THE EFFECTS OF MOTION ENVIRONMENTS ON SEARCH AND RESCUE TASK PERFORMANCE AND POSTURAL CONTROL

by

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ABSTRACT

The purpose of this master's thesis was to investigate the risks associated with performing a vigilance task in a simulated moving environment. More specifically, the effects of simulated motion on both postural stability and the performance of a simulated search and rescue (SAR) task. Many offshore occupations are considered strenuous and potentially dangerous in nature due to continuous wave-induced perturbations. These perturbations are responsible for accidents and injuries related to reduced postural stability and increased work-related energy demands. To investigate these potential adverse effects, a single data collection utilized a motion platform and a 360-degree screen which displayed visuals synchronized to platform motions. The results show that performing a SAR task in a simulated moving environment has a significant adverse effect on SAR task performance and postural response. As simulated wave motions increased, there was a decrease in SAR task performance and increased lower limb muscle activations, as well as the number of steps taken. These results indicate the likelihood of increased risk of falls and human factors errors when performing a simulated SAR task in a motion environment.

Key Words: Motion Environments, Search and Rescue, Task Performance, Postural Control

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CHAPTER 1: INTRODUCTION

The maritime transport, offshore petroleum, seafaring and fishing industries are major sources of employment worldwide. Personnel in these occupations have a unique work environment in that their vocational activities are carried out on bodies of water. The unpredictable motions of the water, along with unfavourable weather conditions, create a high-risk environment which pose a significant risk to worker safety. These adverse effects may have negative consequences on the human body leading to high injury, morbidity and mortality rates (Collins, Matthews, & McNamara, 2000). As well, these adverse effects can have a negative impact on human performance leading to inefficient task performance which may be detrimental to the vocational activity, the individual and/or others around them. For Newfoundland and Labrador specifically, the maritime transport and offshore petroleum industries are significant contributors to the provincial economy. In 2015, these industries directly employed over 9000 individuals and provided business for 600 supply and service companies (Canadian Association of Petroleum Producers, 2016). With such a large population employed in these high-risk industries, it is imperative to place safety at the forefront.

Previous literature has demonstrated that these motion rich environments have adverse biomechanical, physiological and psychological effects on both human performance and worker safety (Collins et al., 2000; Duncan, 2013a; Duncan, MacKinnon, & Albert, 2012, 2013b; Duncan, MacKinnon, Albert, Antle, & Matthews, 2007; Wertheim, 1998). Motion environments have been shown to generate postural instability, increased fatigue, increased human factors error and reduced motivation due to motion sickness (Crossland

& Lloyd, 1993; Duncan, MacKinnon, & Albert, 2010; Duncan et al., 2012; Matthews, MacKinnon, Albert, Holmes, & Patterson, 2007; Wertheim, 1998). While the amount of moving environment research has increased in recent years, there is still much that is not known. In relation to human factors errors, most of the existing literature has focused primarily on performance of manual materials handling (MMH) tasks while standing in motion environments (Duncan, Albert, Langlois, & MacKinnon, 2014a; Duncan et al., 2010, 2012; Duncan et al., 2007; Faber, Kingma, Delleman, & van Dieën, 2008; Matthews et al., 2007). Similarly, there is no known research examining performance of a specific vocational activity in a moving environment; much of the research examines general tasks such as reaction times during visuomotor tracking tasks, speed of trackball manipulation, pen and paper tracing tasks and computer tracing tasks (Crossland and Lloyd (1993); Duncan et al. (2012); Pearcey, MacKinnon, and Button (2015); Wertheim (1998). The drive behind the present research stemmed from an interest in maritime SAR operations. Maritime SAR personnel often perform vital SAR tasks in moving environments. To the author's knowledge, there are no previous research studies examining aspects of maritime SAR performance, including how exposure to wave motion impacts SAR personnel performance. Therefore, Study 1 of this thesis aimed to explore the following question:

Is performance of a maritime SAR task impacted when performed in a moving environment?

For this portion of the thesis, participants were exposed to ecologically valid simulated fast rescue craft motions (DNV GL®, Vancouver, Canada) to better understand how SAR task performance was impacted by motion. In SAR missions, the lives of those in distress and imminent danger rely on the successful performance of the SAR specialists and units. Any delay or error in classification and/or identification will affect the safety of the crew and those who require rescuing. If the crew is at risk for injury or directly injured, the SAR mission is negatively impacted. Therefore, it is essential for human factors specialists and ergonomists to evaluate the risks presented to those in these maritime environments.

Study 2, although related to study 1, had an entirely different focus. A similar simulated SAR task was examined; however, the research question focused on the impact of the task on postural control as opposed to SAR task performance. The impetus behind this study was a desire to better understand the interplay between postural control and secondary task performance. The effects of secondary task performance on quiet standing is generally well understood; more complex tasks and/or more challenging balance scenarios have a greater impact on postural control (Peterka, 2002). Less research has been done in moving environments. However, the exact pattern of observed interaction between postural control and performance of secondary tasks varies across studies (Mitra & Fraizer, 2004). Several studies have demonstrated that when balance is challenged, performance on cognitive tasks degrades (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Mitra & Fraizer, 2004; Pellecchia, 2003; Riley, Baker, & Schmit, 2003) while other studies have demonstrated that performing a secondary task enhances postural stability (Vuillerme, Nougier, & Teasdale, 2000). To the author’s knowledge, no research to date has examined how the performance of a complex vigilance task, like a SAR task, impacts postural control. As such, study two of this thesis asked the following question:

> *How does performance of a SAR task impact postural control when performed in a moving environment?*

The initial plan was to address both research questions in one study. However, pilot testing revealed that the ecologically valid motions needed for study one were not of sufficient magnitude to induce the changes in balance reactions desired for study two (study of motion effects on postural control). As such, a separate study using higher degrees of simulated motion was completed to achieve the answers to the proposed question. Both data collections were, however, performed with the same participants during the same data collection session.

The resulting thesis presents the reader with two different, though related, stories. Chapter three reports the results from study one. It explores the effects of motion on SAR task performance. Its focus is on the human factors implications and as such was written to an audience with an interest in either SAR training and/or ergonomics. Chapter four outlines results from study two. Given the postural control focus of this study, the paper takes a more applied science approach aimed at adding to the current thinking surrounding postural control in moving environments. The SAR task is used simply because it is a complex vigilance task that provided the type of attentional demand required to answer our research question. As such, the discussion in study two is focused on postural control as opposed to human factors during SAR tasks. While both studies investigated different hypotheses, both suggest that there was competition for attentional resources between vigilance (SAR task) and postural control in young, healthy adults, in a moving environment. The concluding chapter of this thesis, chapter five, provides the reader with a general overview of how the results of the two studies add to the current dual-task literature. It does not attempt to draw overall conclusions based on the combined results of the two studies.

CHAPTER 2: LITERATURE REVIEW

The literature review first examines injuries in maritime and offshore industries. It will then discuss how individuals maintain postural control in stable environments. Subsequently, there is a detailed review of the current literature pertaining to the effects of motion on postural control, and how working in a moving environment may affect both fall risk and task performance. Following this, the aspects of performing a SAR mission are discussed.

2.1 INJURIES IN THE MARITIME AND OFFSHORE INDUSTRIES

Most of the research in this area has focused on commercial fishing and petroleum related occupations. Commercial fishing is one of the most dangerous occupations in North America and across the globe (Lincoln & Lucas, 2010). It is characterized by hazardous working conditions, demanding labour, long working hours, harsh weather and unpredictable seas (Lincoln & Lucas, 2010). Norrish and Cryer (1990) state that the combination of these factors, along with social isolation due to prolonged periods away from home, contribute to work related health problems. Fatal injuries that occur in commercial fishing are most likely caused by being crushed between objects, falls overboard due to sea and weather conditions, or due to the vessel filling with water and capsizing (Chauvin & Le Bouar, 2007; Day, Lefkowitz, Marshall, & Hovinga, 2010; Norrish & Cryer, 1990). Whereas nonfatal injuries are generally caused by falls, body parts being crushed between objects (i.e. foot crushed by falling crate), struck by moving objects, caught in lines (i.e. hand caught in fishing lines), collision with fixed objects, or falls into water (Chauvin & Le Bouar, 2007; Day et al., 2010; Jensen, 1996).

The offshore petroleum industry is characterized by operations that occur at great distances from land in potentially severe weather and ocean environments. This industry presents several hazardous working environments as well, which include working with highly combustible materials, heights, heavy machinery and hazardous chemicals. Valentić, Stojanović, Mićović, and Vukelić (2005) found that most injuries in this industry occurred from direct impact with hard metal objects, followed by jamming, overstrain, and slips and falls. For Newfoundland, specifically, the Canada-Newfoundland and Labrador Offshore Petroleum board indicate that there are approximately 160 reported incidents a year between the years of (2006-2012). Most of the major injuries reported have been fractures (wrist, ankle, hip, leg) as a result of slipping or falling. As well, much of the restricted work and lost-time injuries have been due to overexertion or slips, trips and falls (STFs) (Canada-Newfoundland and Labrador Offshore Petroleum Board, 2013). Overall, there has been relatively little research that has examined injury rates in the offshore petroleum industry.

The focus of this thesis is on maritime SAR, and upon reviewing the literature, there is no literature, to the author's knowledge, which examines injury rates in SAR personnel. However, the leading causes of injuries recorded in the maritime, offshore, petroleum and seafaring industries were: STFs, being jammed between objects, or struck by moving objects. These findings may translate to the maritime SAR industry as they carry out their vocational tasks in the same environment. The Occupational Safety and Health Administration (OSHA) state that more than 40% of the injuries reported from the maritime industry are due to a slip and/or fall incident (OSHA, 2014). The risk of STF injuries aboard vessels and platforms are likely due, at least in part, to the unique settings the maritime environment presents. The continuous motions of the water make balance maintenance difficult due to unpredictable vessel movement (Duncan et al., 2007) and weather often produces slick surfaces. With STFs being identified as one of the main contributing factors to injuries in the maritime environment, it is important to gain a better understanding of their causation and the impact they have on human performance.

2.2 SLIPS, TRIPS AND FALLS IN THE MARITIME ENVIRONMENT

Environmental conditions play a significant role in the occurrence of STFs in the maritime environment. Falls often occur due to an inability of an individual to adapt to the environmental conditions (Hansen, 1999), and slips are caused by too little friction or traction between footwear and walking surface. The conditions at sea frequently create the perfect hazardous environment for slips, as there are often wet or oily surfaces with flooring that does not have good traction. Trips are also common, as vessels often present obstructed views, poor lighting, obstacles in path causing the foot to collide (strikes, hits) with an object leading to loss of balance (Gauchard, Chau, Mur, & Perrin, 2001).

While assumptions can be made about the factors that lead to STFs while working in a moving environment, relatively little is known about how individuals maintain balance when in a moving environment. Gauchard et al. (2001) suggest that extrinsic and intrinsic factors influence the likelihood of falls for working individuals on stable ground. The extrinsic factors include: 1) the dimension, permeability, irregularities, and maintenance of the supporting surface; 2) type of footwear; 3) lighting; 4) temperature; 5) the occupational activity being performed; and 6) temporal constraint/urgency of vocational task. The intrinsic factors (human factors) include: 1) experience; 2) attention/vigilance; 3) weakness; 4) fatigue; 5) chronic or acute pathologies; and 6) physical/pathological ageing. The intrinsic and extrinsic factors aforementioned for stable ground, alone or combined, likely play a role in the causation of STFs in the maritime environment as well. Maritime environment motions are unpredictable and often require complex postural control responses to maintain balance (Duncan, 2013a; Duncan et al., 2014a; Duncan et al., 2013b). There has been little research that has attempted to determine if injuries occurring in motion-rich environments are a result of the motions (extrinsic factors), or the postural adaptation strategies (intrinsic) used to counteract the motions (Duncan et al., 2012); or a combination of the two. To better understand postural control responses in a moving environment, we first must gain an understanding of how balance is maintained on stable ground.

2.3 POSTURAL CONTROL IN STABLE ENVIRONMENTS

To maintain equilibrium in upright static stance, the body's center of mass (CoM) must remain inside the area of the base of support (BoS) (feet in stance). When the CoM falls outside the BoS, the body becomes unbalanced (Maki & McIlroy, 1997; Pollock, Durward, Rowe, & Paul, 2000). Stability is greatest when there is a large BoS, lower CoM, and/or a more central location of the body's CoM within BoS (Pollock et al., 2000). However, while standing upright, the human body has a relatively high CoM and a relatively small BoS, making maintenance of stability difficult (Pollock et al., 2000). Stability is also challenged when an individual performs voluntary movements and/or when external forces are applied (Slijper, Latash, & Mordkoff, 2002). However, the human body has an inherent ability to sense a threat to stability by using muscular activity to prevent falling. This demonstrates that humans have control over their balance; also known as postural control (Pollock et al., 2000). Postural control is defined as "the act of maintaining, achieving or restoring a state of balance during any posture or activity" (Pollock et al., 2000). It is a complex motor skill derived from interactions of multiple sensorimotor processes (Horak, 2006). According to Horak (2006), the two most important functional goals of postural control are postural orientation and postural equilibrium. Postural orientation involves the active alignment of the trunk and body with respect to gravity, visual environment, support surface and internal references (Horak, 2006). It requires the sensory integration of information from multiple sensory systems (somatosensory, vestibular, and visual systems) to determine body alignment, motion, and relative stability (Horak, 2006; Horak & Kuo, 2000). Postural equilibrium is the coordination of movement strategies used to stabilize the CoM during self-initiated and/or externally generated disturbances in postural stability (Horak, 2006).

