mass (CoM), defined as the point in space about which the mass of the body is evenly distributed, must remain within the BoS or the person must have control over the CoM if it falls outside of the BoS (Maki & McIlroy, 1997). In addition to BoS, Tinetti, Speechley and Ginter (1988) say that limitations in the size and strength of the base of support or effective control of the feet affect the ability to stay balanced. In addition to BoS, the limit of stability of a person can influence a person's risk of losing balance. The limit of stability is an area that a person can move his or her CoM and maintain equilibrium without changing the base of support. This area is cone-shaped and affected by the size, strength, and range of motion of the ankles, knees, hips and spine (Crutchfield and Shumway-Cook, 1989; McCollum & Leen, 1989). When standing upright, all of the movements people make must stay within these limits or else a person risks falling (Manista & Ahmed, 2012). A second factor that affects how people maintain postural control are the sensory systems. The body has three systems that affect how we maintain our balance: visual, vestibular, and somatosensory. It once was thought that if a person was exposed to stimuli that affected one of these three systems, balance would be restored as a result of reflex responses elicited by a "balance center" within the brain (Peterka, 2002). The body's nervous system develops over time and becomes able to determine how to move to maintain equilibrium; furthermore, the nervous system is able to detect changes in body orientation depending on the context. If a surface becomes unstable, an individual can adjust their posture to reflect the change (Horak, 2006).

However, balance is now viewed as a skill that the nervous system learns to perform using passive biomechanics, all available sensory systems and muscles, and other areas of the brain (Horak, 1997). The ability to interpret complex environments requires the integration of information from the visual, vestibular, and somatosensory systems (Horak, 2006). If an individual has a good base of support and clear vision, they rely primarily on somatosensory information (70% of the time) followed by vestibular (20%) and visual (10%). As an environment changes, so does the distribution of reliance on the three systems (Peterka, 2002). For example, on unstable surfaces a person will begin to use visual and vestibular information more than somatosensory (Peterka, 2002). Being able to redistribute resources is crucial because people change environments many times per day. Similarly, deficits in any of the three systems used to maintain stability will increase the risk of falling (Horak, 2006). A third factor in maintaining postural control is the nervous system's ability to position the body with respect to gravity and the support surface (Horak, 2006). A healthy individual can adapt to an environment by staying perpendicular to the surface. If the surface moves then the nervous system detects the change and can position the body with respect to gravity. A healthy nervous system can detect gravitational vertical even in the dark (Horak, 2006). Lastly, cognitive processing is required to maintain postural control during all movements and even when sitting or standing still.  The more difficult the movement task the more cognitive resources are required for performance (Horak, 2006) When a person is trying to stay balanced and perform an additional, cognitive-based task at the same time then the two tasks are required to share cognitive resources which may cause a decrease in performance of one or both tasks (Horak, 2006).

In the early 1980s, researchers were able to shed more light on how people manipulate postural control and maintain balance through the discovery of anticipatory postural adjustments (APAs) (Cordo & Nashner, 1982). Through the use of EMG, researchers have been able to detect that muscle activity exists before primary movement takes place in both raising of the arms, forward and backward trunk bending, and whole-body forward reaching or stepping (Commissaris, Toussaint, & Hirschfeld, 2000) which are called APAs and occur due to activation in the muscles crossing the ankle joints and in some arm and trunk muscles (Slipjer & Latash, 2000). An APA starts with a shift in the center of pressure (CoP). If the primary movement was forward, there would be a backward shift in CoP, and the opposite holds true. The purpose of an APA is to both counter the reaction forces involved in movement while stabilizing the body's CoM, and allow for CoM to be displaced during voluntary movement (Commissaris & Touissant., 1997). As it relates to this literature review, APAs have been found in a range of dynamic tasks. During the lifting of an object, for example, APAs are typically observed just prior to lifting of an object (Commissaris & Touissant, 1997). Furthermore, APAs were seen in trunk flexion, with a forward shift in upper body CoM creating a backward shift in the CoM of the lower limbs and were shown to occur in the direction that a person voluntarily moved (Oddsson, 1990). This led researchers to believe that APAs were important in preserving balance during movement. In lifting, APAs were discovered to act in minimizing the destabilizing effects that occur when lifting an object (Commissaris

& Toussaint, 1995). Additionally, researchers found that having prior knowledge of a load prior to pick-up was important in how balance was preserved. When researchers gave participants an object that was lighter than anticipated, then participants lost balance nearly every time (Toussaint & Commissaris, 1997). It is proposed that an "expectation pattern" in the nervous system is formed when lifting the same looking objects and when a similar looking object is of different mass, balance is disrupted.

## 2.2 Postural Responses

When an individuals' balance is perturbed there are primarily two strategies they use to try and regain balance. These strategies, known as fixed support and change in support strategies, both serve to return (or maintain) the CoM within the base of support in a manner that helps the individual remain stable (Maki & McIlroy 1997). The original research in this area (Horak & Nashner, 1986) suggested that the choice of strategy was perturbation amplitude dependent (smaller perturbations – fixed support, larger perturbations – change in support). Research by Maki and McIlroy (1997) has shown that perturbation amplitude is not a substantial factor in determining the strategy choice. Furthermore, even though both fixed support and change in support strategies can be used in the presence of small perturbations, only change in support strategies can be used to restore balance during large perturbations (Maki & McIlroy, 1997).

### *2.2.1. Fixed-Support Strategies*

Fixed-support strategies enable balance recovery to occur without the presence of limb movements to alter the BoS. Horak and Kuo (2000) outlined the movements that allow a person to return to equilibrium when CoM is displaced. First, ankle strategies are used when small anterior-posterior forces are placed upon the individual. The strategy works by exerting small moments around the ankle joints and moving the center of pressure ahead of the CoM, allowing the CoM to remain within the BoS. Similarly, the hip strategy is used when the body is exposed to a much larger force, disallowing use of the ankle strategy. This strategy involves flexion at the hips with little to no activation of the muscles surrounding the ankles (Horak & Kuo, 2006). With the use of computer models, Kuo (1995) was able to show that the hip strategy is optimal when CoM must move quickly and that using the ankle strategy is optimal when a vertical trunk movement was necessary. Horak and Nashner (1986) discovered that the use of the ankle and hip strategies could be learned through experience and as such were not due to reflexive behaviour. Using support surfaces of varying lengths, they tested how people would adjust going from one surface to another. After periods of 20 trials on a particular surface, participants adjusted and were able to reduce the time it took to use the ankle or hip strategy following activation of the respective muscles (Horak & Nashner, 1986).

### *2.2.2. Change-in-Support Strategies*

A second strategy to return the body to equilibrium is the change-in-support (CS) strategy. This requires either stepping or reaching with the arms to return the CoM back within the BoS. This strategy is the most common as it is used during gait and any time when keeping the lower limbs stationary is not important (Maki & McIlroy, 1997). This strategy changes the size of the body’s base of support. Change in support strategies work in two ways. First, the BoS can be increased which allows the CoM to work within a much larger range before stability is lost. Second, a larger BoS increases the moment arm between the body's CoM and the point of contact of the limb. This allows for greater moments that act to stabilize and decelerate the CoM and maintain balance (Maki & McIlroy, 1997). In addition to leg movements as a response to perturbations, arm movements are also very common and aim to return the CoM back within the BoS by grabbing onto rails or pressing up against a wall, thus making the BoS larger (Maki & McIlroy, 1997).

### 2.3 Postural control while engaged in a secondary task

The research reviewed above has focused primarily on understanding how individuals remain balanced when standing quietly or moving. However, this situation rarely occurs as most often individuals must stay balanced while performing some other tasks. These tasks include things like talking, lifting, carrying, using various technology (ie. cell phones, tablet computers) and more. As such, maintaining postural control occurs more often in the context of a dual-task than by itself because even standing is attention demanding to some extent (Huxhold, Li, Schmiedek & Lindenberger, 2006). This dual-tasking often leads to a decrease in performance (Ebersbach, Dimitrijevic & Poewe, 1995; Dault, Geurts, Mulder & Duysens, 2001; Lajoie, Teasdale, Bard & Fleury, 1993; Teasdale & Simoneau, 2001). There are a number of theories as to why there is a decrease in performance in one of the two tasks in a dual-task. The first theory is the limited capacity or capacity sharing theory (Kahneman, 1973; Wickens, 1989). The theory suggests that everyone has a limited amount of attention and when a person performs an activity, a percentage of this attention capacity is used. Additionally, if two tasks are performed at the same time and they use more attention than is available, performance of one or both tasks may decrease (Remaud, Boyas, Caron & Bilodeau, 2012). The second theory is the bottleneck theory. It proposes that every tasks requires specific conditions for completion. If another task is introduced and requires the same conditions then one of the tasks must be modified to allow for both to be completed successfully. However, Neumann (1987) believes that performing multiple tasks requires planning, so coordinating the completion of both tasks can be improved with practice. This can result in two tasks combining into one, higher complexity skill with experience (Neumann, 1987).

### *2.3.1. Effects of a dual-task on task performance and postural control*

It is not uncommon for individuals to have to perform some type of memory related tasks while standing (i.e. remembering someone name or recalling a previous conversation). As such, researchers have examined how people would react while performing a memory task while standing. Ebersbach et al. (1995) studied the effects of performing a cognitive activity on motor performance and found changes in gait when performing a memory-retention task. Furthermore, the ability to remember a set of digits was reduced when switching from quiet standing to walking. Additionally, Dault et al. (2001) exposed participants to three different stances: regular shoulder width stance, shoulder width stance on a seesaw, and tandem stance on a seesaw. Participants were asked to do the Stroop test (Stroop, 1935). In this test, participants were shown a card and were asked to say the word on the card, and the colour of the word on the card for 25 different cards. Significant increases in anterior-posterior sway frequency occurred in the shoulder width regular and seesaw stances, and lateral sway frequency was significantly increased only in the tandem seesaw stance. Furthermore, anterior-posterior sway velocity was not affected by the addition of the Stroop test, whereas lateral sway velocity significantly increased in the tandem seesaw stance.

In addition to memory tasks, researchers also looked at how participants would perform on reaction time tasks if combined with a postural control task. For example, Lajoie et al. (1993) had participants perform a reaction time task while walking with varying stance widths. They found that reaction times were significantly longer in the narrower walking compared to the wider walking. These researchers also discovered that reaction times were longer when standing and walking compared to sitting, and more for walking than standing (Lajoie et al., 1993). They suggested these findings were due to the fact that the narrow stance width walking, which would be more unstable, would increase the attentional demands required to remain stable. In addition, these researchers showed that attentional requirements increased as the difficulty of the postural task increased (Lajoie et al., 1993). Teasdale et al. (2001) examined reaction times in people during upright stance under vision and no vision conditions. They found that the addition of a verbal task did not affect reaction times but the center of pressure speed significantly increased in the vision and no vision conditions. As a result, they posited that additional cognitive resources and the ability to reallocate these resources to postural control are needed as multiple tasks are performed. Furthermore, postural control is a continuous process and an increase in demands on posture can “overload” the cognitive system (Teasdale et al, 2001).

While the above research has reported decrements in either task performance or postural control during dual-task situations there is also research where performance of a task or postural control improved. Vuillerme, Nougier & Teasdale (2000) performed a study in which participants were given a reaction time task that required them to respond to the colour of a blinking light. Results from the study showed that postural sway decreased in the presence of the secondary task. Similarly, Vuillerme and Vincent (2006) gave participants two mental arithmetic tests, one easy and one difficult. Their results showed that even in the more difficult arithmetic test, center of pressure displacement was reduced. These researchers believe that even though they provided two tests of varying difficulty that maybe the difficult test still was not challenging enough to elicit changes in postural control (Vuillerme & Vincent, 2006). Another group of researchers administered a two-back test where participants were shown a series of images in succession and had to answer “yes” or “no” to if they had seen the same image two images prior. Postural sway decreased when compared to when participants were not required to perform the task. (Hwang, Lee, Chang & Park, 2013). Prado, Stoffregen and Duarte (2007) used two visual searching tasks in young adults and older adults to test how postural sway was affected. In one condition the participants were only required to look at a blank slate in front of them, while in the other condition they were required to read a block of text silently and count the occurrence of specific letters provided by the researchers. Staring at the blank slate increased postural sway in both age groups while reading and counting letters in the test caused a reduction in postural sway. The researchers suggested that although the results conflict with other related research, that some visual tasks tend to affect postural control differently which explains why some tasks affect balance more than others (Prado et al., 2007). Dault et al. (2001) found that the frequency of sway increased but total sway decreased. This was due to smaller oscillations that occurred at a faster rate while overall sway decreased. These results provide insight for future researchers on how to go about looking at results when analyzing sway in a dual-task scenario. Rather than only reporting on sway velocity it would be useful to be informed of the total amount of sway for a given task in an experiment. Remaud, Boyas, Lajoie and Bilodeau (2013) had participants stand in three different stances: feet together, tandem and single leg with eyes closed and open while in either quiet standing or performing a reaction time task. They found that postural sway decreased when the reaction time task was added.