The ability to control the relationship between the CoM and BoS during activities of daily living (ADLs) is derived from two postural control strategies or a combination of both: predictive (anticipatory) and reactive (compensatory) (Maki & McIlroy, 1997). Anticipatory postural adjustments (APA's) are feedforward strategies used in anticipation of a predicted disturbance (Pollock et al., 2000). They involve muscles either activated or inhibited prior to prime mover onset (Massion, 1992). The generation of APA's is likely affected by three major factors: 1) expected magnitude and direction of the perturbation;

2) voluntary action associated with the perturbation; and 3) postural task (Aruin, Forrest, & Latash, 1998). Compensatory postural control strategies are feedback strategies that involve muscular responses and/or movements that respond to sensory feedback from unpredicted perturbations (Pollock et al., 2000). There are two classes of strategies for compensatory postural control distinguished by the alteration of the BoS: (1) fixed-support strategies and (2) change-in-support strategies (Maki & McIlroy, 1997). Fixed support strategies position and move the body's COM while the BoS remains fixed (Maki, Mcilroy, & Fernie, 2003). Change-in-support strategies occur when the BoS is altered either by taking a step or by reaching and grasping an object for support (Maki & McIlroy, 1997; Pollock et al., 2000). Change in support strategies involve moving the BoS under the falling CoM. They are often used instead of fixed-support strategies when individuals are unfamiliar with perturbations or when they do not receive instructions on keeping their feet planted in place (Horak & Kuo, 2000).

Individuals often use combinations of fixed support and change-in-support strategies. A traditional view has been that change-in-support strategies emerge as the last resort when earlier fixed-support strategies fail to maintain balance (Maki & McIlroy, 1997; Maki et al., 2003). However, Maki et al. (2003) discovered that compensatory stepping and grasping are often initiated early, even when disturbances are small and while the COM is still well within the BoS (Maki & McIlroy, 1997). They noted that the change-in-support strategy was the preferred strategy when balance was perturbed in daily life. Therefore, the postural control strategy used varies depending on an individual's goals and environmental context (Pollock et al., 2000).

Other factors known to influence postural control strategies are any additional cognitive processing that is ongoing. Successful maintenance of balance, irrespective of the strategy employed, requires integration of information from the somatosensory, visual and vestibular systems. These systems are critical in interpreting complex sensory environments (Peterka, 2002). As subjects change their sensory environments (i.e. walk from a well-lit room to a dark room), they need to reweight their relative dependence on each of the senses. When standing on a firm base of support in a well-lit environment, healthy individuals rely most on somatosensory (70%) information, followed by vestibular (20%) and vision (10%) (Horak, 2006).

Based on the review above it is apparent that maintenance of posture, even in a stable environment is a relatively complex process that requires integration of sensory information from many sources. The process is made more complex by the need to correctly select from the multiple postural control strategies that may be used to maintain balance when a perturbation occurs. Despite this complexity, balance maintenance in a stable environment is something that is almost taken for granted. When the environment itself is moving, postural control becomes even more challenging.

2.4 POSTURAL CONTROL IN MOVING ENVIRONMENTS

There are additional factors that come into play when trying to maintain balance in a moving environment, specifically in the maritime environment. Ship motions due to continuous movements of the sea make maintenance of balance more challenging. These unpredictable movements create a more dynamic environment, requiring dynamic stability. Dynamic stability takes into account the velocity of the CoM as well as the possibility of a changing BoS (Winter, 1995). The perturbations caused by ship motions occur in six degrees of freedom (*Figure 2.1*) which ultimately affect the body biomechanically, physiologically and psychologically (Duncan, 2013a).

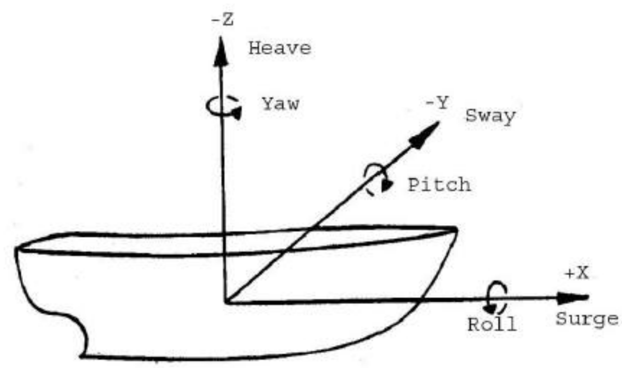

Figure 2.1: A Schematic of Ship Motions About the Six Degrees of Freedom (Duncan, 2013a)

Work by Duncan et al. (2014a) has demonstrated that when asked to remain standing in a simulated moving environment individuals step more often to maintain balance. Results from Duncan et al. (2014a) also found that stepping frequency was significantly higher when subjects were free to move however they wanted (i.e. their foot position was not constrained). When given a chance, subjects stepped more frequently and well before stability limits were reached. However, there are many factors that influence balance in moving environment, other than just the motion itself. Duncan (2013a) developed additional elements to add to the ABCD model (*Figure 2.2*) which was originally created by Dobbins, Rowley, and Campbell (2008) to demonstrate the additional factors that may influence postural responses in a maritime environment.

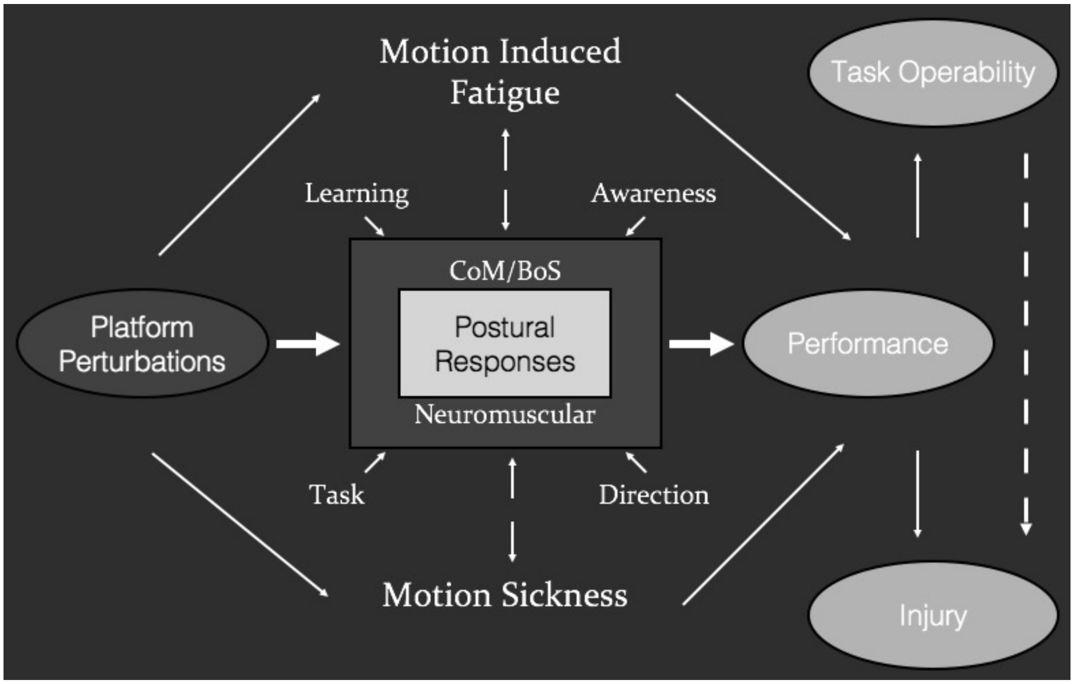

Figure 2.2: ABCD – Working Group Mode of Human Performance at Sea (Duncan, 2013a)

From previous research, experience and learning have been demonstrated to have a significant effect on postural response choices in a moving environment (Duncan et al., 2014a; Duncan, Ingram, Mansfield, Byrne, & McIlroy, 2016; Duncan et al., 2014b; Duncan et al., 2013b; Ingram, Duncan, Mansfield, Byrne, & McIlroy, 2016). Duncan et al. (2014b) revealed that time spent performing corrective strategies was greatest during the first day of simulated motion trials. After the initial exposure to a moving environment, rapid learning and adaptations occur over repeated exposures. It can be hypothesized that when first exposed to the motion, the perturbation is novel and therefore individuals are unaware of the optimal response strategy to use to minimize expenditure. As participants are exposed to more perturbations, their familiarity with the perturbations increase and they can develop intervention strategies that reduce the biomechanical, physiological and neuromuscular demands. However, for most of these studies, the participants involved had no prior experience in maritime environments. This is often the case to simulate the 'worst case scenario' of how working in a moving environment may impact worker safety. Ingram et al. (2016) revealed that unrelated experiences might influence performance on motion simulation tasks; for example, dancers demonstrated significantly lower time spent performing CS strategies as well as reduced lower extremity muscle activation compared to those without similar training.

While there have been a small number of studies that have investigated how individuals maintain balance in moving environments, comparatively less is known about how such postural control is impacted when performing a concurrent task. This is of importance because very rarely is it the goal of an induvial to just maintain balance; they are often required to complete a concurrent task (i.e. work related task). However, limited research exists on the effects moving environments on postural responses while performing a concurrent perceptual task.

2.5 WORKING IN A MOVING ENVIRONMENT

Workers in maritime environments not only have to contend with maintaining postural stability in a moving environment; they must do this while concurrently performing vocational activities (i.e., perceptual, motor or cognitive tasks). Workers in such environments have to perform a variety of work related task – these can range from physical labour, such as lifting tasks, to more cognitively focused tasks, such as monitoring a computer screen or a bank of sensors. While many of these tasks would be challenging to perform on land, workers in maritime environments have the added challenge of weather, ship conditions and ship motion to contend with. The vocational activity that is the focus of this thesis is a SAR task; similar to those performed by SAR units in the Canadian Coast Guard (CCG).

SAR is a national program in Canada which involves federal departments, provinces, territories, municipalities, organizations and volunteers working towards a mutual goal of saving lives (SAR Manual, 2000). The CCG, in collaboration with the federal departments, is responsible for the marine portion of SAR. The CCG is responsible for protecting coastal waters, the St. Lawrence River, the Great Lakes and the Arctic (SAR Manual, 2000). It operates and provides services in the following areas: SAR; boating safety; marine navigation service; icebreaking; environmental response and water protection. In particular to SAR, the CCG is in control of the detection of marine incidents and the coordination and management of SAR operations in maritime SAR situations (SAR Manual, 2000). A marine SAR vessel is equipped with a trained team whose mission is strictly SAR. A SAR mission encompasses the search for, and delivery of aid to, personnel, vessels or other crafts which are feared to be in distress or imminent danger. Good SAR preparation increases the chances of successfully locating and rescuing those in danger. Before a SAR unit deploys, a search plan is developed with four things being of vital importance: 1) a briefing on the search object; 2) description of search area; 3) optimum search pattern, and 4) optimum track spacing (SAR Manual, 2000). The Canadian Coast Guard also discusses the probability of detection (POD) which is the odds of detecting the target (SAR Manual, 2000). According to POD, an observer can be expected to sight most objects in close range under normal conditions, however, as the range increases, fewer targets are to be detected.

One aspect of SAR performance that is sometimes overlooked is the fact that SAR missions are often performed in severe weather, with high sea states. In addition to performing their search task, SAR personnel must remain balanced in the continually moving vessel. Research examining this relationship between balance and perception has received renewed attention, as research has highlighted the importance of conscious processes in posture control (Andersson et al., 2002). Just like those in land-based occupations, workers in offshore environments continuously derive cues from vision, vestibular, auditory, and proprioceptive systems to perceive their complex external environments (Liu, Zhang, Campos, Zhang, & Sun, 2011; Pellecchia, 2003). According to Riley et al. (2003), human beings can maintain balance during small perturbations without consciously focusing on these cues, indicating postural control is autonomous (Pellecchia, 2003; Riley et al., 2003). While it is likely that postural adjustments following perturbations, to some extent, are automatic and not consciously controlled, more demanding situations may call for attentional strategies and monitoring of balance (Andersson et al., 2002; Woollacott & Shumway-Cook, 2002). A secondary cognitive task (e.g. mental math or a search task) that strains an individual's attentional capacity may affect the automaticity of postural control (Dault, Frank, & Allard, 2001). Thus, it is realistic to expect that the extent of the secondary task's perceptual demand may influence postural control either positively or negatively. For example, an easy secondary task may beneficially increase the efficacy of postural control by providing an external attention focus. However, a more demanding secondary task may have an adverse consequence on postural control, due to attentional resource competition between cognitive and sensorimotor processing (Huxhold, Li, Schmiedek, & Lindenberger, 2006).

2.6 DUAL TASK PARADIGMS IN STABLE ENVIRONMENTS

Dual-task paradigms are often used to examine the complex interaction between attention and postural control. In such tasks, participants are often required to perform two or more concurrent activities (Andersson et al., 2002; Dault, Frank, & Allard, 2001; Pellecchia, 2003). A dual-task paradigm assumes that postural control and cognitive functions compete for limited attentional capacity (Huxhold et al., 2006). According to this paradigm, attention is divided between sensorimotor and cognitive tasks in such a way that balance can be maintained while performing a concurrent cognitive task (Huxhold et al., 2006). In dual-task studies any negative change in performance on either of the tasks is suggested to indicate that there is competition for central processing resources; a dual-task effect (Andersson et al., 2002). Andersson et al. (2002) state that there are two outcomes of interest in dual-task studies on perception and balance. First, there is the possible effect of balancing on the performance of the cognitive task and the second is the effect of cognitive tasks on balance. There are several factors that may mediate the effects of cognitive load on balance. These include the degree of attention the individual has towards balance, the level of arousal the individual is experiencing and the choice of postural stance and difficulty of balance task (Andersson et al., 2002).

The notion of competition for attentional resources between postural control and cognition appears straightforward; however, the empirical evidence is conflicting. The exact pattern of observed interaction between postural and cognitive tasks varies across studies (Mitra & Fraizer, 2004). Several studies have demonstrated that when balance is challenged, performance on cognitive tasks degrades (Andersson et al., 2002; Mitra & Fraizer, 2004; Pellecchia, 2003; Riley et al., 2003). The findings across these studies demonstrated that participants performed better when postural control was relatively easy (e.g. sitting or standing with feet shoulder width apart and eyes open) or the cognitive task was easy (e.g. easy mental math or few items to remember). In Mitra and Fraizer (2004), participants performed a visual search task using simulated visualization conditions while standing in an open or closed stance position. Participant's postural sway was greater when they stood in a less stable standing position (feet close together) and when the cognitive task was more demanding. Andersson et al. (2002) found a similar negative effect of cognitive task on postural control. The results of their study showed that performance of a silent mental arithmetic task (counting backward in multiples of seven) was impaired when balance was perturbed by stimulation of the calf muscles. Pellecchia (2003) demonstrated that postural sway during standing on a compliant surface (a dense foam pad) was greater when the difficulty of the concurrent cognitive task increased. Riley et al. (2003) found that postural sway was reduced when participants performed a more difficult digit rehearsal task. Participants were asked to stand barefoot, with feet together on a force plate covered with foam. They were then asked to complete four experimental digit rehearsal tasks that ranged from no cognitive task to difficult cognitive task. Throughout the postural sway measurement period, the participants were asked to close their eyes while rehearsing previously displayed digits. Reduced postural sway during the difficult cognitive task was limited to anterior/posterior sway variability. However, more cognitive performance errors occurred during the difficult cognitive conditions. This appears to indicate that even though postural sway decreased, participants sacrificed cognitive performance to maintain postural stability. The inconsistency in current empirical literature suggests that the relationship between postural control and cognitive processing warrants further analysis (Huxhold et al., 2006). Other studies have demonstrated that increasing cognitive difficulty enhances postural stability (Vuillerme et al., 2000). Results of Vuillerme et al. (2000) experiment showed that center of pressure (COP) displacements decreased during and after performing a secondary reaction time (RT) task. The RT task was to verbally indicate the LED colour (either red or green) as fast as possible. The results demonstrated that an RT task could have positive effects on postural control. One hypothesis suggested for these findings is that performing a concurrent task while standing upright is a naturally occurring, daily task. It would force the subjects to focus attention on the secondary task and to fully delegate postural control to only sensory-motor processes.

From the literature reviewed above, it is clear that there are discrepancies related to the effects of cognitive task performance on postural control and vice versa. A possible reason for the discrepancies is because numerous types of cognitive tasks and postural stance positions have been used (Dault et al., 2001; Mitra & Fraizer, 2004). The cognitive tasks have varied from simple reaction time to more demanding spatial tasks, and the postural tasks have differed from sitting to standing while being perturbed by simulation (including visual, somatosensory and/or vestibular) (Andersson et al., 2002). The discrepancies between studies could also be related to the fact that many secondary tasks rely on verbal responses (Dault, Yardley, & Frank, 2003). A distinction can be made between verbal reaction time tasks, motor reaction time tasks, and cognitive tests involving higher working memory load (Andersson et al., 2002). It has been shown that cognitive tasks requiring oral responses while standing decrease postural control performance (Dault et al., 2003; Yardley, Gardner, Leadbetter, & Lavie, 1999). Yardley et al. (1999) state that articulation is responsible for increased postural sway path when performing a mental task because articulation is known to produce changes in respiration, and respiration is known to modify postural control.

In a "perfect" environment where there is stable ground, proper lighting and appropriate noise levels, the orientation of senses with regards to postural control are as follows: somatosensory (70%), vestibular (20%), vision (10%). Somatosensory is highly weighted as the central nervous system relies on it to initiate postural responses (Horak, 2006). It can be hypothesized that the addition of a complex vigilance task may affect the reweighting of senses, potentially impeding vision and vestibular senses. However, the experience of the individual will play a role in the weighting of senses. When individuals are novice to a situation, they may have a greater reliance on feedback because prior knowledge of the perturbation is limited (Latash, 1998). Both experience and prior knowledge of perturbation are known to affect the size and type of response choice (Maki & McIlroy, 1997). Duncan et al. (2014b) have shown that increased exposure and practice can reduce frequency and size of stepping reactions. It is thought that more experienced individuals potentially use anticipatory postural adjustments (APAs) to adapt to the perturbations and reduce the reliance on feedback.

2.7 DUAL-TASK PARADIGM IN MOVING ENVIRONMENTS

Many researchers have looked at the dual-task of manual materials handling performance and postural control in motion environments (Duncan et al., 2012; Duncan et al., 2007; Faber et al., 2008; Holmes, MacKinnon, Matthews, Albert, & Mills, 2008; Matthews et al., 2007); however, relatively little research has been done examining the performance of a more complex vigilance task in moving environments. Similarly, dual-task paradigms in moving environments have not been studied in as much depth as in stable environments. Pearcey et al. (2015), Duncan et al. (2012), Yau et al. (2011), Crossland and Lloyd (1993) and Wertheim (1998) studied how platform motions negatively affect an individual's performance on reaction times of visuomotor tracking tasks, speed of lifting and lowering loads, speed of trackball manipulation, pen and paper tracing tasks and computer tracing tasks, respectively. As well, Yu et al. (2010a; 2010b) studied vigilance performance and standing posture during mild and rough seas. Yu and colleagues (2010a; 2010b) found that vigilance performance in rough seas was reduced relative to the same participants completing the same tasks in mild seas. Additionally, Hickey (2016) investigated how task performance, postural control and lower limb muscle activation changed in motion and no motion conditions. Hickey (2016) examined the performance of a lifting task, a mental arithmetic task and a visual tracking task. The results from this study indicated that performance of the visual tracking task was negatively affected by motion, while arithmetic task performance was unaffected. However, the lifting task was the only task where postural control appeared to be negatively affected; participants exhibited significant increases in lower limb muscle activation. Hickey (2016) concluded that the decline in performance on the visual tracking task is representative of the potential for increased human factors errors during vocational tasks in the offshore environment.

2.8 CONCLUSION

The literature presents conflicting results on whether there is an increase or decrease in balance with the addition of a secondary cognitive task, due to the complexity of the relationship between postural control and cognitive activity. It is an area of great importance as many vocational tasks in the maritime environment require the use of attentional and vigilance resources while maintaining postural control. Individuals performing SAR missions are a prime example of such a vocation. These workers are required to scan the horizon and their surrounding environment while maintaining postural control in unpredictable wave motions.

The safety of maritime workers is a top priority for the maritime transport and offshore petroleum industries. These industries are regularly reviewing health and safety programs and looking for new technologies and opportunities to further enhance safety. With such a large proportion of individuals working off the coast of Newfoundland and Labrador, it is imperative to understand how motion-rich environments affect an individual's postural control and their ability to perform tasks safely and more efficiently.

2.9 PURPOSE & HYPOTHESES

The purpose of this master's thesis was to investigate the risks associated with performing a cognitive focused task in a simulated moving environment. More specifically, the effects of motion on the performance of a SAR task and postural stability. The goals of this research were to:

1. Investigate the performance of a SAR task in a simulated moving environment
2. Investigate how postural control is affected when performing a SAR task in a simulated moving environment

The following hypotheses were made:

Hypothesis 1: Performance of a SAR task will decline (decrease in number of objects correctly identified, increase in number of errors committed) when conducted in a simulated moving environment.

Hypothesis 2: Postural control will be challenged when a SAR task is performed in a simulated moving environment. This will be evidenced by an increase in lower limb muscle activation and number of change in support reactions observed.

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CHAPTER 3: PERFORMANCE OF SEARCH AND RESCUE TASK IN A MOVING ENVIRONMENT

3.1 ABSTRACT

The purpose of this study was to examine how exposure to wave motions impacts the performance of a maritime search and rescue (SAR) task. Twenty-four participants (12 male, 12 female) performed a simulated SAR task on a six degree of freedom motion platform at Memorial University of Newfoundland. The variables analyzed were task performance, electromyography (EMG) and number of steps taken. The results show that as the magnitude of simulated motion increased, performance on the simulated SAR task decreased with simultaneous increases seen in EMG and number of steps taken. While the current study used simulation, these results suggest that the performance of a SAR task may be impeded by the motions of the vessel.

Keywords: search and rescue, moving environments, task performance, simulation

3.2 INTRODUCTION

The maritime environment is considered a high-risk work environment due to the continuously challenging and variable environmental conditions. The often unpredictable, wave-induced platform or ship motions and external factors, such as weather and icy or wet deck conditions, can have adverse effects on the human body and task performance (Collins et al., 2000). One group of individuals that must work in these extreme conditions are SAR personnel. In situations where people, ships or other crafts are feared to be in distress or imminent danger, the maritime SAR personnel are the first to respond. Typically, SAR missions occur when conditions are at their worst, making even simple and routine tasks extremely difficult. Any factor or combination of factors such as rain, fog, winds, currents, stress, fatigue and heavy seas/waves that cause unpredictable perturbations, may negatively impact their performance. These adverse conditions can lead to unsuccessful recoveries and unfavourable consequences. The Canadian Maritime SAR program responds to approximately 6000 maritime incidents per year (Fisheries and Ocean Canada, 2012). Timely and effective SAR performance is paramount to preventing human injuries, loss of life and environmental disasters.

Accurate navigation, observant lookouts, and trained and knowledgeable crewmembers can make the difference between successful and disastrous outcomes (SAR Manual, 2000). Two essential components of a successful SAR mission are sustained attention and alertness, as searches often involve scanning for objects in less than favourable conditions over long periods of time (SAR Manual, 2000). Scanning the maritime environment in heavy seas/waves creates a unique challenge for SAR personnel as they must also maintain balance in their rescue craft while performing the search. Literature in both simulated environments (Duncan, 2013a; Duncan et al., 2014a; Duncan et al., 2013b) and sea trials (Crossland & Lloyd, 1993) have shown that balance maintenance in these moving environments is challenging, resulting in individuals having to step more to remain stable. According to Riley et al. (2003), human beings can maintain postural control during small perturbations without consciously focusing on these cues, however, more demanding situations may call for additional attentional strategies (Andersson et al., 2002; Woollacott & Shumway-Cook, 2002). Therefore, having to perform a SAR task, which strains an individual's attentional capacity may affect the automaticity of postural control (Dault et al., 2001) and/or negatively impact the performance of the SAR task. Thus, it is realistic to expect increased risk of human error (negative impact on search capabilities) and falling for SAR personnel, due to the perturbations caused by motion rich environments.

While the literature reports that motion-rich environments have biomechanical, physiological and psychological effects on human performance and worker safety (Duncan, 2013a; Duncan et al., 2014a; Duncan et al., 2007; Holmes et al., 2008; Matthews et al., 2007; Wertheim, 1998), little research to date has specifically examined the effects of motion environments on SAR performance. Despite this lack of research, the dual-task literature can give some insight into the complex interaction between motion rich environments and SAR task performance. Several studies, all performed in non-moving environments, have demonstrated that when balance is challenged, performance on cognitive tasks degrades (Andersson et al., 2002; Mitra & Fraizer, 2004; Pellecchia, 2003; Riley et al., 2003). The results of these studies demonstrated that participants performed better when the postural stance and/ or cognitive task required, were relatively easy. The decline in both postural control and cognitive task performance was suggested to be due to cognitive interference, caused by competing demands for attentional resources. Within the research that is more directly applicable to SAR performance, Yu et al. (2010a); Yu et al. (2010b) studied vigilance performance and standing posture during mild and rough seas respectively, through measurement of postural activity, vigilance performance and subjective mental workload. The vigilance task for this study was a display of vertical lines presented on a video monitor screen. The tasks were broken down into easy and hard tasks based on contrast and length of the lines presented on the screens. Their results indicated that performance of a more difficult vigilance task (lighter and shorter lines) was associated with poorer performance, postural activity and greater subjective mental workload than easier tasks. Similarly, performance and perceived mental workload were worse in rougher vs. milder seas, indicating performance is impacted more when postural control demands are higher. Work by Hickey (2016) supported the findings of Yu et al. (2010a; 2010b). Hickey (2016) had participants perform a visual tracking task and a mental arithmetic task in motion (simulated ship motion) and no motion conditions. While balance was not impacted by task performance, participants' ability to execute the visual tracking task was negatively impacted during the motion condition. No such effect was noted for the arithmetic task. Hickey (2016) hypothesized the complexity of the visual tracking task compared to arithmetic may have been one reason for the differential effects of motion on performance. While the work of both Yu et al. (2010a; 2010b) and Hickey (2016) do add insight into the influence of sea state on performance of a simple vigilance task, they lend relatively little insight to how sea state may impact the performance of SAR task.