Researchers have also conducted studies where there were no differences found in either take performance or postural control. For example, Siu and Woolacott (2007) exposed participants to a visual stimulus at different intervals of time and participants were required to remember where objects were on a screen when cued to react. While these researchers found faster reaction times when participants directed their focus on the memory task compared to when they focused on maintaining posture or when they focused on both tasks at once, they found that postural sway was not affected irrespective of where participants directed their focus. These results suggest that people have less conscious control over maintaining posture (Siu & Woollacott, 2007). However, only quiet standing with eyes open was tested and it is possible that differences may have been found if more complex postural conditions were tested.

Based on the research reviewed above the effect of performing a dual-task on both task performance and postural control is not straight forward. In general, it tends to either affect task performance or postural control but typically not both. The variability in research findings in dual task literature is likely due to differences in experimental design. Based on a review of this literature there appear to be three main factors to consider when performing dual-task research: the difficulty of the postural control task, the difficulty of the secondary task (ie. cognitive-based task or MMH-based task) and the attentional focus of the participants.  In the studies described above, Lajoie et al. (1993) and Remaud et al. (2013) found that the more difficult the postural control task the greater the decreases in performance of cognitive task. Kelly, Janke and Shumway-Cook (2010) looked at the ability to perform increasingly difficult postural control tasks while walking. They reported increases in stepping accuracy when participants performed an auditory response task while walking, as opposed to only walking. While the reason for increase in stepping accuracy is unclear, the authors suggested that these results indicate that walking does not require any extra attention when performed alongside another task (Kelly et al., 2010).

While the above dual tasks experiments do add some insight in to how doing two things at once potentially impacts performance the research reviewed is not specific to the types of motions experienced in offshore environments. Currently, little is known about the effects of concurrently performing a work-related task while standing in moving environments. While relatively little research has been done in this area researchers have done some work in the areas of the effects of motion on memory, fine motor skill performance, perceptual tasks and manual material handling. This research will be reviewed below.

## 2.4 Model of human performance in moving environments

A model of human performance has been created for those who are working in moving environments (Dobbins, Rowley & Campbell, 2008). Until more recently, platform motion was viewed as causing three different reactions: motion-induced fatigue, motion sickness or some type of postural response (Figure 2.1), ultimately having some effect on workers on board a vessel. In more recent years, this model has been updated to include interdependent factors that may all work together to affect performance, injury and task operability (Figure 2.2) (Duncan, 2012). As such, it is important to gain a larger understanding of all of the factors that can lead to performance decrements for workers in moving environments. Research that examines the effects that motion has on postural response choice and subsequent task performance is detailed in the sections below.

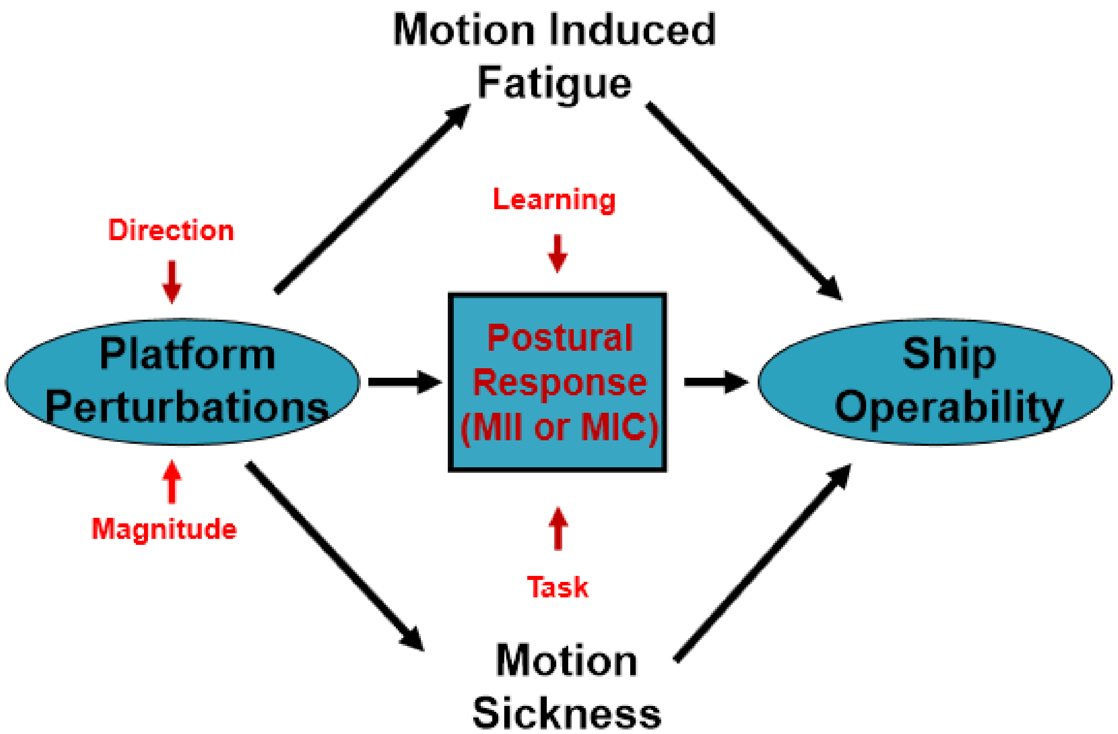


*Figure 2.1: Model of human performance in moving environments. This figure represents what was originally known and researched in moving environments. Platform motion lead to a postural response as well as possible accompanying fatigue or motion sickness, all which play a role in the performance of workers in moving environments. Factors being researched include the direction and magnitude of motion as well as how learning and performance of different tasks affect postural control (Duncan, 2012)*

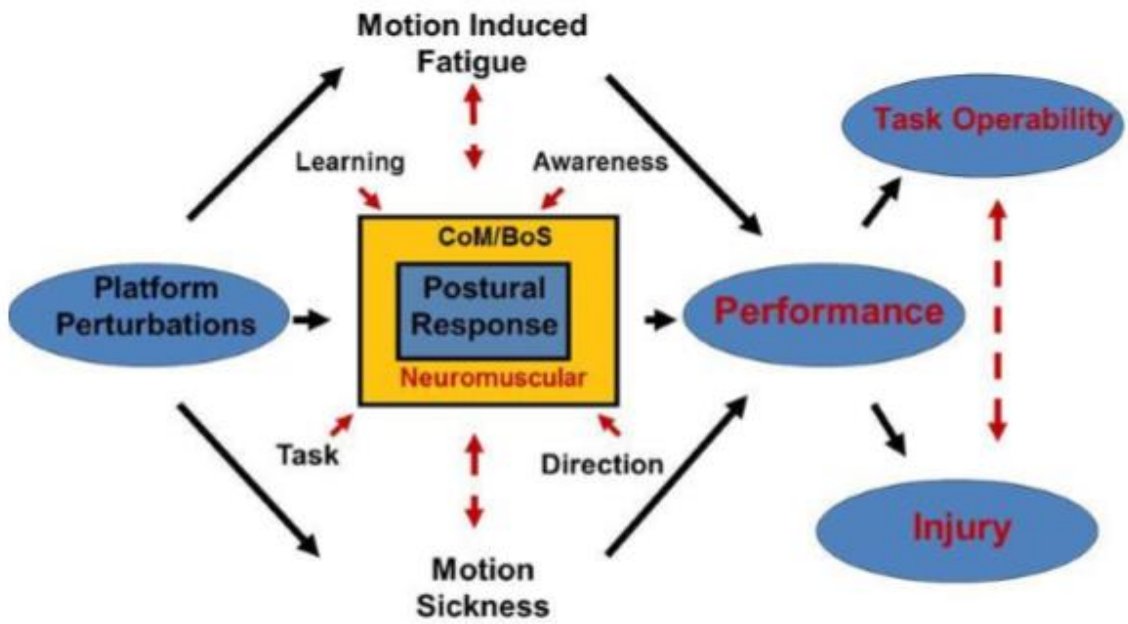


*Figure 2.2: Updated model of human performance in moving environments. This revised model represents a more holistic approach to how moving environments affect postural control with task performance, task operability and injury combined (Duncan, 2012).*

## 2.5 Moving environments and task performance

### *2.5.1. Postural Responses in Moving Environments*

Studying the effects of moving environments on postural control is a relatively new area of research. Unlike on solid ground where workers' only concern is completing the task at hand, individuals who must work in moving environments must do two things simultaneously: 1) maintain balance as their environment moves and 2) complete their required work. This creates a situation where workers are faced with the challenge of completing dual tasks – both of which must be done efficiently and safely to ensure work place injuries don't occur and task performance does not suffer. Research in this field is growing rapidly. Initial research in this area examined individuals who simply had to stand quietly in a moving environments in an effort to better understand how balance was maintained in these challenging environments. Duncan (2012) did some of the seminal work in this field. She showed that people tend to experience a large increase in stepping when in a moving environment. Furthermore, the amount of experience that a person has in these moving environments has a large impact on how they will be able to stay balanced (Duncan, 2012). In addition, Ingram, Duncan, Mansfield, Byrne and McIlroy (2016) discovered that people who were previously exposed to a motion platform and people with dance training had significantly better postural control compared to those who were complete novices in moving environments or balance training. Researchers have also recently discovered that people initially have poor postural control in moving environments but tend to habituate after only a few minutes and have been found to retain this learning from one session to another (Duncan, Langlois, Albert & MacKinnon, 2014). Additionally, the research is now clear that being exposed to a moving environment creates significant increases in CoP motion (Duncan et al., 2010; Duncan et al., 2012; Duncan et al., 2007; Kingma, Delleman & van Dieén, 2003), which may lead to loss of balance. As ship motions increase in intensity, anterior-posterior CoP velocity increases and people tend to step more often which shows that people adapt their posture when faced with an unpredictable environment (Duncan et al., 2010). Torner et al. (1994) found that the joints that are closest to the perturbation are most affected. In marine environments, this would mean that the joints of ankles, knees, and hips and lower back are affected the most.

### *2.5.2. Manual Materials Handling in Moving Environments*

In addition to what is currently known about postural control in moving environments, research in the past decade has enabled us to better understand the effects of performing MMH in moving environments. The National Institute for Occupational Health and Safety (NIOSH) lifting index is designed to be applied to stable, basic movements on land and represents safe lifting limits for workers performing MMH (Lu, Waters, Krieg, & Werren, 2013); however, the models these researchers used are based on static mechanics rather than moving environments as an acceptable limit to lift has not been established for workers in moving environments. Furthermore, safe lifting limits differ based factors such as gender, muscle mass, muscle strength, body mass and the degree of motion (Stellman, 1998). As such, there is a need for data in moving environments to establish safe lifting guidelines during motion (Lu, Waters, Krieg & Werren, 2013). Currently research shows that ship motions cause added stress on the hips, knees, feet and during lifting the motions affect the lower back (Torner et al., 1988). However, lower back pain may not be as big of an issue because performing MMH on a moving platform may not increase load on the lower back if it doesn't involve any twisting, compared to performing the same task on land (Kingma, Faber, Bakker, & van Dieen, 2006). On the other hand, more recent studies have been done showing that lifting in a moving environment requires greater maximal muscle activation of the erector spinae, latissimus dorsi, external obliques and trapezius muscles (Holmes et al., 2008; Matthews et al., 2007) and also takes longer to perform the lifting task as the weight of the load increases (Holmes et al., 2008). Furthermore, research by Duncan et al. (2007;

2010; 2012) in moving environments showed that concurrently performing a lifting task caused increases in anterior-posterior CoP velocity which may lead to people losing balance.