Therefore, the purpose of the current research is to examine, under controlled laboratory settings, the performance outcomes of a simulated SAR task in a motion environment. The results of this study will add to current understanding of the potential risks to those who work not only in the SAR field, but those who perform similar cognitive tasks in motion rich environments overall. It is hypothesized that SAR performance will decline when simulated motion environment is increased.

3.3 METHODS

3.3.1 Participants

Twenty-four participants (12 male, 12 female; stature 171.60+/- 9.46 cm, mass 80.41 +/- 18.42, and age 23.44 +/- 2.12 years old) were recruited from the university student population. All participants were novice to motion simulation, were not susceptible to motion sickness, had little to no experience working in moving environments, had no prior SAR experience and did not have any known musculoskeletal injuries or balance disorders. The Interdisciplinary Committee on Ethics in Human Research of Memorial University approved this study.

3.3.2 Procedures

Participants attended a single, two-hour data collection session. Before the study commenced, participants filled out a misery scale (Wertheim, Bos & Bles, 1997), a Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent form. The PAR-Q was completed by participants to determine if it was safe to complete the study based on their health history, current symptoms and risk factors. It was also completed, in conjunction with the misery scale, to avoid the additional factors influencing the results (i.e. altered muscle activity due to injury and altered search performance due to motion sickness). Participants were then prepared for electromyography (EMG) collection by placing electrodes bilaterally on gluteus medius, biceps femoris, rectus femoris, medial gastrocnemius, peroneus longus and tibialis anterior muscles bilaterally. The muscles of the lower limb were chosen as research has shown that muscles closest to the perturbation are affected the greatest (Törner, Almström, Karlsson & Kadefors, 1994). The skin was shaved and cleaned with alcohol at the electrode sites to improve signal quality prior to electrode application. Maximal voluntary isometric contractions (MVIC) of all muscles of interest were then performed by applying manual resistance. Each MVIC was held for five seconds and completed twice for each muscle, bilaterally, for a total of 24 MVICs. Muscle activation data was collected through-out all MVIC trials. The EMG data were collected using a 16-channel wireless Delsys Trigno Myomonitor system (Delsys Inc., Natick, Massachusetts) with a sampling rate of 2000Hz.

Participants were instructed to stand on a Moog 6DOF2000E electric motion platform (Moog Inc. East Aurora, New York) (*Figure 3.1*). The motion platform was capable of moving in six degrees of freedom (*Figure 3.2*), with rotations in roll, pitch, and yaw. A large 360-degree screen that displayed visuals synchronized to platform motions, surrounded the platform. The simulated environments projected on the screens depicted a Fast Rescue Craft (FRC) travelling through the ocean in Bamfield, British Columbia, an environment where maritime SAR would typically be carried out. The visibility of the simulated environment was decreased by the addition of fog, to increase the vigilance demands of the task and represent typical weather conditions a maritime SAR mission would occur in.

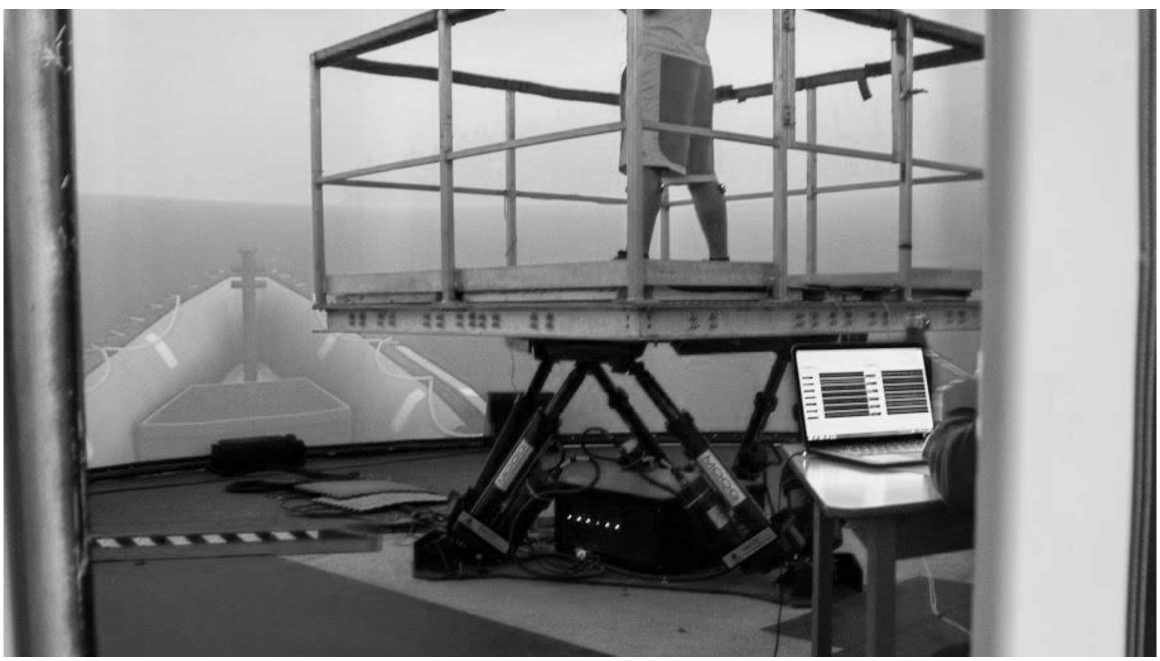

Figure 3.1: Data collection set-up showing the 6 DoF motion platform and the screen of the simulator. The bow of the simulated FRC is visible on the screen.

Participants completed a total of five, five-minute trials with a five-minute rest period in-between. These trials included data collected for study two as well. As such, only two of the five trials were part of the present study. Randomization of trial order was completed across all five trials. Prior to the start of data collection, all participants were exposed to a washout trial. This trial allowed participants to acclimatize to the motions of the simulator with no visuals present. It was included as Duncan et al. (2014b) demonstrated that there is a large learning curve for participants in the first motion trial. The two experimental trials consisted of a low motion and high motion simulated SAR task (Table 3.1). The simulated SAR task represented a fast rescue craft (FRC) travelling through the ocean. The low motion condition simulated an FRC travelling at a low speed, with almost no simulated motion – this was considered the control condition and was meant to replicate performance of a SAR task with minimal wave magnitude. The high motion condition was representative of an FRC travelling at low speeds, in a sea that had high wave magnitudes. This condition represented the most realistic SAR scenario that specialists would encounter during a SAR mission. All conditions were reviewed by a subject matter expert to ensure their ecological validity.

Table 3.1: Details of FRC speed and roll, pitch and yaw motions for each of the 2 simulated FRC motion conditions.

Condition	Simulated Speed of FRC	Max Roll Value (Deg)	Min Roll Value (Deg)	Max Pitch Value (Deg)	Min Pitch Value (Deg)	Max Yaw Value (Deg)	Min Yaw Value (Deg)
Low Motion	10 kts/ hour	0.802	-1.089	2.979	-0.000	0.000	-0.000
High Motion	10kts/ hour	0.361	-3.953	7.448	-1.261	0.057	-0.286

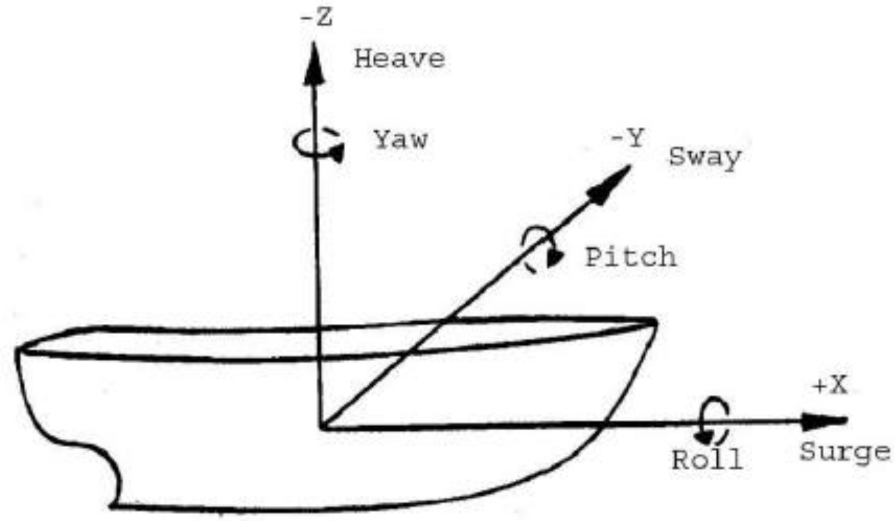

Figure 3.2: A schematic of ship motions about the six degrees of freedom (Duncan, 2013a)

After the washout trial, participants were briefed on the SAR task they were about to perform. Specifically, participants were introduced to, but not visually shown, the objects they were looking for in the water. These objects included: two people, a sailboat, a team FRC, and other debris in the water such as a life ring. The briefing on the scenarios only occurred once, as would typically occur in a real SAR mission. In the briefing, participants were informed that all scenarios incorporated the same type and number of objects. Participants were instructed to take the scenarios seriously as if they were a real-life situation. In all conditions, participants stood unsupported, facing forward on the motion platform. From this position they were asked to scan approximately 270-degrees of the visual screen, or until they reached their peripheral vision, to look for the objects in the water. Turning around on the platform to look for objects that may have passed was not allowed. When participants saw an object, they were instructed to verbally report the sighting to the researcher. To enable this reporting all participants were outfitted with a wireless hands-free microphone that allowed them to communicate in real-time. All communications through this microphone were recorded using Audacity® 2.1.1 recording software. Participants were asked to report any objects they saw that they thought were important, even if they could not correctly identify the objects. In between trials, participants were provided with a five-minute rest period. During the rest period participants were provided with a stool to sit on to reduce the likelihood of fatigue. They were also asked to complete the misery scale (Wertheim, Bos & Bles, 1997). This index was a scale from 0-10, and if participants indicated a 6 or higher, the study was stopped immediately.

For all trials, participants were instructed to stay balanced, to the best of their ability, in the center of the motion platform, which was marked by a grey rectangular mat on the floor of the platform. They were asked to stand with their feet shoulder width apart, parallel to the front of the motion platform. Participants were informed that it was okay to take steps as long as they returned to center when balance was recovered. A video camera was set up behind the motion platform to record the number of steps the participants took. The EMG data collection began when the motion platform was engaged and the trial began. The collection continued for the full five-minute trial.

3.4 DATA ANLYSIS

3.4.1 SAR Task Performance

The recorded audio data for each trial was analyzed to determine the number of correctly identified, incorrectly identified and missed targets. Correctly identified targets were considered to be targets that were correctly identified by participants; incorrectly identified targets were targets that were seen but were misidentified (i.e. a person in the water being identified as debris); and missed targets were defined as those targets that were not reported by participants at all. The number of objects correctly identified, incorrectly identified and missed were recorded for every participant and then divided by the total number of objects (5) in each condition to determine the percentage of targets in each category.

3.4.2 Steps

The video from each of the trials was reviewed to determine the number of steps of motion induced interruptions (MIIs) that occurred during each trial. An MII was counted any time the participant stepped from their original position. As per Duncan et al. (2014b), in order for a stepping movement to be considered a new MII, there must have been a minimum of 1s between it and the last stepping movement. To enable more accurate quantification of participant's balance reactions a slight modification to the Duncan protocol was used. For the present study, we were interested in determining if a step was taken by the participant to prevent falling, or if a step was taken to readjust for comfort. As a result, we had two main categories of MIIs that were identified: 1. Motion induced interruption (MII) fall (i.e., large steps taken to prevent falling) and 2. MII readjust (i.e., relatively small readjustments of foot position to either regain original stance or simply for comfort). These were further broken down to identify the direction of the step taken: total forward MII; total backward steps; total sideway steps; and overall total MII (MII falls + MII adjustments). The distinction between an MII fall and an MII readjustment was determined by overall body posture. If a participant moved their arms for greater balance control or if they looked like they were unbalanced due to a perturbation, it was categorized as an MII fall (*Figure 3.3*). An MII readjustment was recorded if the participant looked like they were comfortable and balanced in their stance, but they took a step to reposition (*Figure 3.4*).

Figure 3.3: MII Fall. Participant has taken a step forward with their left foot and moved their arms out for greater balance.

Figure 3.4: MII readjustment. Participant has taken a step forward with their left foot with arms comfortably by side.

3.4.3 Electromyography

The EMG data was bandpass filtered (20-450 Hz) during the data collection process. Raw EMG data from all trials were amplitude normalized by dividing the raw EMG data from simulation trials by the maximum EMG amplitude that occurred during MVCs. Maximum EMG was determined as per Burden and Bartlett (1999). A 100-millisecond moving window was used to calculate the root mean square (RMS) EMG. The resulting smoothed signal was then examined to determine maximum EMG for each muscle. The maximum activation was used to amplitude normalize all the motion trial EMG data. The amplitude normalized signals were then averaged across of full five-minute trial.

3.5 STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS (SPSS 18.0 for Macintosh, IBM Corporation, Armonk, New York, USA). Tests for normality were completed for the vigilance task data (percent correct, percent incorrect and percent missed), stepping data, and EMG data. The Shapiro-Wilk test statistic revealed that neither the vigilance nor the stepping data were normally distributed. For this data, a Wilcoxon Signed Rank Test was used to determine statistical differences between variables and conditions. For the EMG data, paired-samples t-tests were used. A p-value of $p<0.05$ was used for all comparisons. This was corrected, using a Bonferroni correction, to account for multiple comparisons.

3.6 RESULTS

Due to technical difficulties, not all data was collected for each dependent variable. The following provides a summary of the data that was collected for each dependent variable:

1. SAR Task performance **-** 24 Participants (12 male, 12 female; stature 171.60+/- 9.46 cm, mass 80.41 +/- 18.42, and age 23.44 +/- 2.12 years old).
2. Steps - 18 Participants (7 male, 11 female; stature 171.28 +/- 9.64 cm, mass 77.46 +/- 18.31, and age 23.17 +/- 1.95 years old).
3. EMG - 18 Participants (7 male, 11 female; stature 171.28 +/- 9.64 cm, mass 77.46 +/- 18.31, and age 23.17 +/- 1.95 years old).

No participants had to discontinue participation due to issues with motion sickness.

3.6.1 SAR Task Performance

The SAR task performance data was divided into three categories: 1) correctly identified objects, 2) incorrectly identified objects and 3) missed objects. Participants correctly identified objects 74% of the time for low motion and only 58% of the time in the high motion condition (*Figure 3.5*). The Wilcoxon Signed Rank Test demonstrated that there was a statistically significant difference between the low motion and high motion conditions (z = -2.913, p = 0.004). For the number of incorrectly identified objects (*Figure 3.6*), the results of the Wilcoxon Signed Rank Test indicated that there was a statistically significant difference in the percentage of incorrectly identified objects across the two conditions, z = -3.090, $p = 0.002$. The participants incorrectly identified 18% of objects the low motion condition and 4% in the high motion condition.

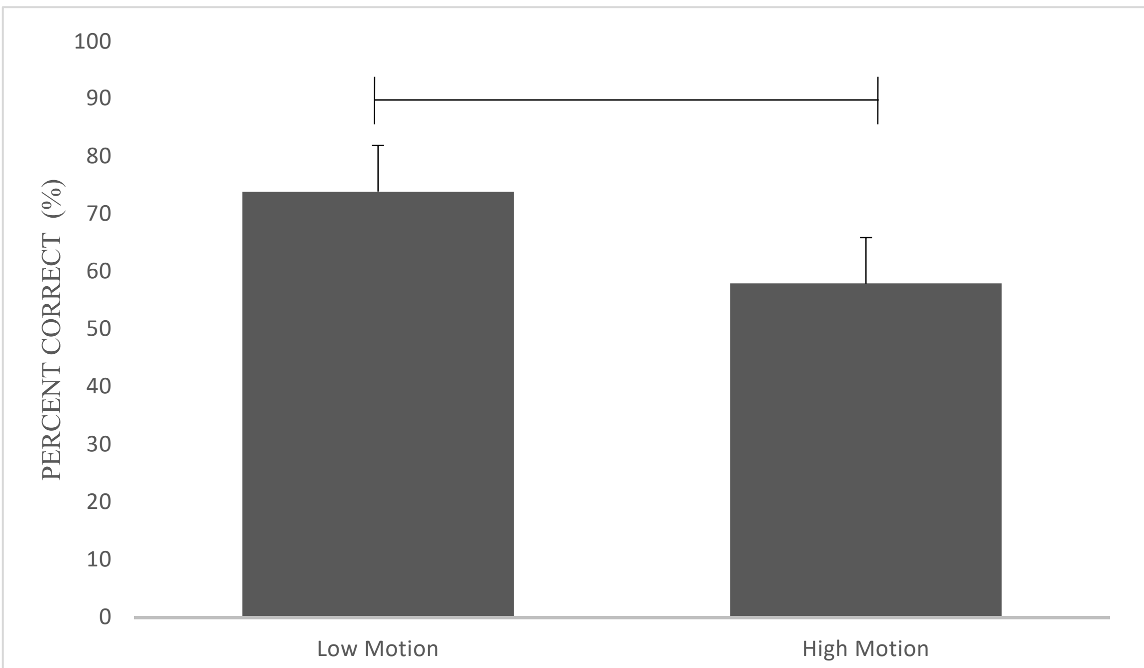

Figure 3.5: Percentage of correctly identified objects. Asterisk (*) indicates significant differences at p<0.05.

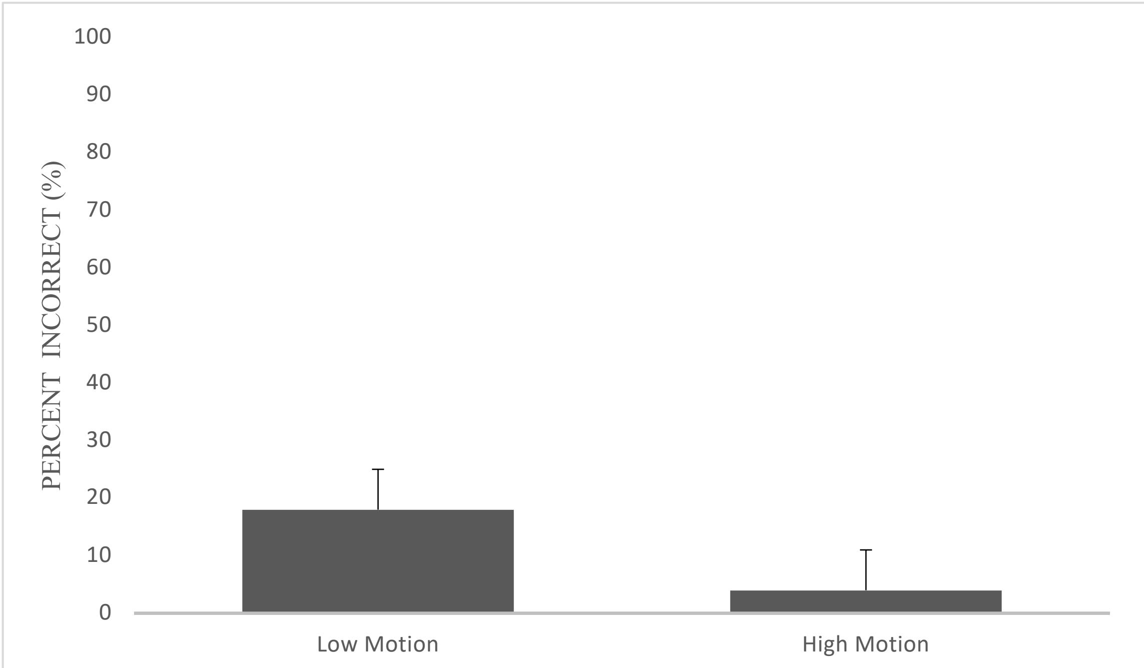

Figure 3.6: Percentage of incorrectly identified objects. Asterisk (*) indicates significant differences between conditions indicated at p<0.05.

The number of missed objects was also compared between conditions (*Figure 3.7*). The results of the Wilcoxon Signed Rank Test showed that there was a statistically significant difference in the percentage of missed objects across the two conditions, z = -4.187, $p < 0.001$. Participants missed the objects 38% of the time the high motion condition and for the low motion condition, objects were missed only 8% of the time.

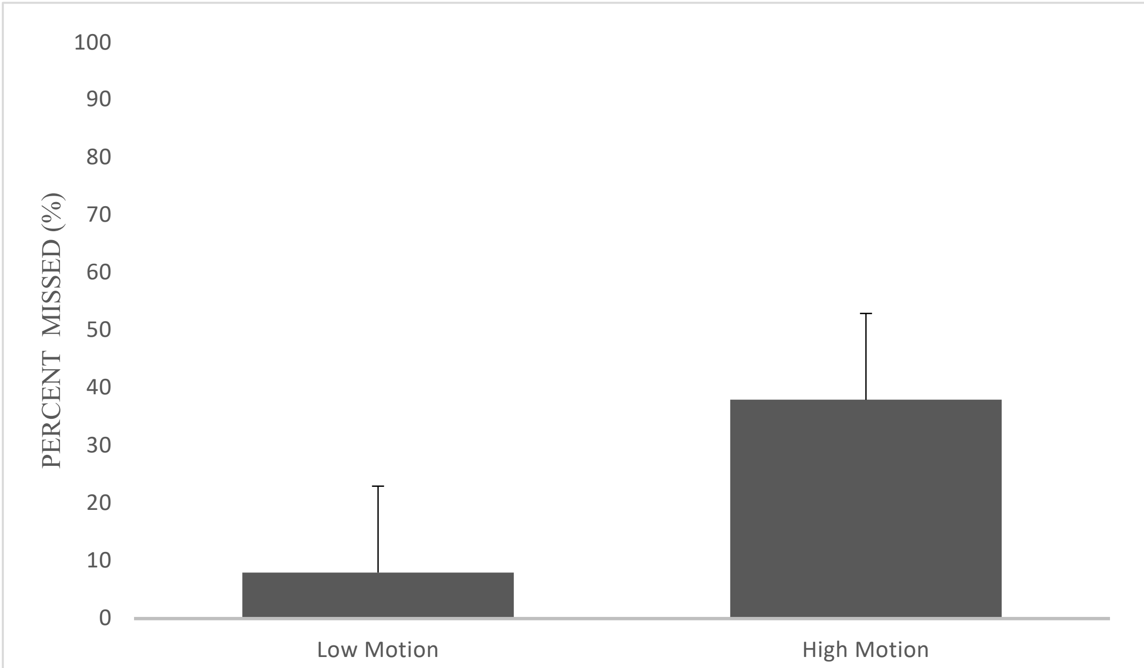

Figure 3.7: Percentage of missed objects. Asterisk (*) indicates significant differences between the conditions indicated at p<0.05.

3.6.2 Steps

A Wilcoxon Signed Rank Test was performed to compare the low motion and high motion conditions with regards to the number of steps taken, direction of steps and the reason for stepping. It is important to note that there were no steps taken by any of the participants in the low motion condition (*Figure 3.8*). The test revealed statistically significant differences between high and low motion (*Figure 3.8*) for MII_Fall (z = -2.539, p = 0.011), MII_Readjust (z = -2.527, p = 0.012), total forward (z = -2.692, p = 0.007), total backward (z = -2.692, p = 0.007), total sideway (z = - 2.032, p = 0.042) and overall total steps (z = -2.670, p = 0.008).

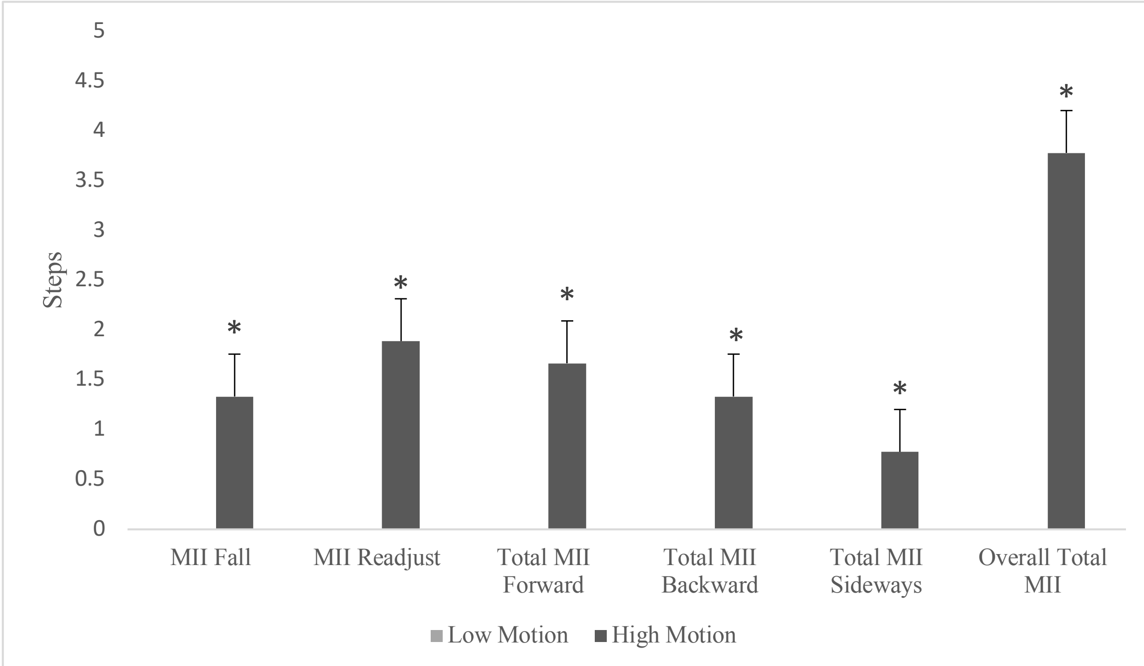

Figure 3.8: Average number of steps taken throughout the low motion and high motion trials. There were zero steps taken by all participants in the low motion trial. Asterisk (*) indicates significant differences at p<0.05.