#### *2.5.3. Effects of Moving Environments on Task Performance*

While ergonomists have considerable knowledge of the factors that impact performance of a variety of different cognitive tasks (ie. memory tasks, arithmetic tasks, tracking tasks) on solid ground, relatively little is known about how working in a moving environment while trying to complete these tasks impacts task performance, injury risk or postural control. Insight into the possible effects of these competing demands of balance and task completion can be gained from examining literature related to dual tasks.

#### *2.5.4. Effects of Motion on Memory*

Bles and Wientjes (1988) studied the effects of a tilting room on participants' ability to remember. The researchers used a visual-comparison memory test where participants were shown two pictures on a display and asked to remember which picture they had seen when shown again at a later time. They observed no decrease in memory performance when the room was moving compared to a non-moving room. When this study was replicated using a ship instead of a moving room there was still no decrease in memory performance (Bles & Wientjes, 1988). Crossland and Lloyd (1993) used a ship motion simulator and also found no negative effects when asking people to perform cognitive tasks. However, Wientjes and Bles (1989) used a rotating platform to test memory using the same visual-comparison memory test as above and this time found that whole-body rotation caused a decrease in performance. The literature on the effects of motion on memory tasks provide contrary findings. Wientjes and Bles (1989) were the only ones to use whole-body rotation in motion simulation and find a decrease in performance, potentially causing blurred vision and an inability to see the display properly or motion sickness which could impair function.

### *2.5.5. Effects of Motion on Fine Motor Skills*

In addition to motion's effects on memory recall there has been research that examines how fine motor skills are affected when performed in a moving environment. In 1980, McLeod, Poulton, Du Ross and Lewis performed one of the first studies on a moving simulator. They created a cabin that was mounted on a ship motion simulator that moved in three dimensions: heave, pitch, and roll. They studied the effects motion would have on fine motor skills. First, they had participants perform a tracing task where a picture was given to the participants to draw over. Second, participants were asked to perform a visual-motor tracking task whereby they used their arms to move a crosshair on a display over a moving circle. Lastly, participants were shown a four digit number that they had to say aloud. A decrease in tracing and tracking performance was found when the simulator was moving compared to not moving but the digit task was not affected. Years later, a similar study, that appears to have used similar motions, was performed except this time it was a just the visual-motor tracking task and again a decrease in performance was found (Wertheim, Wientjes, Bles & Bos, 1995). While neither Wertheim nor McLeod provided definitive reasons for the performance decrements they observed, in his review of the topic Werthiem (1998) suggested they were due to individual biomechanical factors. Unfortunately Wertheim does not provide details about the specific biomechanical factors that he is referring to. Contrary to the findings of McLeod et al. (1980) and Wertheim (1998), Bles and Wientjes (1988) (as reviewed Wertheim 1998) found no decrease in visual-motor tracking performance when using a ship motion simulator. This may have been the result of relatively low ship motions used by these researchers compared to the ones used by McLeod et al. (1980) as well as the fact that the ones used by McLeod et al. (1980) were more representative of a real ship. One difficulty in drawing conclusion related to the effect of motion on fine motor skills is the fact that details of the magnitude of the motions used is not clearly reported in the studies. Future research in this area should endeavor to provide clear descriptions of both the type and magnitude of the motions.

### *2.5.6. Effects of Motion on Perceptual Tasks*

While the performance of fine motor and memory related skills are important job related task, many offshore workers need to perform tasks that involve incorporating visual or auditory detection. Such tasks are typically referred to as perceptual tasks (Wertheim, 1998). Malone (1981) performed a study utilizing a radar monitoring task and found no decrease in performance when participants were exposed to wavelike motions in a ship motion simulator. Wientjes and Bles (1989) performed an experiment using a rotating chair with a display attached in front of the participants. There was a performance decrement when the chair was rotating compared to when it remained still. Furthermore, Wertheim and Kiestmaker (1997) used a visual performance task where participants were asked to identify letters on a monitor. There was no decrease in performance when larger letters were displayed, but when smaller letters were used the participants' performance decreased. The authors suggested that during the moving conditions it is possible for the eyes to experience blurred vision, resulting in decreased performance. Smaller, high-frequency vibrations which occur on ships cause the eyes and control panels to vibrate, resulting in a possible decrease in performance (Wertheim, 1998). Again, the literature provides contradictory findings on the effects that motion has on perceptual tasks. The studies where researchers find decreases in performance are when participants are required to have good control of their vision, so it is possible that only ship motions that cause vibration of either the visual display or the participants' vision will show performance decrements.

### 2.6 Conclusion

Research aimed at determining the relationship between complex moving environments and their effect on postural control and task performance has grown rapidly in the past 15 years. Many studies (Duncan et al., 2010; Duncan et al., 2012; Duncan et al., 2007; Holmes et al., 2008; Matthews et al., 2007) have explored how performing manual materials handling tasks affects postural control in a moving environment. Additionally, a few studies (Bles & Wientjes, 1988; McLeod et al., 1980; Wertheim et al., 1995) have examined the effects of motion on task performance in a 3-degrees of freedom motion platform. To the author's knowledge, there is no research done looking at effects of ship motion which compares two types of tasks, a manual materials handling task and a cognitive task. This research looks to fill in the gaps by using a 6-degrees of freedom motion platform to determine the effects that ship motion has on postural control and the performance of these two types of tasks.

# Chapter 3: Methods

## 3.1 Participants

Nine male and seven female participants (males: height 183.5 ± 6.4cm, mass 89.9 ± 14.3kg and age 23.8 ± 1.7 years old; females: height 164.7 ± 8.3cm, mass 72.8 ± 24.2kg and age 24.8 ± 3.6 years old) participated in this study. Participants were recruited from the Memorial University student population. All participants were free of any known musculoskeletal injuries or balance issues. Furthermore, participants had no previous exposure to marine moving environments and no experience on a motion platform in the past six months. Participants were screened for susceptibility to motion sickness by being asked if they have ever been sick on a roller coaster, in the backseat of a car or been seasick before. If the answer to those questions was "no" then they were allowed to continue. This ensured their risk of developing motion sickness during the trials would be minimal. All participants were given a form that outlined the study and were provided the opportunity to ask questions before completing a Physical Activity Readiness and Medical Questionnaire (Appendix A) and providing informed written consent to participate. This study was approved by the Interdisciplinary Committee on Ethics in Human Research of Memorial University of Newfoundland.

## 3.2 Preparation

Before the data collection began, participants were fitted with 12 electromyography (EMG) electrodes for collection of muscle activity. Prior to placement of the electrodes participants had their skin shaved and cleaned with an alcohol swab at the location of the electrode placement to enhance signal quality. The electrodes were placed bilaterally on the biceps femoris, gastrocnemius, tibialis anterior, peroneus longus, vastus lateralis and erector spinae and attached to the skin using medical grade tape. Locations of electrode placement were according to Cram's Introduction to Surface Electromyography (Criswell, 2011). Electrical activity of the muscles were collected using Delsys Trigno wireless EMG system (Delsys Incorporated, Natick, Massachusetts; collection frequency 2000Hz, CMR of 80db; bandpass filter 20Hz – 450Hz).

Participants then performed isometric maximum voluntary activations (MVAs) for each muscle of interest. Each MVA lasted for approximately 5 seconds and was completed twice per muscle. The method used for MVA collection was as follows:

- Biceps femoris: the participant sat on the edge of a table with the knees flexed at 90° and feet not touching the ground. The researcher then applied a force to the lower leg while the participant resisted knee extension by activing their biceps femoris.

- Vastus Lateralis: the participant sat on the edge of a table with the knees flexed at 90° and feet not touching the ground. The researcher applied a force to the lower leg toward while the participant resisted knee flexion by activating their quadriceps.

- Gastrocnemius: the participant stood on one foot and activated their ankle plantarflexors while the researcher stood on a stool located behind the participant. The researcher applied resistance to the shoulders from above while the participant provided resistance by further activating their ankle plantarflexors.

- Tibialis Anterior: the participant laid supine with their toes pointed toward the ceiling. The researcher applied a force to plantar flex the ankle while the participant resisted by activating their ankle dorsiflexors.

- Peroneus Longus: the participant laid supine while pronating the foot, while the researcher applied resistance while the participant resisted by activating the ankle supinators.

- Erector Spinae: the participant laid face down with the hips on the edge of a table and extended into an erect position while the researcher applied resistance.

### 3.3 Study Protocol

Immediately following the collection of the MVAs, participants were familiarized to the motion platform used for the remainder of the study. The platform used was a Moog 6DOF2000E (Moog Inc., Elma, NY), a 6-degrees-of-freedom electric platform used to replicate underfoot platform motions caused by waves that occur in marine environments. This platform was located in the Safety at Sea Simulation Lab at Memorial University of Newfoundland. The platform was equipped with a cover so that participants were unable to see outside of the simulator in the areas front of them and to their sides, but could see outside of the simulator behind them if they were to turn around (Figure 3.1). However, participants were encouraged to face forward whenever possible. Once familiarization to the equipment was complete each participant completed a practice trial on the motion bed, which consisted of one, five minute motion trial so they could become habituated to the simulated motions. No data was collected during this trial as previous research has shown significant differences in average time spent stepping from the very first trial on a motion platform compared to subsequent trials (Duncan et al., 2014).

*Figure 3.1: Picture showing the motion simulator and setup used for the study. A table is in front of the participant while he or she remains facing forward, unable to see outside of the simulator as a result of the cover.*

Once the practice trial was complete participants then completed the seven data collection trials. These consisted of the following conditions: a control trial where participants were required to simply maintain balance while the motion bed moved (i.e. no additional task was performed), two lifting task trials, two arithmetic task trials and two visual tracking task trials (see Table 3.1). The lifting, tracking and arithmetic trials were done with motion and without motion. The order of the trials was randomized with the exception of the practice trial, which always came first. Two minutes of rest was given between each trial and during the rest period participants were given the Misery

Scale (Wertheim, Bos & Bles, 1997) and asked how they felt on a scale of 1-10 with regards to motion sickness, 10 being “extremely motion sick”. If a participant reached a “6” out of “10” on the motion sickness questionnaire then they were required to withdraw from the study. Each trial used the same motion profile, which was derived from deck motions collected on a research fishing vessel using a complex linear equation theory (Crossland & Lloyd, 1993; see equations in Table 3.2). In all trials participants could step, grasp handrails or move in any manner needed to maintain balance, but had to return to the original standing point as soon as balance was regained. Participants could orient their feet however they felt was best for maintaining balance.

Table 3.1

*Description of the seven trials participants completed in the study. With the exception of the practice trial, all trials were done in random order with a 2 minute rest break in between. Arithmetic task was based on the work of Ryu and Myung (2005).*

| Condition | Task |
|---|---|
| Control | Maintain balance during platform motion |
| Arithmetic motion | Answer 60, 2 –digit addition questions. |
| Arithmetic no motion | |
| Tracking motion | Perform a tracking task on a tablet |
| Tracking no motion | |
| Lifting motion | Lift and lower a 7kg box from a table once every 10 sec. |
| Lifting no motion | |

Table 3.2

*Equations used to create the motion profile used for the present study (Crossland and Lloyd, 1993).*

| Direction | Equation |
|---|---|
| **Roll** | **0.8(6sin(1.050t) + 1.25sin(0.11t + 0.5))** |
| **Pitch** | **0.8(2.5sin(1.76t + 0.5) + sin(t - 1.5))** |
| **Heave** | **0.1(5sin(1.595t + 2) + 15sin(1.21t))** |
| **Surge** | **0.1(7.8sin(0.649t + 4.8) + 7.8sin(0.825t + 3.8) + 0.5)** |
| **Sway** | **0.1(18sin(0.583t + 5) + 9sin(1.122t + 5.4) - 0.25)** |

### 3.4 Description of Tasks

For the lifting task the participant stood in front of a table that was attached to the floor of the motion platform. For the duration of the trial the participant was asked to maintain a position whereby the medial malleoli was 50cm from the front edge of the table. This position was marked by a piece of tape for reference. The participant was asked to perform lifting and lowering of a 7kg box onto a table that was 74cm high. The participant was then instructed to lift (or lower) once every ten seconds for the duration of the trial. This resulted in the box being lifted 15 times and lowered 15 times over the span of five minutes. A schematic of the lifting task is located in Figure 3.2. The timing of the lift/lower was signaled to the participants with the use of a metronome. The mass of the box, optimal table height and horizontal lift displacement were all determined using the recommended weight limit guidelines from the National Institute for

Occupational Safety and Health to ensure the lift was safe for participants (Waters & Putz-Anderson, 2003). Participants were instructed to lift and lower the box in a manner that felt most comfortable for them and were given the opportunity to practice prior to the testing session to ensure that they could lift at the required rate.

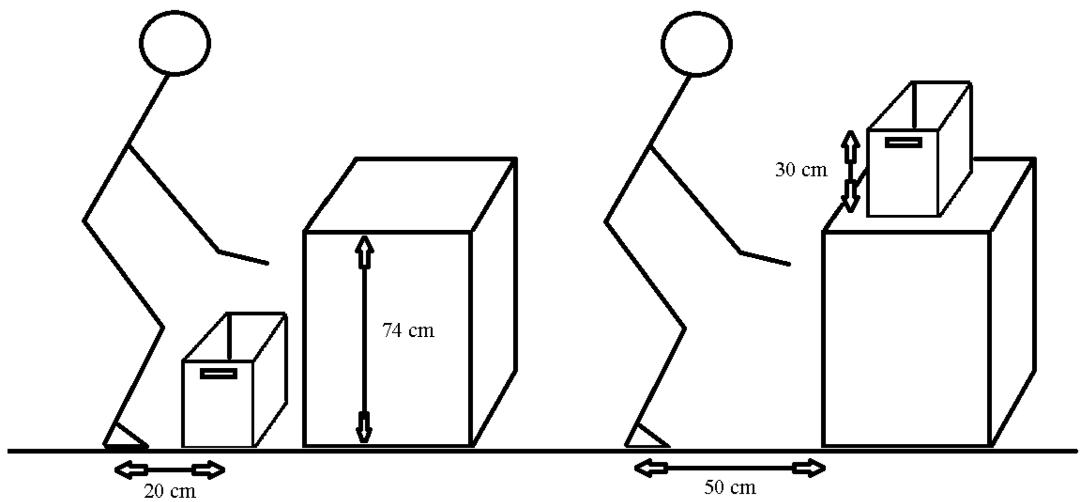


*Figure 3.2: Schematic illustrating the performance of the lifting tasks. Participants completed two, 5 minute lifting trials. One was performed while the motion platform simulated real-life wave induced ship motion and the other when the motion platform was stationary. The load lifted in both trials was 7kg.*

The arithmetic task required participants to respond to a series of arithmetic questions displayed on a tablet computer that was placed on the table on the motion platform. This task was based on research by Ryu and Myung (2005) who used arithmetic tasks of varying difficulty to test the effects of dual tasking on various brain waves. For the current study two sets of two-digit addition questions were used. The equations consisted of random numbers between 10 and 99. These numbers were randomly generated using Microsoft Excel (Microsoft Corp., Redmond, Washington). The resulting equations were typed, one equation per screen, into a Microsoft PowerPoint presentation that was programmed to display a new slide every 5 seconds (see Figure 3.3). All participants completed one arithmetic trial with the platform stationary and one with the platform moving. Half of the participants performed the first set of equations in motion while the other half performed the second set of equations in motion. During both trials participants were permitted to step as close to the table as they felt necessary in order to adequately view the tablet. They were presented with the first question on the tablet and given five seconds to answer before the next question appeared on the screen. This continued until the 5 minute trial ended. In that time participants were able to answer 60 questions. Participants were required to articulate the answer to the researcher so it could be recorded and were allowed to correct themselves if the correction was done before the next question was shown.


*Figure 3.3: Sample of what appeared to the participants during the arithmetic task trials*

For the visual tracking task, participants were required to solve a maze that was displayed on the tablet computer placed on the table as described above. The maze used was Cogstate's Groton Maze Learning Test (Cogstate Ltd., New York, NY). For this task participants were required to complete the maze five times as fast as they could. The software had 16 different maze options that participants could potentially be required to complete for both the motion and no motion trials – the software randomly chose one for the participant to complete for each of the two trials. Each maze consisted of a set of 10 x 10 blocks and were all considered to be of the same difficulty (see Figure 3.4). The objective of the task was for the participant to 'discover' the predetermined path from the starting point to the end of the maze. Participants began the maze by touching the top left "starting" block – this started the timer. To solve the maze participants had to correctly guess the next block in the sequence until they found their way to the bottom right corner of the maze, marked by a target. The only valid moves throughout the trials were "up", "down", "left" or "right"; touching diagonally or touching a block two or more spaces away were considered invalid moves and were recorded by the software as "rulebreak errors". If a move was successful then a green checkmark was displayed on the screen. The participant then proceeded to try and guess the next block in the maze. See Figure 3.4 for sample screens with valid moves indicated.

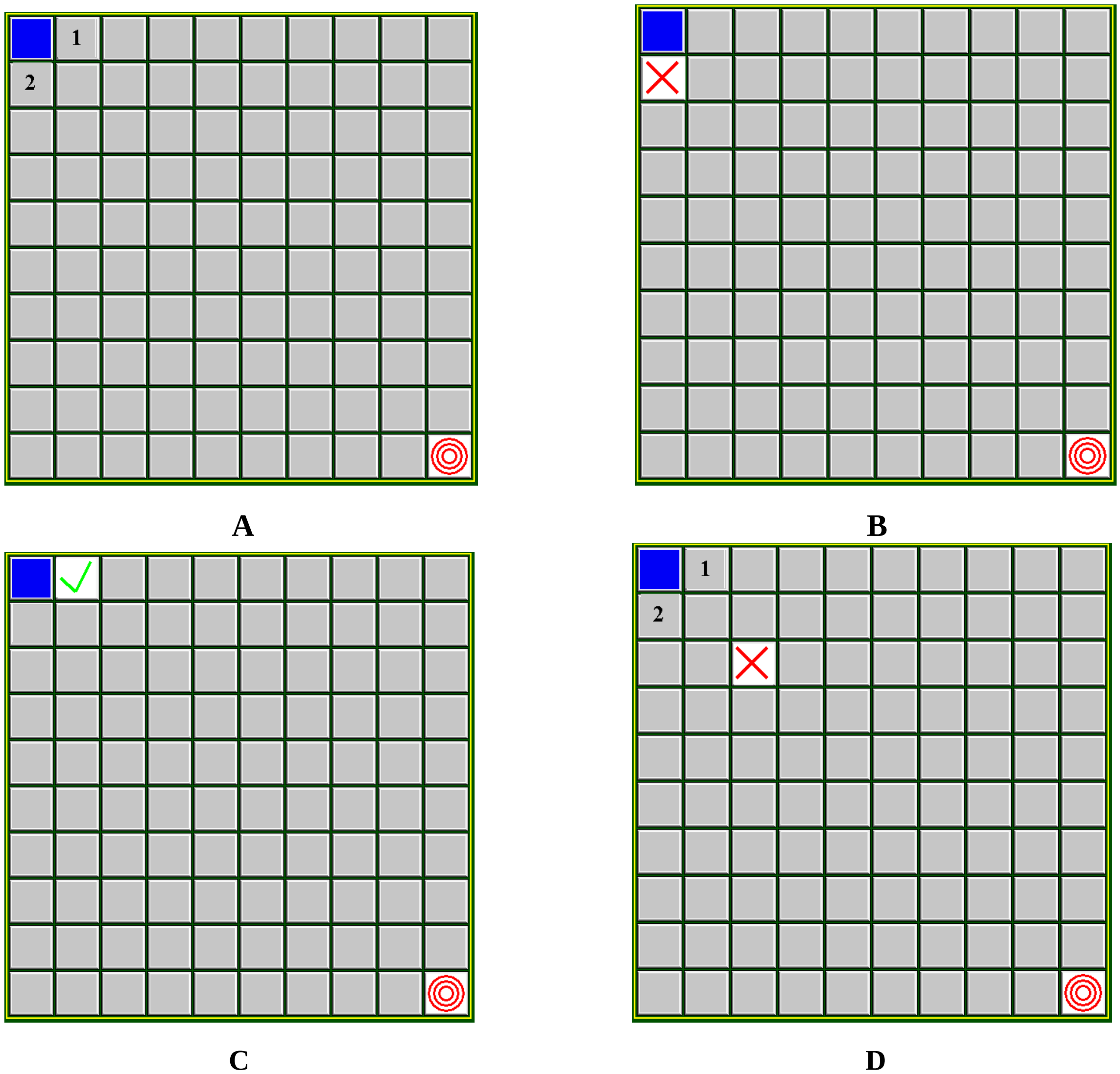


*Figure 3.4: a) Example of the initial screen participants would see for one trial of the visual tracking task. As the only valid moves in this task are 'UP', 'DOWN', 'LEFT','RIGHT' participants could either select block 1 or 2. b) If participant selected block 2 in this case they would see an 'X' as this was not a block in the actual maze – this would be recorded as a legal error by the software. They would then have to select another block. c) If the participant selected block 1 they would see a green check mark indicating they had selected the correct next block in the mace. d) If the participant selected a block other than 1 or 2 they would see a red 'X' and a rulebreak error would be recorded. Participants would proceed this way through the maze until reaching the end. Once they reach the end they would repeat the same exact maze again until it has been completed five times.*

Once the participant successfully reached the target in the bottom right hand corner the maze had to be solved four more times to complete the entire task. Each of these four attempts used the same maze as the first attempt. As such maze performance could improve as participants learned the path through repetition. Task performance on each of the five repetitions of the maze was tracked by the Cogstate software. While numerous performance metrics were tracked by the software only legal errors and rulebreak errors were used for the current study.

Participants completed two 5-minute trials for each of the 3 tasks. One trial of each task was done with the platform stationary and the other trial with the platform in motion. They were videotaped during all of the motion trials so that specific performance measures could be obtained. One camera was located behind the participants so that movement of the feet could be observed, while another camera was located to the participants' left side to capture if any grasping of the table or platform railings occurred. Stepping and grasping captured by both cameras were combined and used to form total MIIs.

### 3.5 Data reduction and analysis

EMG data collected from the MVA trials were examined to determine the maximum activation levels in each of the muscle examined. This was done by calculating the root mean square (RMS) from the MVAs using a moving window of 100ms (Burden & Bartlett, 1999). Maximum amplitude was then determined by finding the peak values from the EMG signal of each muscle. All of the EMG from the testing trials were then normalized to these peak values. The mean values of this normalized EMG were then determined for the full five minute trials.

For all the motion trials videos were examined to determine the stepping reactions that people used to remain balanced. Video recordings were viewed in slow motion using Microsoft's Windows Movie Maker. The stepping analysis that was done was based on work done by Duncan et al. (2014).  The video analysis initially identified instants when participants either lifted a foot from the platform or grabbed a railing or the table. Based on the criterion set by Duncan et al. (2014), in order for a new step to be counted at least 1 sec must have occurred between the present step (or grab) and the previous one. In addition to recording step rate (steps/min), the direction of the step, the foot doing the stepping and the duration of each step were also determined. Unlike the work of Duncan et al. (2014), during the lifting trials the stepping analysis was done over the full 5 minute trial (Duncan et al. only considered steps performed during lifting/lower motions when lifting).

In addition to the video data, performance measures were determined for the arithmetic and tracking tasks. These are explained in detail below:

- *Arithmetic task:* Task performance was based on the number of successful answers given out of 60. Video data was used to confirm answers given by participants and questions left unanswered were considered incorrect.

- *Visual tracking task:* Performance in this task was quantified using measures provided by the Cogstate Software. While the software provided a variety of outcome measures (see Table 3.3 for sample output provided by Cogstate), the measures used for this study were the time it took to complete the task (ie. finish the maze five times), and how many legal and rulebreak errors were made.