3.6.3 Electromyography

Results of the paired sample t-test revealed that muscle activation increased significantly in the high motion condition for all muscles (*Figure 3.9 and Table 3.2*). While muscle activity was measured bilaterally, only the right muscle activation is displayed as there were no significant differences found between the left and right activation for all muscles.

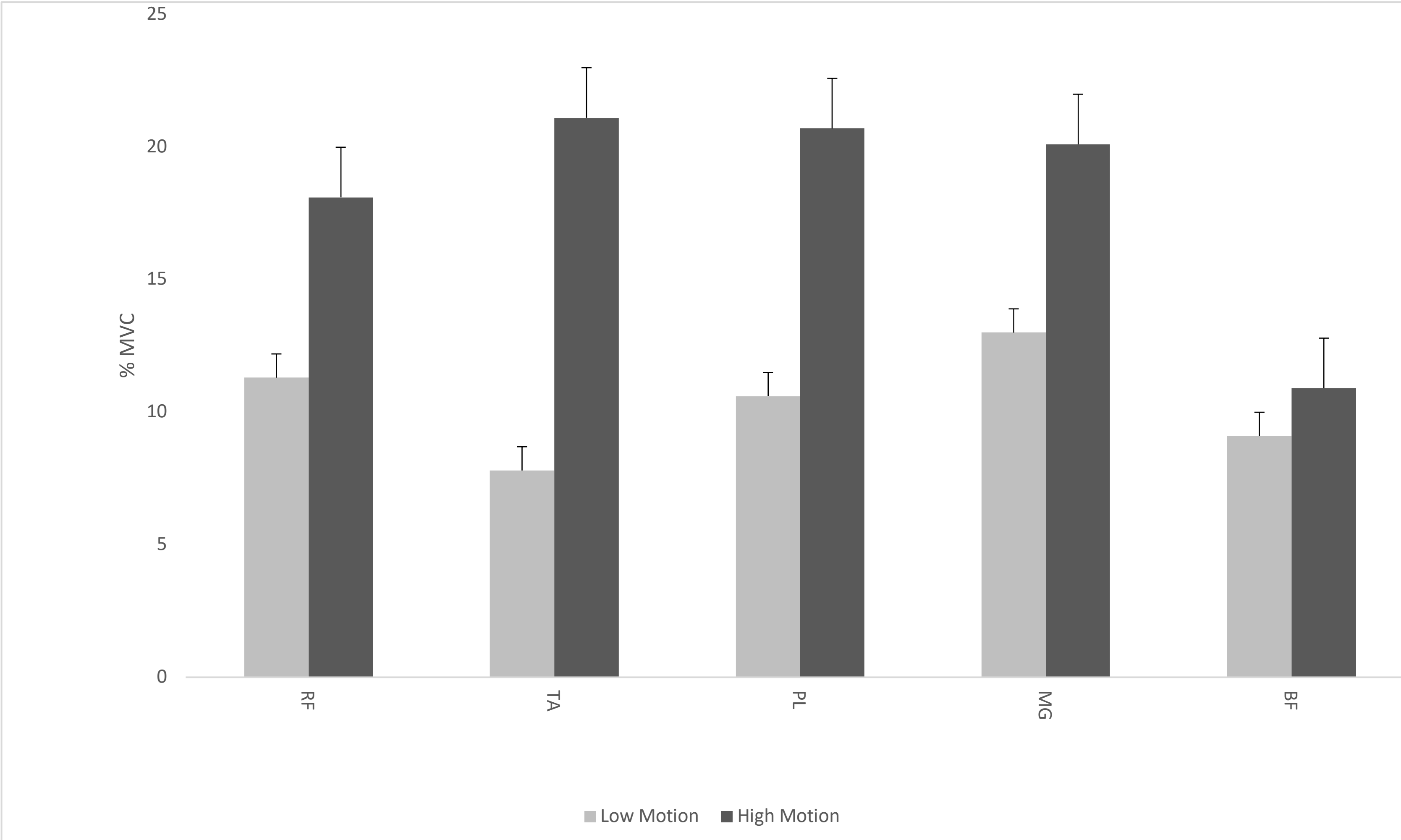

Figure 3.9: Percent (%) MVC muscle activation for all muscles collected (right side only). Asterisk (*) indicates significant differences at p<0.05.

Table 3.2: Paired t-test results comparing muscle activation between the low motion condition and high motion condition.

Muscle	**df**	**t-test statistic**	**P value (two-tailed)**
Rectus femoris	**17**	-4.185	$p < 0.001$
Tibialis anterior	**17**	-10.023	$p < 0.001$
Perenoeus longus	**17**	-6.614	$p < 0.001$
Medial gastorcnemius	**17**	-3.849	$p < 0.001$
Biceps femoris	**17**	-2.134	$p < 0.001$

3.7 DISCUSSION

The purpose of the study was to examine how SAR task performance was impacted by a moving environment. The results demonstrate that SAR task performance was negatively impacted when performed in a simulated environment that exposed participants to ecologically valid platform motions. Under these conditions, the percentage of correctly identified targets decreased with an increase in the percentage of missed targets. The number of steps taken by participants and muscle activation levels was also highest for this condition. These findings represent the first time, to the author's knowledge, that the effects of motion on SAR task performance have been examined.

As this is the first study to examine SAR task performance in a simulated environment, it is difficult to compare the results directly to other studies. The results are, however, similar to those of Crossland and Lloyd (1993); Duncan et al. (2012); Pearcey et al. (2015) who found that platform motions negatively affect an individual's performance on reaction times of visuomotor tracking tasks, speed of lifting and lowering loads, speed of trackball manipulation, pen and paper tracing tasks and computer tracing tasks, respectively. The results are also consistent with Yu et al. (2010a); Yu et al. (2010b) who studied vigilance performance and standing posture during mild and rough seas. Yu and colleagues (2010a; 2010b) demonstrated that vigilance performance in rough seas was reduced relative to the same participants completing the same tasks in mild seas. While these results are similar to the current study, the individuals examined and experimental conditions differed as Yu and colleagues (2010a; 2010b) used experienced crewmembers on a Navy ship at sea. The participants and the environment used in Yu et al. (2010a; 2010b) studies were more representative of a realistic offshore setting, while the task in the current study was more complex and realistic. This indicates that regardless of experience and vessel type, vigilance tasks, performed in high motion environments, are challenging.

The decrease in SAR performance with increased wave motion may be explained by the theory of dual-task attentional resources. The decline in the SAR performance suggests that there was potential attentional resource competition between cognitive and sensorimotor processing. For this study, participants had to maintain postural control while performing the vigilance task. Scanning the surrounding screen for objects (cognitive task) while maintaining balance (sensorimotor processing) on a moving platform potentially strained an individual's limited attentional capacity resulting in decrements in the SAR performance. The empirical evidence on the competition for attentional resources between postural control is conflicting. The inconsistency in current literature indicates that the relationship between postural control and cognitive processing warrants further analysis (Huxhold et al., 2006). The exact pattern of observed interaction between postural and cognitive tasks varies across studies (Mitra & Fraizer, 2004). Possible reasons why there are discrepancies within the literature may be because numerous types of mental tasks, postural stance positions and different postural control measures have been used (Dault et al., 2001; Mitra & Fraizer, 2004). Therefore, future research would need to be completed to determine if the decline in visual search performance was due to the postural control maintenance.

The results demonstrated that with increased platform motions there was a decrease in the number of correctly identified objects and increase in number of missed objects. However, for the incorrectly identified objects, it is interesting to note that the percentage was greater in the low motion condition than the high motion condition (*Figure 3.6*). This result may be due to the fact that participants were more likely to miss objects altogether in the high motion condition. Whereas in the low motion condition, they were likely to see the object, but were unable to correctly identify it. The identification of objects, both correct and incorrect, demonstrate that vigilance tasks require not only sensory processes but require a decision processes as well. The individual must decide if the object is of importance to the task at hand. A theory that helps to explain these decision processes is the signal detection theory (SDT); a theory that is widely used to provide a measure of performance on memory, perception and categorization tasks (Lynn & Barrett, 2014). It was first proposed by Tanner and Swets (1954) as a “decision-making theory of visual detection”. When individuals are presented with visual stimuli, uncertainty may be present and discrimination between the stimuli must be made. For this study, calculations were not completed to evaluate SDT, however, the theory provides insight into the results of the study. As all participants were all novice to SAR missions, it was important for participants to err on the side of caution and provide any information they felt would lead to the safe retrieval of the individuals in the water. Any delay or error in classification and/or identification indicated a potential for competition of attentional resources with postural control.

In addition to the decrements in SAR performance created by the addition of motion, it is also important to note that participants took more steps (*Figure 3.8*) and exhibited increased lower limb muscle activation (*Figure 3.9*). Both findings are indicative of increased demands being placed on the postural control system (Duncan et al., 2010; Duncan et al., 2012; Faber et al., 2008; Horak & Kuo, 2000; Matthews et al., 2007). These results indicate that if SAR specialists are preoccupied performing the required search task, they may have less cognitive resources available for the maintenance of postural control, leading to increased fall risk and work-related energy demands. The risks of falls and fatigue will be discussed in greater detail in the following paper.

3.7.1 Implications

The successful performance of SAR tasks is crucial to saving those who are in distress. Lives depend on the sustained attention and visual search of those performing the SAR missions. If a SAR specialist is unable to perform optimally on a search task because they are distracted by the maintenance of balance, it increases the likelihood of a human factors error. Similarly, if SAR personnel are focused more on the search than on their posture it puts them at greater risk for injuries due to falls and fatigue.

Previous literature has demonstrated that in motion rich environments, individuals show a reduction in performance and are exposed to greater risk of injury due to loss of balance, increased musculature activity and alterations in trunk motion (Duncan et al., 2010; Duncan et al., 2007; Faber et al., 2008; Holmes et al., 2008; Kingma, Delleman, & van Dieën, 2003; Matthews et al., 2007). However, the degree that motion affects postural stability is dependent on a variety of factors, such as task parameters, as well as magnitude and direction of vessel motions (Duncan et al., 2007). While much of the literature (Duncan et al., 2014a; Duncan et al., 2010, 2012; Duncan et al., 2007; Faber et al., 2008; Matthews et al., 2007) has shown increased risk of injury during MMH tasks in moving environments, based on the results of the current study it can be hypothesized that the risks are transferable to other types of occupational activities in marine environments. As well, the results of the current study match the previous literature in that it demonstrates a reduction in vigilance performance as motion increases. Therefore, if SAR specialists are preoccupied performing the required search task, they may have less cognitive resources available for the maintenance of postural control, leading to increased fall risk and work-related energy demands. However, future research would need to be completed to determine these effects.

While much of SAR training does take place in the natural marine environment, there is a possibility for the design of safety training simulation. The simulator provided an ecological valid simulated environment, which can be used as a training tool to enhance motor and operational skills and associated decision-making skills. Employees can gain experience performing tasks in dangerous scenarios that otherwise would not be as ethically, logistically or financially feasible (Veitch, Billard, & Patterson, 2008a;2008b).

3.7.2 Limitations

When interpreting the results from the current study the following should be considered: (a) while the motion simulator is ecologically valid and provides a controlled environment to reliably collect data, it does not provide the same type of environment one would experience in harsh conditions at sea; (b) all participants in the data collection were naïve. Experienced SAR specialists would employ advanced search techniques and may have developed compensatory mechanisms to maintain postural control.

3.8 CONCLUSIONS

The following conclusions can be made from the results of the current study:

1. Performance of a SAR task declines as magnitude of motion of simulated vessel increased.
2. Future research should include SAR specialists to see if similar findings between postural control and performance SAR task would be identified. One could hypothesize that the decrements in the SAR task performance are due to the

increased focus on maintaining postural control. However, future research would provide a better understanding of this potential competition of attentional resources.

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CHAPTER 4: POSTURAL CONTROL IN A MOVING ENVIRONMENT

4.1 ABSTRACT

The purpose of this study was to examine the impact of a SAR task on postural control in a moving environment. Eighteen participants (7 male, 11 female) performed a simulated vigilance task on a six degree of freedom motion platform at Memorial University of Newfoundland. Electromyography (EMG) and number of steps taken were the variables analyzed. The results showed that when the SAR task was added to the concurrent postural task, there were increases seen in EMG and number of steps taken. These results suggest that postural control will be challenged when a SAR task is performed in a simulated moving environment.

Keywords: postural control, moving environments, secondary task, simulation.

4.2 INTRODUCTION

The study of the relationship between information processing and balance control has both theoretical and practical implications to the understanding of balance control and disorders (Andersson, Yardley, & Luxon, 1998). While postural adjustments, to some extent, are automatic responses, postural control does require continuous regulation and integration of information from the visual, somatosensory, and vestibular senses (Lajoie, Teasdale, Bard, & Fleury, 1993; Yardley et al., 1999). Consequently, more cognitively demanding situations, such as vocational tasks, may call for attentional resources in order to control balance (Andersson et al., 1998; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997; Shumway-Cook & Woollacott, 2000; Yardley et al., 1999). Therefore, a question that arises is; do cognitive functions and postural control functions compete for central processing resources?