Table 3.3

*Sample tracking task output: CMV = Correct moves; TER = Total errors; LER = Legal errors; RTH = Return to head (ie. previous tile); RER = Rule-break errors; DUR = Duration (in milliseconds); MPS = Moves per second. NOTE: only DUR, RER and LER were used in the present study.*

| Code | Task Name | GMLidx | CMV | TER | LER | RTH | RER | PER | DUR | MPS |
|---|---|---|---|---|---|---|---|---|---|---|
| GML1 | Maze | 17 | 28 | 12 | 12 | 12 | 0 | 0 | 29594 | 0.95 |
| GML2 | Maze | 17 | 28 | 15 | 11 | 13 | 4 | 0 | 30944 | 0.90 |
| GML3 | Maze | 17 | 28 | 7 | 7 | 7 | 0 | 0 | 24242 | 1.16 |
| GML4 | Maze | 17 | 28 | 8 | 7 | 7 | 1 | 0 | 23099 | 1.21 |
| GML5 | Maze | 17 | 28 | 8 | 7 | 7 | 1 | 0 | 21185 | 1.32 |
| GML | Maze | 17 | 140 | 50 | 44 | 46 | 6 | 0 | 136796 | 1.02 |
| GMR | Maze Recall | 17 | 28 | 5 | 5 | 5 | 0 | 0 | 18775 | 1.49 |

### 3.6 Statistical Analysis

Sphericity was tested using Mauchly's test. In cases where sphericity was violated degrees of freedom were corrected using Huynh-Feldt or Greenhouse Geiser as appropriate. Tests for normality were performed on all data. All data was normally distributed except for task performance measures. Statistical analyses were conducted using IBM SPSS software (Version 20, IBM Corp.).

There were two primary questions that needed to be answered: 1) How did the addition of motion affect lower limb muscle activation? 2) How did the type of task impact postural control and lower limb muscle activation? and 3) How did motion impact task performance? The statistical analyses used to answer these questions are outlined below:

**How did the addition of motion affect lower limb muscle activation?** A two-way repeated measures ANOVA was for this analysis. The factors were task (arithmetic, tracking and lifting) and motion condition (no motion and motion). Unfortunately there was no quiet standing trial collected during the no motion condition. As such the control trial could not be included in this two-way ANOVA.

**How did the type of task impact postural control and lower limb muscle activation?** A 1-way repeated measures ANOVA was used. The only factor in this ANOVA was task and it had 4 levels (control, arithmetic, tracking and lifting) all of which were performed while the platform was moving. This analysis was used both to examine difference in lower limb muscle activation and also number of steps taken and the length of time spent stepping. Significant effects for both the 1-way and 2-way ANOVAs were further examined using paired t-tests with p-values corrected using a Bonferroni correction (baseline p-value was $p < 0.05$).

**How did motion impact task performance?** As this data was not normally distributed a Wilcoxon-signed rank test was performed to test for significant differences between correct answers given when participants performed the arithmetic task in motion and no motion conditions and also to compare the effects of motion on the time it took to complete the visual tracking task as well as the number of legal and rulebreak errors committed ($p < 0.05$).

# Chapter 4: Results

## 4.1 Muscle activation

Two separate analyses were done to examine the effects of both motion and task on lower limb muscle activation. In the first analysis a one-way ANOVA was used to assess the effect of performing a secondary task on muscular activation. Results of the ANOVA revealed a significant effect of task on lower limb muscle activation for all muscles (see Table 4.1). Post hoc analyses for these effects are reported in Table 4.2. As results from both left and right sides were consistent with one another, results from just the right side are displayed in Figures 4.1a-e.

Table 4.1
*Results of one-way repeated measures ANOVA.*

| Muscle | Side | Task Effect | |
|---|---|---|---|
| | | F-value | *p*-value |
| Tibialis Anterior | Right | 13.36 | < .01 |
| | Left | 12.31 | < .01 |
| Peronei | Right | 13.70 | < .01 |
| | Left | 13.28 | < .01 |
| Medial Gastrocnemius | Right | 3.68 | < .05 |
| | Left | 3.78 | < .05 |
| Vastus Lateralis | Right | 8.23 | < .01 |
| | Left | 4.96 | < .01 |
| Biceps Femoris | Right | 18.18 | < .01 |
| | Left | 20.53 | < .01 |

Table 4.2

*Post-hoc testing results based on the significant main effect of task reported in Table 1.*

| Muscle | Side | Significant between task effects (p<0.01) |
|---|---|---|
| **Tibialis Anterior** | **Right** | **Lifting>Control<br>Lifting >Arithmetic<br>Lifting >Tracking** |
| | **Left** | **Lifting>Control<br>Lifting >Arithmetic<br>Lifting >Tracking** |
| **Peronei** | **Right** | **Lifting>Control<br>Lifting >Arithmetic<br>Lifting >Tracking** |
| | **Left** | **Lifting > Control<br>Lifting > Arithmetic<br>Tracking>Arithmetic** |
| **Medial Gastrocnemius** | **Right** | **No significance differences** |
| | **Left** | **No significance differences** |
| **Vastus Lateralis** | **Right** | **Lifting>Control<br>Lifting>Arithmetic** |
| | **Left** | **Lifting>Arithmetic** |
| **Biceps Femoris** | **Right** | **Lifting>Control<br>Lifting>Arithmetic<br>Tracking>Control<br>Tracking>Arithmetic** |
| | **Left** | **Lifting>Control<br>Lifting>Arithmetic<br>Tracking>Control<br>Tracking>Arithmetic** |

Results of the two-way ANOVA found a significant main effect of motion and task as well as a significant interaction effect for most muscles. Because this analysis was done only to examine the effect of motion on muscle activation only the main effect of motion and the interaction effect were examined further. Details of these results can be found in Table 4.3. Post-hoc analysis of the main effect of motion revealed that for all muscles, with the exception of left biceps femoris, motion resulted in increased activation. Comparisons of the tasks in motion and no motion conditions can be found in Figure 4.2.

Table 4.3

*Results of two-way repeated measures ANOVA showing interaction of task and motion.*

| **Muscle** | **Side** | **Main effect of Motion** | | **Interaction effect (Task x Motion)** | |
|---|---|---|---|---|---|
| | | **F-value** | ***p*-value** | **F-value** | ***p*-value** |
| **Tibialis Anterior** | **Right** | **107.57** | **< .01** | **9.34** | **< .01** |
| | **Left** | **113.17** | **< .01** | **7.68** | **< .01** |
| **Peronei Group** | **Right** | **40.99** | **< .01** | **11.91** | **< .01** |
| | **Left** | **153.38** | **< .01** | **9.91** | **< .01** |
| **Medial Gastrocnemius** | **Right** | **24.64** | **< .01** | **5.70** | **< .05** |
| | **Left** | **52.67** | **< .01** | **3.68** | **< .05** |
| **Vastus Lateralis** | **Right** | **42.35** | **< .01** | **1.34** | **NS** |
| | **Left** | **41.35** | **< .01** | **0.70** | **NS** |
| **Biceps Femoris** | **Right** | **1.69** | **NS** | **7.33** | **< .01** |
| | **Left** | **13.84** | **< .01** | **3.43** | **< .05** |

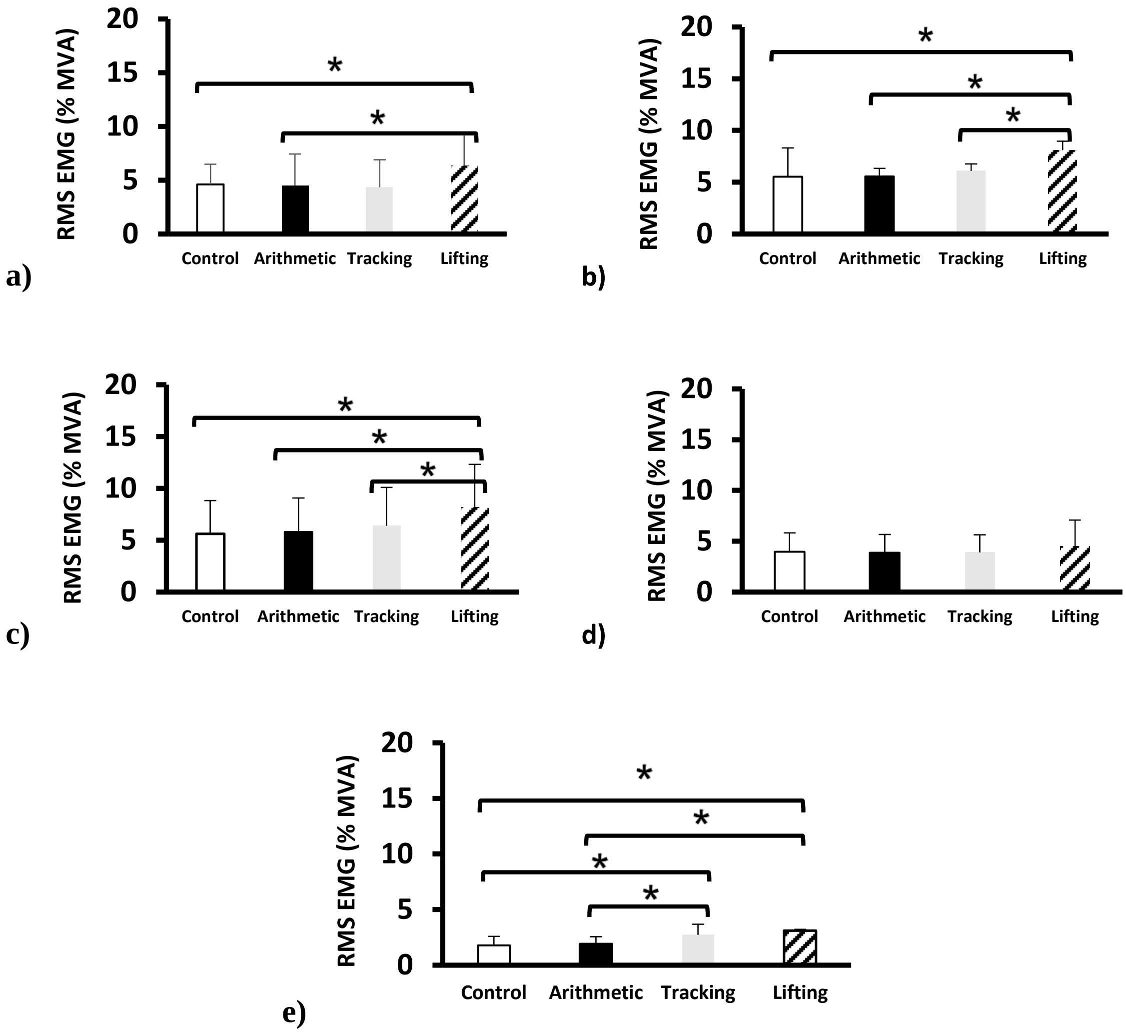


*Figure 4.1: Root mean square EMG (% MVA) for the right side across tasks in motion: a) vastus lateralis b) tibialis anterior c) peronei d) gastrocnemius and e) hamstrings.*