To investigate this question, dual-task paradigms are often used (Andersson et al., 2002). The results of previous dual task studies examining the effects of cognitive tasks on postural control are conflicting. Several studies demonstrate that postural sway increases when performing a concurrent cognitive task (Andersson et al., 1998; Shumway-Cook et al., 1997; Shumway-Cook & Woollacott, 2000; Yardley et al., 1999) while others demonstrate a decrease in postural sway (Andersson et al., 2002; Dault et al., 2001; Hunter & Hoffman, 2001; Kerr, Condon, & McDonald, 1985; Yardley & Redfern, 2001). These contradictory results likely occur for a variety of reasons, including but not limited to, the cognitive task employed, the postural control/ balance task examined, arousal level reached by participants and the health and/or age of participants. For example, the cognitive tasks examined in previous studies range from simple silent mental math (Andersson et al., 2002) to more difficult visuospatial grid search tasks (Andersson et al., 1998) and memory tasks (Dault et al., 2003; Kerr et al., 1985). Furthermore, the method used to perturb the participants' balance also varied between studies. A variety of methods including electrical stimulation of the calf muscles (Andersson et al., 2002) to unstable surfaces created by inflatable objects (Dault et al., 2003) have been used. Because of the variation in experimental approaches to the question, it is difficult to draw concise conclusions pertaining to competition for central processing.

While this current literature provides some insight into how postural control is affected when performing a cognitive task, it is not directly applicable to situations where there are continuous, irregular, on-going destabilizing perturbations; like those experienced when working on a boat or moving platform in a maritime environment. In comparison to research done in stable environments, there has been relatively less research examining the effects of a vigilance task performance on postural control in moving environments (Yu et al., 2010a; Yu et al., 2010b). Such research is important as it will add another layer of understanding to how the postural control is potentially impacted when it must be maintained during dual-task performance. Therefore, the purpose of the current research is to examine, under controlled laboratory settings, the effects of performing a vigilance task, specifically a SAR task, on postural control when standing in a moving environment. Unlike the previous paper, which focused on how motion impacted the performance of a SAR task, the present work used similar methods to add insight into an unstudied aspect of postural control. It differs from the previous paper in that the platform motions needed to be higher to adequately challenge postural control. In contrast, platform motions in the previous paper had to be consistent with those experienced by SAR personnel on the job. It is hypothesized that the addition of a vigilance task, to an already challenging moving environment, will result in decrements in postural control; evidenced by an increase in the number of steps individuals must take to stay balanced as well as increased muscle activation.

4.3 METHODS

The methods of the current study were similar to those of the previous paper. Participants were exposed to motion trials that lasted for five minutes. During each of the trials, muscle activation was recorded from the same 12 muscles mentioned in the previous study (gluteus medius, biceps femoris, rectus femoris, medial gastrocnemius, peroneus longus and tibialis anterior muscles, bilaterally) using the same Delsys Trigno wireless EMG system. The simulated SAR task examined used the same environment and visibility conditions as study one. Participants were asked to identify the following objects floating in the simulated environment: two people, a sailboat, a team FRC, and other debris in the water, such as a life ring.

The difference between this and the previous paper include:

Twenty-four participants were recruited from a university student population. However, due to technical complications, only 18 participants (7 male, 11 female; stature 171.28 +/- 9.64 cm, mass 77.46 +/- 18.31, and age 23.17 +/- 1.95 years old) were included in this study for EMG and step count. No participants had to discontinue participation due to issues with motion sickness.

1. The data collection session included a total of five, five-minute trials with five-minute rests periods in-between; however, only three of the trials were used in this study. The three trials that were of interest in the current study were separated into three conditions: 1) control (low motion, low speed with simulation), 2) Motion_SIM (high motion, high speed with simulation), 3) Motion_NOSIM (high motion, high speed with no simulation) (*Table 4.1*). The simulated motions for the motion conditions in this study were chosen because they more closely approximated motion profiles used in previous work examining postural control in a moving environment (*Table 4.2, Chapter 4*) (Duncan et al., 2013; 2014a).

Table 4.1: Breakdown of Condition Characteristics

Control	Motion_SIM	Motion_NOSIM
➢ Sim ➢ Motion ➢ 10kts/hr	➢ Sim ➢ Motion ➢ 35 kts/hr	➢ No Sim ➢ Motion ➢ 35kts/hr

Table 4.2: Maximum and Minimum Values for the Roll, Pitch, Yaw Variables of the Motion Platform for Each Condition

Condition	Simulated Speed of FRC	Max Roll Value (Deg)	Min Roll Value (Deg)	Max Pitch Value (Deg)	Min Pitch Value (Deg)	Max Yaw Value (Deg)	Min Yaw Value (Deg)
Control	10 kts/ hour	0.802	-1.089	2.979	-0.000	0.000	-0.000
Motion	35kts/hour	3.262	-2.476	4.210	-2.832	0.114	-0.099

4.4 DATA ANLYSIS

Using methods identical to the previous paper, the following outcome variables were examined: average EMG amplitude across each of the three trials, number of motion induced interruptions (MIIs) anterior, posterior, right and left. The MIIs were also classified as either MII falls (the step was subjectively determined to have been needed to prevent loss of balance) or MII readjustments (the step was subjectively determined to have been taken to reposition their feet for comfort).

4.5 STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS (SPSS 18.0 for Macintosh, IBM Corporation, Armonk, New York, USA). For the EMG data, assumptions of sphericity were tested using Mauchley's Test of Sphericity. If the assumption was violated, degrees of freedom were corrected using the Greenhouse-Geisser estimate. A one-way repeated measure analysis of variance (ANOVA) was used to determine between condition effects for muscle activation of the ten muscles of interest. Post hoc analysis used the Bonferroni correction to identify significant differences between conditions. The correction produced a significance level at $p = 0.005$ Descriptive statistics in text and figures represent mean +/- SE.

Tests for normality were completed for the stepping data. The Shapiro-Wilk test statistic revealed that the data was not normally distributed. Therefore, a Friedman Test was used to determine significant main effects between variables and conditions, followed by a post hoc analysis using a Wilcoxon Signed Rank Test.

4.6 RESULTS

4.6.1 EMG

There were no significant differences in muscle activation between the right and left side for all muscles measured. Therefore, the results presented are for the right muscles only. All EMG results are summarized in Figure 4.1.

<u>Tibialis Anterior</u>

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi2(2) = 4.252$, $p = 0.119$. Statistically significant differences were found between conditions for tibialis anterior muscle activation ($F(2, 34) = 75.367$, $p < 0.001$). Post hoc tests revealed the muscle activation was higher in the Motion_SIM condition (0.371 ± 0.029) than both the Control (0.078 ± 0.012) and Motion_NOSIM (0.228 ± 0.025) conditions, ($p < 0.001$). As well, all three conditions were statistically different from each other ($p < 0.001$).

<u>Peroneus Longus</u>

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi2(2) = 4.997$, p = .082. Muscle activation differed significantly between conditions for the peroneus longus muscle ($F(2, 34) = 61.723$, $p < 0.001$). Post hoc analysis indicated statistically significant differences in muscle activation in the peroneus longus muscle between the Control condition (0.106 ± 0.018) and the Motion_SIM (0.329 ± 0.032) condition, ($p < 0.001$). As well, statistically significant differences between the Motion_NOSIM (0.214 ± 0.023) condition, and Motion_SIM (0.329 ± 0.032), ($p < 0.001$). There were also statistically significant differences found between control condition (0.106 ± 0.018) and Motion_NOSIM (0.214 ± 0.023) at ($p < 0.001$).

Gastrocnemius

Mauchly's Test of Sphericity indicated that the assumption of sphericity has not been violated, $\chi 2(2) = 1.797$, p = 0.407. A significant main effect of condition was found for muscle activation in the gastrocnemius ($F(2, 34) = 21.256$, $p < 0.001$). Post hoc analysis revealed that the Control condition (0.130 ± 0.015) and Motion_SIM (0.263 ± 0.026) differed significantly ($p < 0.001$). As well as Motion_SIM (0.263 ± 0.026) and Motion_NOSIM (0.195 ± 0.025), ($p = 0.009$). The Control condition (0.130 ± 0.015) and Motion_NOSIM (0.195 ± 0.025) also differed significantly, ($p = 0.006$)

Biceps Femoris

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi 2(2) = 2.304$, p = 0.316. Biceps femoris muscle activation differed significantly between conditions ($F(2, 34) = 8.632$, $p < 0.001$). Post hoc analysis indicated statistically significant differences in muscle activation in the peroneus longus muscle between the Control condition (0.091 ± 0.014) and the Motion_SIM (0.132 ± 0.015) condition at $p = 0.002$. As well, statistically significant differences between the Motion_NOSIM (0.097 ±

0.014) condition, and Motion_SIM (0.132 ± 0.015), (p = 0.10). There were no statistically significant differences found between control condition and Motion_NOSIM (p = 1.00).

Rectus Femoris

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi2(2) = 2.456$, p = .293. Rectus femoris muscle activation differed significantly between conditions ($F(2, 34) = 12.910$, $p < 0.001$). Post hoc analysis indicated statistically significant differences in muscle activation in the rectus femoris muscle between the Control condition (0.113 ± 0.020) and the Motion_SIM (0.211 ± 0.018) condition, (p = 0.002). Statistically significant differences were noted as well between the Motion_NOSIM (0.194 ± 0.019) condition and Control condition (0.113 ± 0.020), (p = 0.001). There were no statistically significant differences found between Motion_NOSIM and Motion_SIM (p = 1.00).

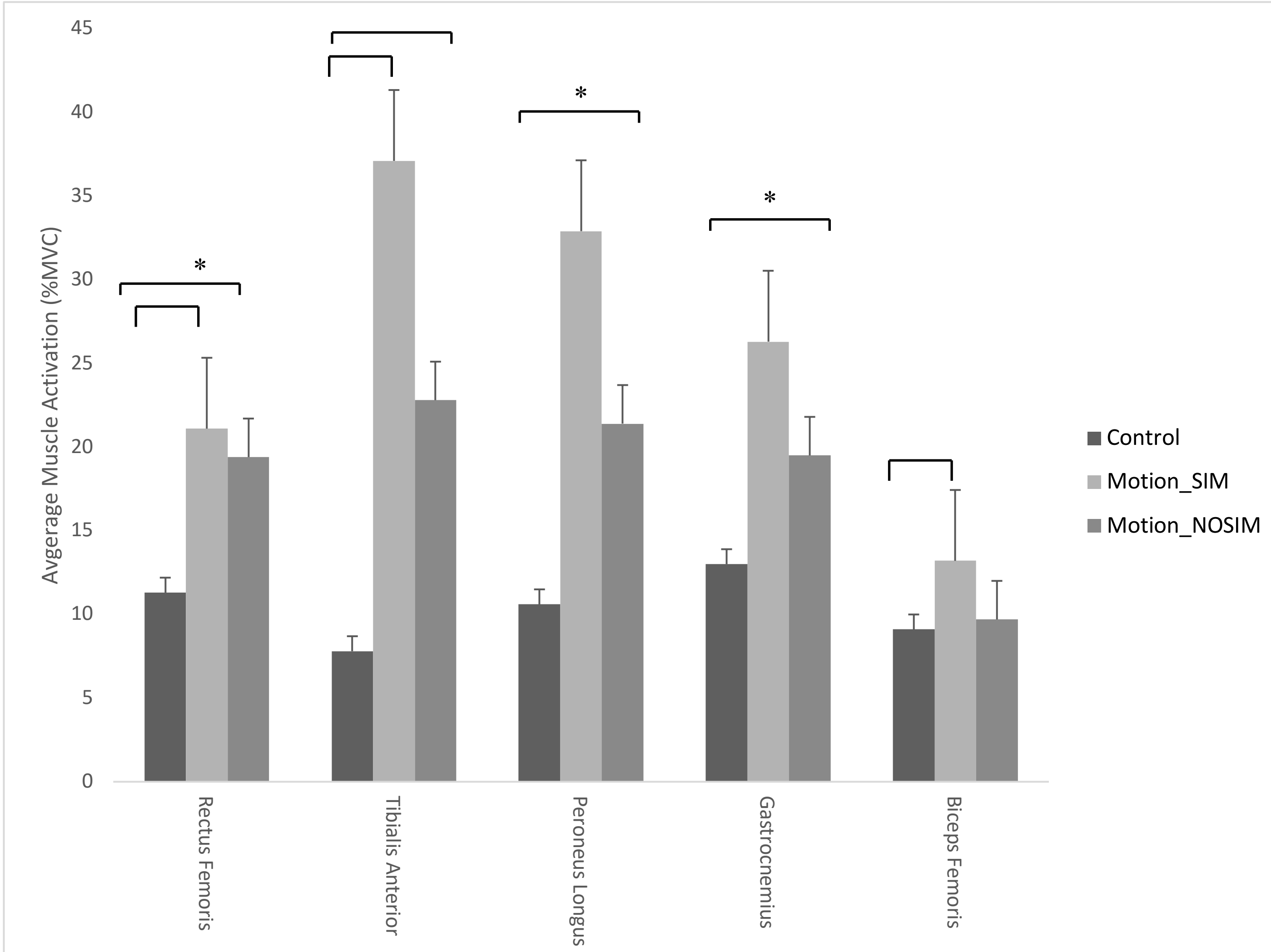

Figure 4.1: Average EMG Recorded During the Five-Minute Motion Trials. Muscle activation shown is for muscles on the right side. Asterisk (*) indicates significant differences at p<0.05.