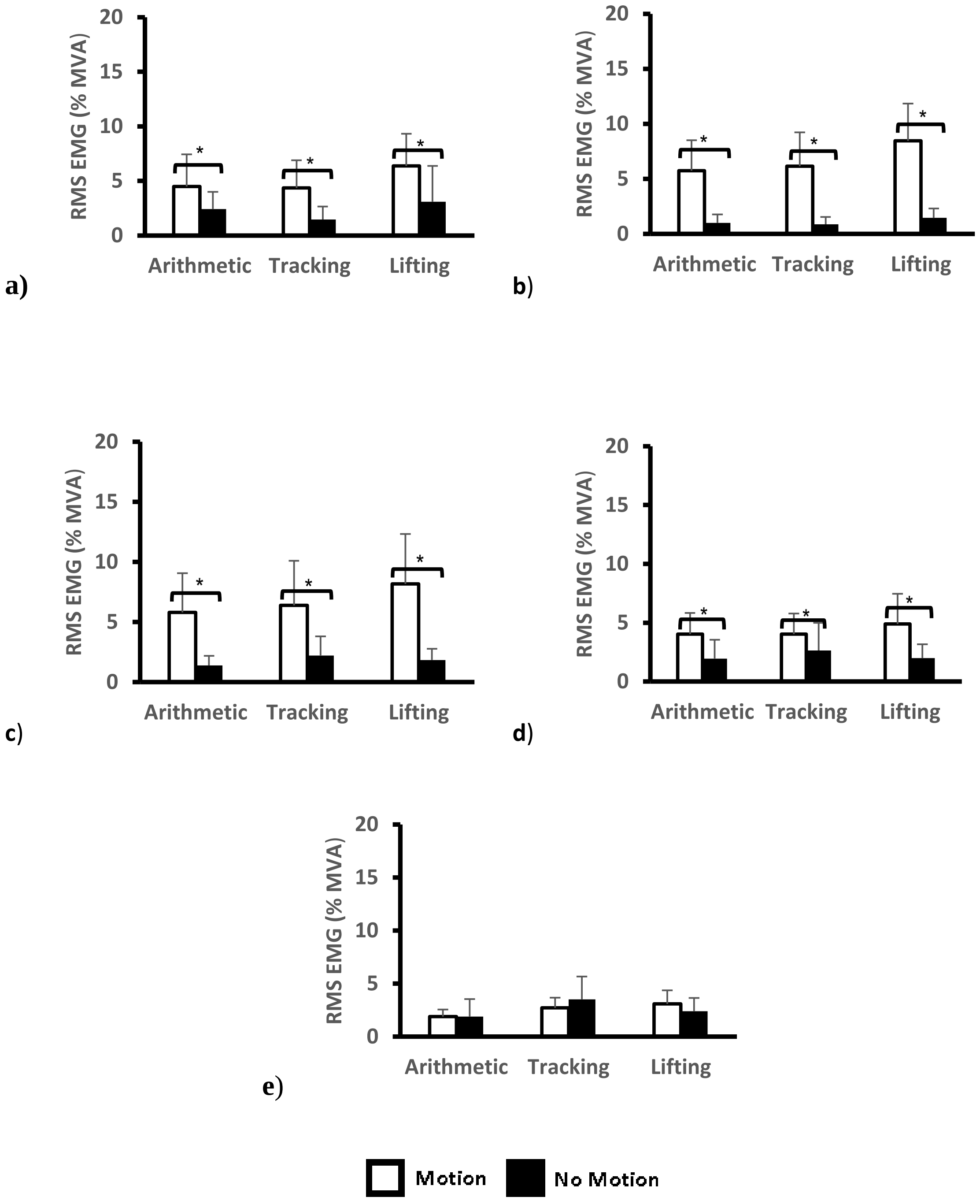


*Figure 4.2: Root mean square EMG (% MVA) comparing motion and no motion conditions: a) vastus lateralis b) tibialis anterior c) peronei d) gastrocnemius and e) hamstrings.*

## 4.2 Stepping

One-way ANOVA results for stepping rate indicated a non-significant effect of task ($p$ = 0.189). Despite this non-significant effect, when lifting, participants stepped more frequently than during either the control, arithmetic or tracking tasks (see Figure 4.3). Control (*M* = 2.62; *SD* = 4.29), Arithmetic (*M* = 3.04; *SD* = 5.98), Tracking (*M* = 3.70; *SD* = 5.79), Lifting (*M* = 6.31; *SD* = 6.00).

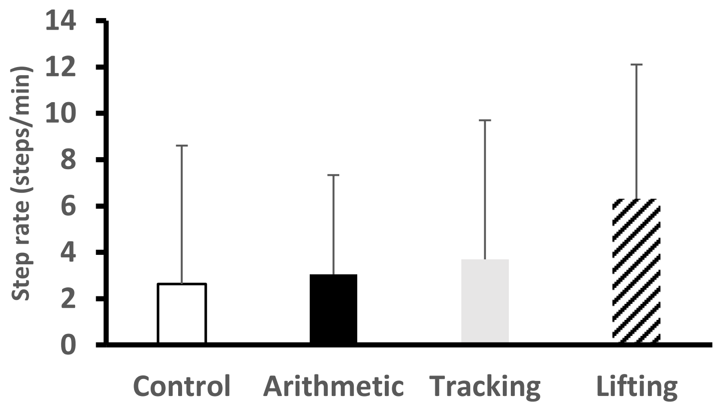


*Figure 4.3: Stepping rate across different tasks in motion.*

One-way ANOVA results for the total time stepping per minute indicated a non-significant effect of task ($p$ = 0.061). While participants did spend a longer time stepping on average during the lifting task compared to the other three tasks (see Figure 4.4), these results were ultimately not significant. Control (*M* = 1.52; *SD* = 2.82), Arithmetic (*M* = 2.01; *SD* = 4.02), Tracking (*M* = 2.52; *SD* = 4.45), Lifting (*M* = 3.71; *SD* = 3.51).

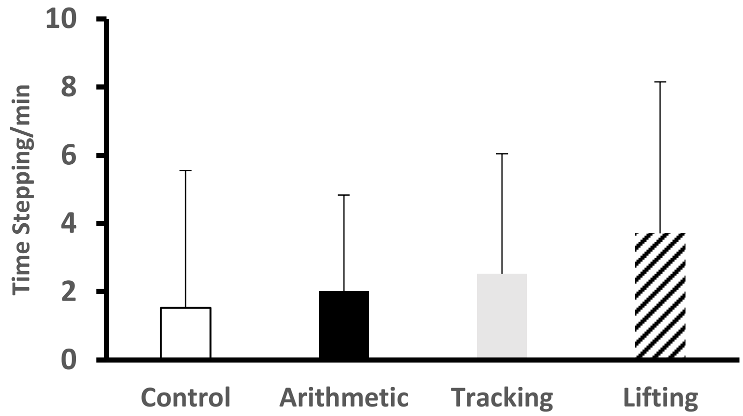


*Figure 4.4: Average time spent stepping across different tasks in motion.*

## 4.3 Performance measures

When performance on the tracking task was examined results of the Wilcoxon signed rank test showed a significant difference between motion and no motion conditions (Z = -2.896, $p$ = 0.004). While participants took 212.08 sec to perform the tracking task in motion they only required 155.91 sec to complete it during the no-motion condition (Figure 4.5). When the number of rulebreak errors were examined participants committed 38.75 errors during the motion trial. This was significantly more errors (Z = -3.466, $p$ = 0.001) than they committed during the no-motion condition ($M$ = 12.38 errors) (Figure 4.6).

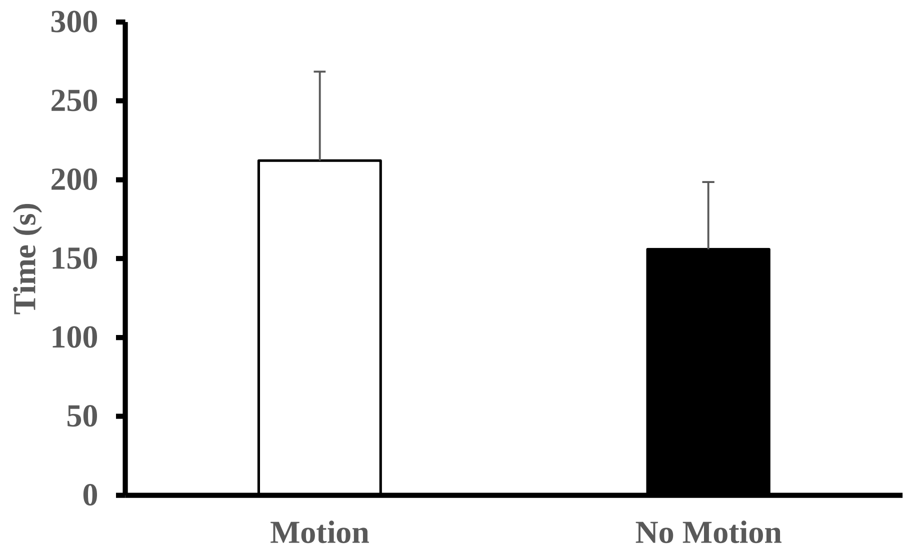


*Figure 4.5: Total time required to complete the tracking task in motion versus no motion conditions.*

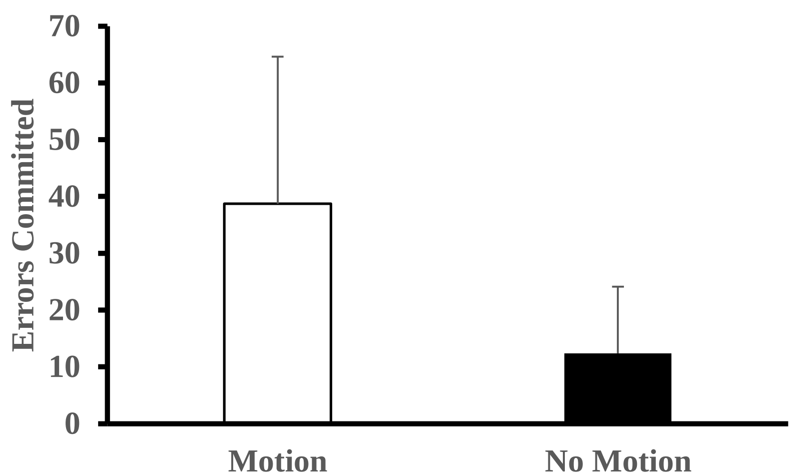


*Figure 4.6: Number of invalid, rulebreak errors committed in motion versus no motion conditions.*

Analysis of arithmetic task performance indicated no significant difference in the percent of answers correct between motion and no motion conditions (Z = -0.810, *p* =

0.418). As shown in Figure 4.7 irrespective of whether participants performed the arithmetic task in a stable or a moving environment on average they got 78% of their responses correct.

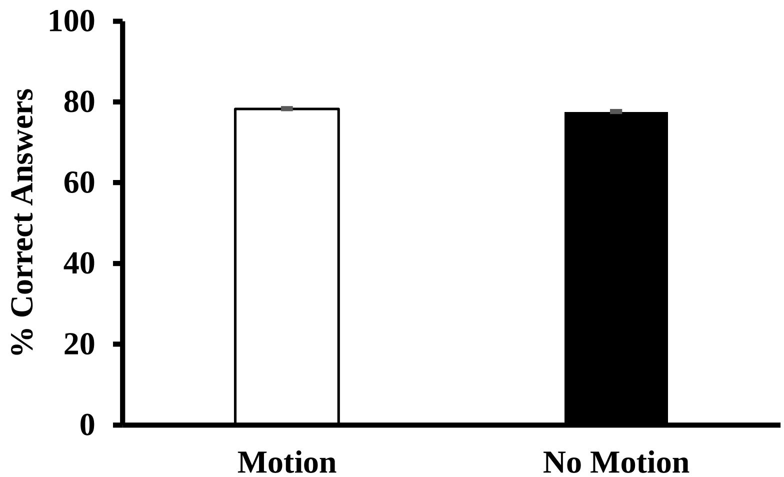


*Figure 4.7: Percent of correct answers given in motion versus no motion conditions in the arithmetic task.*

# Chapter 5: Discussion

In recent years, research examining the effects that ship motions have on postural control and injury risk has expanded rapidly (Duncan et al., 2014; Duncan et al., 2010; Duncan et al., 2012; Duncan et al., 2007; Holmes et al., 2008; Matthews et al., 2007). These studies provide insight for ergonomists in offshore environments, but the research that exists explores the effects of lifting as opposed to cognitive-based tasks. The purpose of the study was to observe the effects that simulated wave motions had on the ability to maintain postural control while performing a secondary lifting or cognitive-based task. The most important finding from this study suggests that ship motion negatively impacts performance of a tracking task but does not affect doing arithmetic. Furthermore, results revealed that lifting presents the greatest challenge to postural control of the three tasks.

## 5.1 Cognitive

The most important and novel finding of the current study was the fact that the effects of performing an arithmetic task when in a moving environment differed from the effect of performing a tracking task. This study represents the first time, to the authors knowledge, that researchers have compared the effects of moving environments on multiple types of work related tasks. The results have application to ergonomists, who can apply the knowledge directly to risk assessment in the workplace. They also add insight to current understanding of human postural control and as such will be of interest to those engaged in postural control research. To better understand these results, each task will be examined separately before a discussion of the combined results is presented.

#### *5.1.1. Tracking task*

The tracking task used in the present study required participants to perform both fine motor skills (i.e. placing a finger on a square on the tablet), cognitive skills (i.e. participants had to complete the same maze five times each trial and be able to retrieve previous maze performance from short-term memory to complete the task) and perceptual skills (i.e. participants had to take visual feedback from the computer screen and use it to determine the direction of their next move). As such this task was included as it was felt to represent a complex task, such as making decisions based on being shown radar images, that would be similar to those carried out by individuals working on ships or moving platforms (Wertheim, 1998). When the tracking task was performed in the motion trial there wasn't a significant increase in either muscle activation (see Figure 4.1) or the number of steps taken (see Figure 4.3). In contrast to these findings, task performance was significantly decreased in the presence of motion (see Figures 4.5 & 4.6). There is limited research on the effects of performing tracking tasks in moving environments and that which has been done has only focused on task performance and not postural control or muscle activation.

Based on the results of the current study, and those of previous researchers, the effect of motion on tracking task performance is fairly clear – task performance in motion negatively impacts performance. The reasons for this performance degradation are less clear. Three hypotheses likely exist to explain the observed results. These hypotheses are: 1) motion effects on fine motor control 2) motion effects on visual information 3) sharing of cognitive resources between tasks. An examination of previous research can assist in determining which of the above hypotheses is most likely at play. Support for hypothesis one can be found in McLeod et al. (1980). In this study three different tasks were performed which included the tracing task requiring gross arm movements, an arm-supported tracking task and a digit-keying task requiring only use of the fingers. The only task to show a decrease in performance was the tracing task. The movements of the present study most closely replicated those of the tracing task from McLeod et al. (1980). In the current study, when participants performed the tracking task in motion they were required to make use of their entire arm to complete the maze. As a result, the number of rulebreak errors significantly increased. Rulebreak errors result from touching a tile that is not a valid move which suggests that the motion causes participants to be less able to control their hands while in motion. This supports the hypothesis that the addition of fine motor skills to a cognitive task may be the reason why there were performance decrements. To try and explain the second hypothesis, Wertheim (1998) hypothesized that visual sensory system may be affected (eg. blurred vision) by motion rather than an individuals' fine motor control. Research by Wertheim and Kistemaker (1997) found that the ability to read large letters was not impacted in motion but a persons' ability to read smaller letters was significantly decreased in the moving environment. As a result, it is unlikely that visual blurring was the reason that there were decreases in performance in the tracking task because the tasks used in this study were easily visible on the screen. The third hypothesis, the sharing of cognitive resources, posits that there are limited resources available to perform any number of tasks at the same time. In the case of a dual-task, if the two tasks combine to use up more resources than are available then performance in one or both of the tasks may decrease (Remaud et al., 2012). Based on the research surrounding these three hypotheses, the second hypothesis (blurred vision) does not appear to be a factor for this study.  While it is still unknown exactly what creates decreases in performance in these types of tasks, requiring fine motor skills and the sharing of cognitive resources are the two likely reasons. Future research in this area could perform research similar to McLeod et al. (1980), with participants performing a variety of different tracking tasks. The main difference would be the use of 5DOF motion similar to that used in the current study to better simulate a working environment.

### *5.1.2. Arithmetic task*

In contrast to the complexity of the tracking task discussed above, the arithmetic task used in the current study was primarily cognitive. The task was chosen as it mimics jobs that would require workers to read and process information from a screen and report details to a co-worker. When this task was performed in the moving environment there was no decrease in either task performance (see Figure 4.7) postural control (see Figure 4.3) or lower limb muscle activation (see Figure 4.1). To the author's knowledge, there are no other studies in motion looking at a similar arithmetic task like the one used in the present study. As such, the results for the arithmetic task are unable to be compared to previous findings. Other researchers studied the effects that performing an arithmetic task had on postural sway during quiet standing. Results showed a reduction in sway which would suggest that the demands the task placed on the nervous system somehow impacted postural control (Vuillerme & Vincent, 2006). Work by Weeks, Forget, Mouchnino, Gravel and Bourbonnais (2003) reported similar results, finding that postural sway decreased in the medial-lateral direction when individuals simultaneously performed a simple arithmetic task. A group of researchers (Yardley, Gardner, Leadbetter & Lavie, 1999) examined the effect of performing two different arithmetic tasks on postural sway on an unstable surface. The two tasks they examined were counting backwards out loud and silently. Postural sway significantly increased when participants counted aloud, while counting silently did not have an impact on postural sway. While the effects of silent counting on postural sway agreed with previous research (i.e. decreased postural sway) the out loud counting results contradicted pervious findings (i.e. increased postural sway) Yardley et al. (1999) suggested that speaking may impact postural control as speech and balance may share common resources within the brain. This hypothesis was subsequently supported by Dault et al. (2003). With the exception of Dault et al. (2003) and Yardley et al. (1999), who used unstable surfaces that differed markedly from the 5DOF motion of the current study, all the research examining an arithmetic based dual-task has been done during quiet standing. As such comparison of the postural sway results from the above studies are difficult to compare to the present research.

Of particular interest for the present study, the verbalization performed during the arithmetic task did not affect muscle activation or stepping compared to the control condition. This contradicts the findings of both Dault et al. (2003) and Yardley et al. (1999). Researchers from these two particular studies hypothesized that the increased respiration created from verbalization was to blame for performance. The differences between the current study and the other two studies may have been due to the postural control challenge presented to participants. The studies above used an unstable surface that was very similar to a wobble board to create the postural challenge. The 5DoF movements created by the motion platform used in the present study produced motions that were of far greater amplitude than those in both the Dault and Yardley studies (Dault et al., 2003; Yardley et al., 1999). The tasks in the above two studies may use the same muscles to maintain balance as the current study but the muscles required in a high-amplitude 5DOF moving environment are done so more extensively. As a result, any perturbations that people were subjected to as a result from respiration from verbalization would be relatively small compared to perturbations caused by the simulator.

The extremely novel aspect of this study is the fact that it is the first, to the authors' knowledge, to examine two cognitive tasks being performed in a 5DOF moving environment that simulates motions similar to those in offshore environments. As such the results provide an opportunity to examine the differential effects of motion on two different cognitive tasks. As discussed above, while motion impacted tracking task performance, it had no effect on arithmetic performance. In addition, neither of the tasks negatively impacted postural control or altered muscle activation. While the practical application of these findings will be discussed later, the current focus is on why the two cognitive tasks were affected differently. Research by Ryu and Myung (2005) may provide some insight into this. These authors examined performing a tracking and arithmetic task individually and concurrently to determine differences in a variety of physiological variables in addition to brain wave activity between the tasks. The tracking task used by Ryu and Myung (2005) simulated having to prepare to land an aircraft and control the pitch for glide slope correction, while the arithmetic task consisted of two-digit addition and typing the answer into a computer program. They reported that while performing only arithmetic, electroencephalogram alpha activity was lower than in the task that required tracking aircraft pitch levels on the screen. The authors went on to explain that performing arithmetic requires retrieving information from memory and number recognition whereas tracking involves constantly processing new visual information which may create the difference in cognitive demands between the two tasks (Ryu & Myung, 2005). Although the tracking and arithmetic tasks used by Ryu and Myung (2005) differed from the ones used in the current study, their results do provide one possible hypothesis as to why tracking performance was affected and arithmetic was not. Based on their results tracking may have required more cognitive resources to complete and as such more severely taxed the cognitive resources available resulting in the observed performance decrement. Additionally, as discussed in detail above, it is possible that the motion of the platform meant that individuals could no longer accurately position their finger on the intended target. Future research is needed to determine which of the two (cognitive resource demands vs. fine motor control impairments) contribute most to the results found in the current study.

### *5.1.3. Lifting task*

When participants performed the lifting tasks in the motion conditions increases in muscle activation were observed. The results also suggest that postural stability was negatively impacted as the number of steps that individuals took increased during the motion condition.  The present study is the first, to the author's knowledge, to examine lower limb muscle activation during a lifting task. Two others studies (Holmes et al. 2008; Matthews et al., 2007) have reported on upper limb muscle activation when lifting in a moving environment. While it is valuable to understand how upper body muscle activation is affected from lifting in motion, these studies did not provide insight into how the lower body behaves so they were unable to comment on lower body injury risk and postural control in moving environments. In the current study, the increases in lower limb muscle activation (see Figure 4.1) while lifting in a moving environment likely reflect the increased effort required to remain balanced. As will be reviewed below participants stepped more frequently while lifting during the motion trials. As stepping has been shown to require increased lower limb muscle activation (Houck, 2003) it is not surprising that muscle activation increased. Based on studies examining CoP during lifting in motion (Duncan et al., 2010; Duncan et al., 2007; Matthews et al., 2007) it is safe to assume that participants in the current study had greater CoP motion when lifting than in quiet standing. Since the lower limb muscles, especially the tibialis anterior and peroneal group, are responsible for controlling CoP (Tropp, 1988) this is another likely reason that increases in muscle activation were found.

As stated above the stepping results during the lifting trials also suggest participants were more unstable when lifting was performed during the motion trials. Before discussing these results it is important to acknowledge that these results did not reach statistical significance. As a result of the high variability in the data and the low sample size used, detection of significance differences is more difficult (Fields, 2009). Despite this lack of statistical significance the clear increase in stepping observed when lifting during the motion trials warrants further discussion. The increase in number of steps taken when lifting during motion trials is contrary to findings by Duncan et al. (2007) and Duncan et al. (2014) whose research examining task performance in moving environments found that more steps were taken in quiet standing rather than while performing a sagittal lifting task. While on the surface these findings may seem to contradict one another closer examination of the methods used by Duncan et al. (2007; 2014) may provide some insight as to why the results differed. The stepping analysis used was different for both Duncan et al. studies compared to the present study. The two Duncan studies analyzed the occurrence of stepping only when participants were actively engaged in the act of lifting. This is in contrast to the current study where step occurrence was assessed for the full duration of the 5-minute trial. When the stepping results from the current study were broken down into steps taken during lifts and lowers and steps taken outside of lifting, participants took an average of 7.21 steps while lifting and 24.43 steps while not lifting. Based on these findings, if the step analysis in the current study had only examined steps taken during the lift / lower motion our findings would have been similar to Duncan's (i.e. less steps during lifting then during quiet standing). These results also suggest that it is important that the steps taken while not lifting or lowering are included in the analysis. Workers in a real life scenario would not only be worried about lifting or lowering an object and then forgetting about it; they would also be worried about what is happening between lifts. In addition, lifting is a dynamic task and is destabilizing in nature because of the fact that it alters whole body CoM due to the additional mass being added to the anterior aspect of the body. Commissaris and

Touissaint (1997) performed research looking at APAs in lifting and discovered that, even before shifting the CoM backwards in preparation to pick up an object, there were APAs present. This suggests that the act of lifting is not isolated to what the eye can see and actually starts earlier. For the above reasons it makes sense to collect data on steps taken for the duration of the full 5 minute trial.

Clearly participants in the current study stepped more during the lifting task when the platform was in motion. This increased stepping is felt to be indicative of increased instability and greater demands on the postural control system. During the lifting trials participants had to reach in order move the box to and from the table. This reaching, combined with the 7kg mass being added to the anterior portion of the body, likely resulted in a deviation of CoM and increased the likelihood of having to perform a change in support strategy like stepping (Commissaris & Touissaint, 1997). In addition to the demands created by having to control the addition mass of the load lifted, the act of stepping itself creates additional demand on the postural control system due to the periods of single support it creates as steps are completed (Maki & McIlroy, 1997). As such the very postural control strategy adopted by individuals when lifting may in fact place them at greater risk of falling. While knowledge into the effects of lifting on postural control has been widely expanded over recent years, future research examining lifting tasks in moving environments should look at quantifying task performance (eg. time to perform a lift) in lifting.

## 5.2 Applications

The results of the current study have important implications both for those working as ergonomists and human factors specialists as well as individuals interested in better understanding human postural control. From an ergonomics perspective the present study fills in multiple gaps in the literature. This study is the first, to the author's knowledge, that compared the effects of a moving environment on lower limb muscle activation, postural control and task performance for both lifting and cognitive focused tasks. As a result of this fact, the results of this study provide ergonomists with evidence they can use to better assess worker risk. Prior to this study ergonomists assessing risk in individuals who performed multiple tasks as part of their job would have had to look at several bodies of literature to assess risk. While this would enable practitioners to gather some evidence to use in the risk assessment, trying to combine results from different sources is problematic as the data comes from a variety of populations. In the present study all of the tasks were performed by the same participants so that within-subject comparisons could be made. Additionally, many studies have used environments that do not move in 5DoF and do not simulate a moving environment that is realistic for offshore workers. As such, this study allows ergonomists to gain insight into task performance in motion from the types of environments where they will be assessing people. Furthermore, the present study uses tasks that simulate those which people in moving environments will perform on a daily basis. While many other studies do test the ability for people to perform fine motor, tracking, memory and other types of tasks, it is believed the construct validity of the present study is high. As a result, the current study provides evidence that is invaluable to ergonomists to more accurately assess risk.

Ergonomists are often tasked with performing cost-benefit analyses to justify if making a change to a workplace is worth the investment. Companies in the offshore industry have budgets to adhere to so using the money to improve workplace safety most effectively is important. The results show performance of complex visual tracking type of tasks decreases in motion and provide preliminary evidence that ergonomists can use when evaluating these types of tasks in the workplace. The findings suggest that ergonomists need to be aware of the fact that cognitively demanding, tracking types of tasks that can be performed effectively on a stable surface, may be more prone to human factors errors when performed in a moving environment. On the other hand, the arithmetic task saw no decreases in performance when performed in motion. As such, the ergonomist can recognize that these tasks are less likely to contribute to incidences of human factors errors in moving environments. While there was a non-significant increase in stepping when lifting was performed during motion trials, stepping was unaffected by the performance of both cognitive tasks. As the increase in stepping will likely result in increased instability, these results provide evidence that suggests risk of falls may be increased when individuals lift objects in moving environments. Ergonomists concerned about fall risk should therefore be aware of this increased risk when assessing jobs that require MMH in the offshore. Additionally, as muscle activation was significantly higher in the lifting condition in motion compared to the cognitive tasks then ergonomists should continue to look at workers' lifting as a source of workplace injury from the strain that these motions can put on the body over a longer period of time.

In addition to the ability to now more effectively compare between tasks, the current research has also added to the body of knowledge on the effects of performing MMH in a moving environment and the effects of cognitive task performance in 5DOF motion. Prior to this study no information was available on lower limb muscle activation while lifting in simulated ship motion. As discussed above the results suggest that the increase in postural instability leads to the higher levels of muscle activation found. As such, ergonomists can use this information to make the necessary changes to the workplace to reduce injury, make lifting safer and reduce instances of stepping. Similarly, the cognitive task research is the first of its kind done in 5DOF. This finally gives ergonomists a resource to see the effects that performing two workplace tasks high in validity.

## 5.3 Limitations

One limitation to this study is the lack of a performance measure for the lifting trials, such as the time required to complete a lift. As such, it cannot be commented on whether or not performance of the lifting task was affected by motion. From a human factors error perspective, the study only allows for the comparison between arithmetic and tracking tasks as the potential for human factors errors while lifting in moving environments cannot be addressed. Previous research examining lifting in moving environments has reported conflicting results regarding lifting time (Duncan et al., 2012; Holmes et al., 2008; Matthews et al., 2007) so it is difficult to speculate as to how lifting time would have been impacted in the present study. Future research should look at the length of time it takes to lift an object in similar 5DOF environments, as ergonomists would be able to use this information to complete more thorough risk assessments and help cut down on worker injury.

While the study was novel in that it used a 5DOF motion profile, we only examined the effects of one particular motion profile. As such, the results of the study only apply to this particular motion profile. Further studies are needed to determine how individuals would react in situations where the motions were either higher or lower than the ones examined in this study. It is important to note however that the motion used in the study are based on real ship motion recorded off of a medium-sized shipping vessel in high seas. Because of this the results should be indicative of how individuals would perform under similar motion conditions on board a ship.

Another possible limitation is that the arithmetic task that was used was too easy. If this was indeed the case then performance on the task would have been less likely to be affected. The type of arithmetic used in the present study was 2-digit addition, which is a task that people commonly perform in their everyday lives. Additionally, participants were primarily graduate-level university students who may have an easier time answering these types of questions. This particular tasks was chosen as it has been used by other authors to examine the effects of a cognitive task on postural sway. Ryu and Myung (2005) reported that doing a task almost identical to the one used in the present study negatively impacted postural sway. As such it is unlikely that the task was too easy.

Further research, using these methods, could examine this issue by making the task more challenging through using larger, 3-digit numbers a combination of addition, subtraction, division and multiplication questions. It would be interesting to discover if there is a threshold and what that threshold is when arithmetic becomes too challenging to stay balanced; furthermore, it would be interesting to see how well people from other populations perform on the arithmetic task. As the difficulty of the questions is subjective it is possible that certain groups of people may have had their postural control affected while participating in this study.

Another limitation is that while participants had five seconds to answer each arithmetic question, the time it took participants to answer each question was not measured. It is possible that although the percentage of correct answers did not differ between the motion and no motion conditions, participants may have taken more time (within the 5 sec answer period) to come up with the correct answer. Limitations of the experimental set-up and available equipment meant we could not measure this time. As in work situations, task performance efficiency, in addition to correctness, is of the essence, it would be valuable to have insight into this aspect of cognitive task performance. As a result, future studies looking at cognitive task performance in moving environments could provide participants as much time as is required to answer with the added performance measure of how many questions could be answered in each trial.

The method used to assess postural control or postural stability could also be considered a limitation of the study. The present study used the number of steps as a way to measure postural control. To more accurately assess postural control whole body CoM or CoP motion could have been determined. As equipment to collect these measures was either unavailable or was not appropriate to be paired with other equipment used for the study these measure were not feasible for this study. Examining the number of steps taken was viewed as being a good measure of instability as the more steps a person takes the more unstable he or she becomes. Future studies similar to this one should consider quantifying whole body CoM as a more robust way of determining the effect of motion and/or task on postural stability.

Choice of participants for the study is another factor that may have impacted results. The study examined novice participants as opposed to using individuals with experience working in moving environments. As such the results are not generalizable to those with experience working in this environment. This decision was made because, previous research (Duncan et al., 2014; Duncan et al., 2007; Holmes et al., 2008; Matthews et al., 2007) used participants who were also novices so the results of the present study are able to be compared with results from previously published literature. Future work in this area that examines similar research questions needs to be done with experienced offshore workers.

The conditions of the present study were dry and absent of any windy or rainy conditions. As such, it can be applied to many offshore environments where this is the case. On the other hand, workers in these moving environments will often be exposed to extreme conditions on deck outside of the vessel. One of the ways to simulate extreme working conditions is using a simulator that mimics different weather conditions such as rain or wind. To ensure safety of the participants a harness can be attached to them in instances of high wind or to protect from falls in slippery conditions. The limitation that exists in simulating more extreme working conditions is the cost of more expensive simulators and safety precautions. Hypothetically the simulation of wind, rain or other weather conditions would add to the negative effects created from motion and task performance. Research that examines these conditions is worth researching in the future.

**5.4 Future Directions**

There is still a need for a better understanding of how cognitive tasks of varying complexity affect postural control and vice versa. While two tasks of high construct validity to offshore environments and differing difficulty were used, the diversity of offshore working environments has workers performing tasks of varying levels of complexity. As a result, research should be done that looks at different cognitive tasks in the same 5DOF motion. Furthermore, there is a need to further explore the effects that 5DOF motion has on the time it takes to lift. This will provide ergonomists with a performance measure for lifting so that comparisons between all tasks can be made. In addition, it would be beneficial for future research to examine the effects that more extreme conditions have on task performance. This would provide ergonomists with a larger body of knowledge to pull from and ensure the safety of more workers in these environments. For example, a moving environment that can simulate weather conditions on a main deck of a shipping vessel (ie. wind, rain, higher wave motions) would be useful. Another direction research can go is adding to the difficulty of the arithmetic task. Similarly, as the current motion profile did not affect task performance in the arithmetic task it would be interesting to see what effects that more severe motion would have on performance of this task.

### 5.5 Conclusions

Based on the results of this study the following conclusions can be made:

1. When performed in motion, human factors errors will tend to be higher for complex tracking tasks as seen by the increase in time to complete the task and the number errors committed, whereas low-complexity arithmetic tasks are unaffected by motion and performing these job-related tasks may not put a worker at risk in a moving environment.
2. The risk of falling is greatest in the lifting task as people perform more change-in-support strategies like stepping or grasping more often compared to when performing the cognitive-based tasks. Every time a person is forced to step the risk of falling increases. On the other hand, the risk of falling does not appear to increase when performing cognitive-based tasks as these were unaffected by the presence of motion.
3. In motion, lifting is the only task that required an increase lower limb muscle activation. As a result, the lifting task puts a person at most risk of fatigue and subsequent injury. As a person lifts over time this may lead to fatigue and, over a long period of time, increase the risk of injury due to the repeated strain placed on the body.

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# Appendices

## Appendix A: Physical Activity Readiness and Medical Questionnaire

### Medical/Past Experience Questionnaire

Data Collection Date: __________________

| | | | |
|---|---|---|---|
| Participant Code: | Gender: M F Other | DOB: dd/ mm/ yyyy | Age: |
| Height: in cm | Weight: kg lbs | | |

**Information in this form will help ensure that you can safely participate in this research study and also it will ensure you meet the participation requirements in place for the study. Please answer all questions below:**

| **Participant Information** | **Circle** |
|---|---|
| Are you right or left handed? | R L |
| Which hand do you write with? | R L Both |
| With which foot would you kick a ball? | R L Both |
| Have you ever participated in any postural balance studies before? | Y N |
| Have you ever participated in a motion platform study in the engineering building? | Y N |

| **General Questions** | **Circle** | **Describe** |
|---|---|---|
| Do you have experience working or performing in maritime environments? | Y N | |
| Do you frequently (i.e. at least once a week) perform balance intensive activities (e.g. yoga, dance, snowboarding, etc.)? | Y N | |
| Do you participate in a regularly structured exercise program? | Y N | |
| In the past year have you had any episodes where you felt dizzy, unsteady, or weak? | Y N | |

| | | |
|---|---|---|
| Are you susceptible to motion sickness? | Y N | |
| Do you have any conditions that limit the use of your arms and legs? | Y N | |
| Do you have any vision problems that limit your ability to read, watch TV, drive a car, or do any other activities? | Y N | |
| Do you take medications that make you dizzy or weak? | Y N | |

| **Have you ever severely injured or had surgery on your:** | **Circle** | **Describe** |
|---|---|---|
| Head | Y N | |
| Neck | Y N | |
| Back | Y N | |
| Pelvis | Y N | |
| Ankle | Y N | |
| Knee | Y N | |
| Hip | Y N | |

| **Physical Activity Readiness – Questionnaire (PAR-Q)** | |
|---|---|
| 1. Has your doctor ever said that you have a heart condition AND that you should only do physical activity recommended by a doctor? | Yes No |
| 2. Do you feel pain in your chest when you do physical activity? | Yes No |
| 3. In the past month, have you had chest pain when you were not ding physical activity? | Yes No |
| 4. Do you lose your balance because of dizziness or do you ever lose consciousness? | Yes No |
| 5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in physical activity? | Yes No |
| 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? | Yes No |
| 7. Do you know of ANY OTHER REASON why you should not do physical activity? | Yes No |

*****If you answer yes to any PAR-Q question you must have a doctor's permission before participating***

**Appendix B: The Misery Scale (MISC)**

| Symptom | | Score |
|---|---|---|
| No Problems | | 0 |
| Uneasiness (no typical symptoms) | | 1 |
| Dizziness, warmth, headaches, stomach awareness, sweating | Vague | 2 |
| | Slight | 3 |
| | Fairly | 4 |
| | Severe | 5 |
| Nausea | Slight | 6 |
| | Fairly | 7 |
| | Severe | 8 |
| | (near) Retching | 9 |
| Vomiting | | 10 |

*Misery Scale (Wertheim, Bos & Bles, 1997)*