4.6.2 Steps

A Friedman Test was performed to compare all three conditions with regards to the number of steps taken, the direction of steps and the reason for stepping (*Table 4.3*). It is important to note that there were no steps taken by any of the participants in the control condition.

Table 4.3: Friedman Test Results

	MIC Fall	MIC Readjust	Total MIC Forward	Total MIC Backward	Total MIC Side	Overall Total MIC
N	18	18	18	18	18	18
df	2	2	2	2	2	2
χ^2	29.93	19.43	26.26	28.00	16.67	29.93
Sig.	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*

Post Hoc analysis, using a Wilcoxon Signed Rank Test, revealed a statistically significant difference between control condition and Motion_SIM (*Figure 4.2*) for MIC_Fall, (z = -3.529, $p <$ 0.001), MIC_Readjust, (z = -3.062, p = 0.002), total MIC forward, (z = -3.300, p = 0.001), total MIC backward, (z = -3.413, p = 0.001), total MIC Side (z = -3.083, p = 0.002) and overall total MIC, (z = -3.519, p < 0.001). When Motion_NOSIM and Motion_SIM conditions were compared all step indicators were significantly greater in the Motion_SIM condition except for the total MIC side. The results are as follows: MIC_Fall (z = -3.529, p < 0.001), MIC_Readjust, (z = -2.238, p = 0.025), total MIC forward (z = -3.301, $p = 0.001$), total MIC backward (z = -3.414, $p = 0.001$), and overall total MIC (z = -3.519, $p < 0.001$).

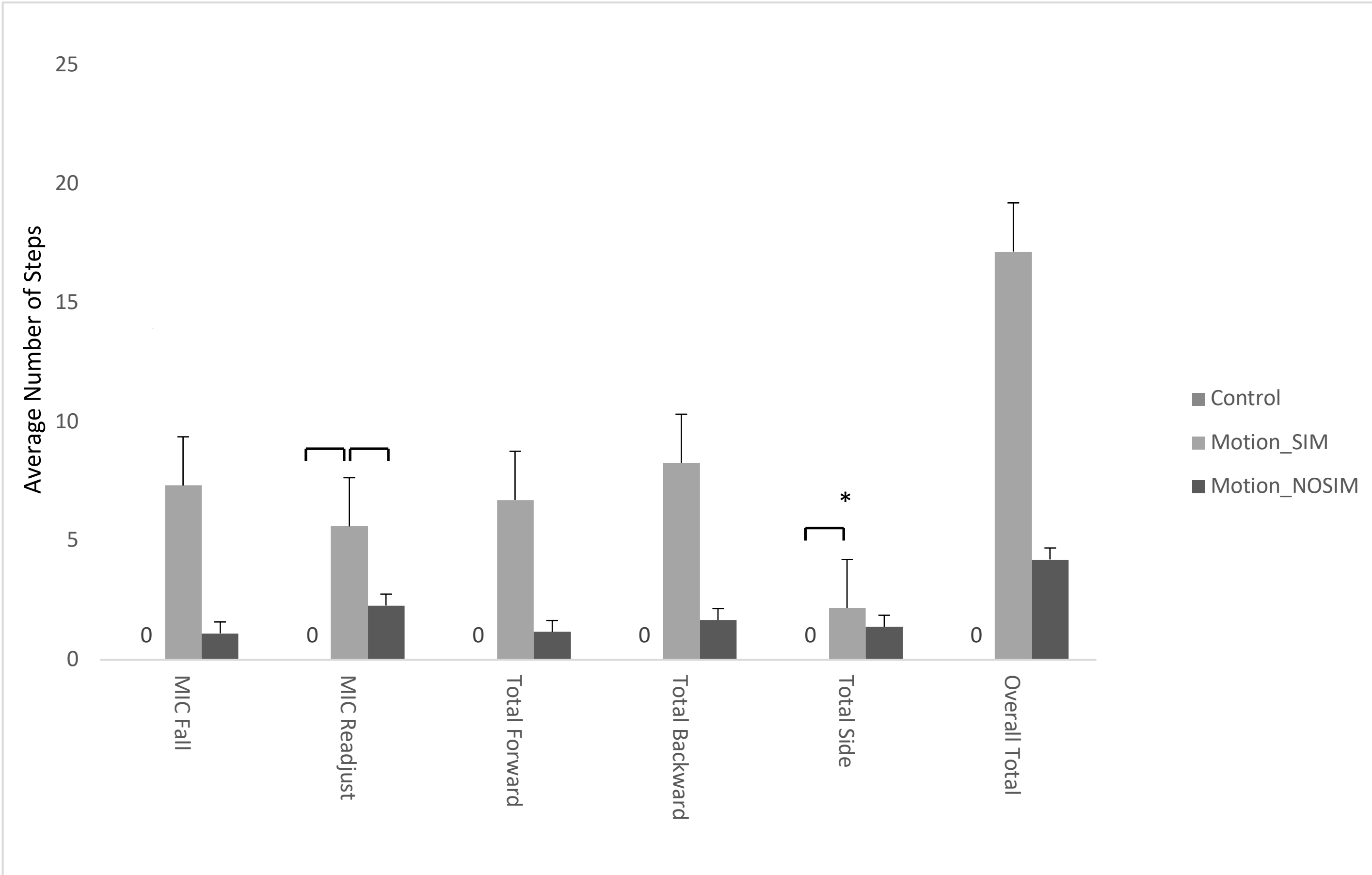

Figure 4.2: Average number of steps taken during the 3 conditions. Asterisk (*) indicates significant differences at $p<0.05$. There were no steps taken by participants in the control condition; bars for this condition appear as zeros.

4.7 DISCUSSION

A person's ability to remain balanced can be impacted by numerous intrinsic and extrinsic factors. In daily life, individuals are constantly multitasking (dual-task) by maintaining balance while completing other recreational or job-related tasks. As such, researchers have examined how postural control is impacted by secondary task performance. The present study was the first study, to the author's knowledge, which investigated the potential competition for attentional resources between vigilance (SAR task) and postural control in young, healthy adults, in a moving environment. The results of this research indicate that when the SAR task was added to the postural control task, participants exhibited increased levels of lower limb muscle activation across all muscles examined; with greatest increases seen in tibialis anterior, medial gastrocnemius and peroneus longus. The results also demonstrated that participants took more steps when completing a SAR task on the moving platform compared to when there was no SAR task present. This suggests that participants found it more difficult to maintain balance when completing the SAR task, even though the balance task was identical in both the Motion_SIM and Motion_NOSIM conditions. These findings add to the current understanding of how postural control is impacted while performing vocational tasks in moving environments.

The results indicated that lower limb muscle activity and number of steps increased when individuals were required to perform the SAR task while standing in a simulated moving environment. These increases suggest that the addition of the SAR task altered the strategies individuals used to maintain balance. In the Motion_NOSIM condition, individuals were able to maintain balance using primarily fixed support reactions that required minimal (and non-significant) increases in lower limb muscle activation, compared to the control condition. When the simulation was added to the motion trials, muscle activation changes were most pronounced at the ankle. The tibialis anterior, peroneus longus and gastrocnemius muscles demonstrated the greatest muscle activity in the Motion_SIM condition (*Figure 4.1*). These increases agree with the suggestions of Törner, Almström, Karlsson, and Kadefors (1994) who stated that the joints closest to a destabilizing perturbation are most affected. As a result, the muscles that cross these joints would likely have to contribute more to keep them stable leading to increased activation. These increases in muscle activation also agree with the increased stepping observed in this condition. Gastrocnemius, tibialis anterior and the peronei are all known to play critical roles in the generation of anterior/posterior propulsion forces (Hamill & Knutzen, 2006). As most of the steps taken were in the anterior/posterior direction (*Figure 4.2*) it would follow that the increased activation observed in these muscles was also related to increased steps. As both rectus femoris and biceps femoris are viewed as stabilizing muscles for the knee joint, a joint that that would be relatively less stressed during platform motion according to Torner et al. (1994), it is not surprising that activations in these muscles were lower and less affected by higher motions.

There are many reasons why participants may have used a stepping strategy to maintain balance in the Motion_SIM condition. These include having reached the limits of their base of support or feeling that stepping optimized their chances to protect against falling. The average number of total steps that participants took during the five-minute trial increased from five in the Motion_NOSIM condition to 17 in the Motion_SIM condition (*Figure 4.2*). While the use of a change in support strategy is not necessarily tied to the size of the perturbation (Maki & McIlroy, 1997), the increase in number of steps taken would suggest that participants were more unstable in this condition. Duncan et al. (2014a) have shown that when individuals are placed in a moving environment, similar to the one used in the current study, stepping frequency increases when not asked to maintain a constrained foot position. Based on these results, Duncan (2013a) concluded that postural response to wave-induced ship motions is not simply physics-based. When participants are given a choice, they will step more frequently, and often before stability limits have been reached. One hypothesis given by Duncan (2013a) as to why stepping is favoured over fixed support strategies is because the physiological requirements are lower. The EMG findings from the current study would seem to argue against this hypothesis as muscle activation was clearly higher when more steps were taken. Although, admittedly the present study captured EMG from only a fraction of the muscles needed to remain balanced in this type of environment. Further work that quantifies the physiological cost of stepping and fixed support strategies in moving environments are needed to clarify this point and further investigate the reasons underlying the balance strategy being used.

This study has clearly demonstrated that the need to step more frequently was not due to the nature of the perturbations, as they were identical in Motion_SIM and Motion_NOSIM conditions. The competition for attentional resources is a theory that may explain why (Andersson et al., 1998; Shumway-Cook et al., 1997; Shumway-Cook

& Woollacott, 2000; Yardley et al., 1999). This theory suggests that when two tasks are performed concurrently, there may be a decline in performance in one or both of the tasks (Dault et al., 2003). In the Motion_NOSIM trials, participants were required to complete one task only; balance maintenance. With the addition of the vigilance task, participants could no longer just focus on balance; they were now required to simultaneously scan the surrounding environment to find objects in the water. During the Motion_SIM trial, it appears as though there were not sufficient attentional resources available to perform the required tasks (cognitive and balance) simultaneously. With the addition of the SAR task, a decline in postural control was seen. Previous literature, examining the effect of vigilance task performance on postural control, has found similar results. Several studies have demonstrated that postural sway increases (decline in postural control) when performing a concurrent cognitive task (Andersson et al., 1998; Shumway-Cook et al., 1997; Shumway-Cook & Woollacott, 2000; Yardley et al., 1999). Also, previous studies have demonstrated that when balance is challenged, performance on cognitive tasks degrades (Andersson et al. , 2002; Mitra & Fraizer, 2004; Pellecchia, 2003; Riley et al., 2003). The findings across these studies demonstrated that participants performed better when postural control was relatively easy (i.e. sitting or standing with feet shoulder width apart and eyes open), or the cognitive task was easy (i.e. easy mental math or few items to remember). The observed decline in performance was suggested to be due to cognitive interference, caused by competing demands for attentional resources (Dault et al., 2003).

It is also important to note that the SAR task employed in the current study was multifaceted. To perform the task correctly, the participant had to search for an object visually, mentally comprehend what the object was and then verbally articulate the answer to the researcher. Therefore, there were many factors that came into play when trying to understand the tasks influence on postural control. The importance of vision to postural control is very well documented (Andersson et al., 2002; Nashner, Shupert, Horak, & Black, 1989; Woollacott, Shumway-Cook, & Nashner, 1986). Hunter and Hoffman (2001) state that postural stability decreases when there is a loss of visual input, or in conditions that alter the quality or type of visual input. It has also been shown that variability in postural sway decreased when looking at nearby objects as opposed to distant objects (Lee & Lishman, 1975; Stoffregen, Hettinger, Haas, Roe, & Smart, 2000). Participants in the current study were examining targets at various locations and distances from their central point of reference. Stoffregen et al. (2000) found that postural sway was reduced when performing a visual search task compared to an inspection task. They suggest that postural sway decreased to facilitate the visual search. While the current study did not examine postural sway, the Stoffregen et al. (2000) study is of interest as it clearly indicates that performance of a visual search task can impact postural control. Verbally articulating the responses to the researcher may have also had an impact on postural control. Yardley et al. (1999) examined the idea that changes in postural sway seen in dual tasks studies may partly be due to the articulation of the task. The results indicated that sway path only increased when participants were asked to perform an articulation task, and not during a silent task. The production of speech requires the coordination between articulatory and respiratory processes (Conrad & Schönle, 1979). The duration of expiration during speech is approximately ten times longer than during quiet respiration, producing changes in respiration patterns, which in return can produce changes in postural control (Conrad & Schönle, 1979). Based on these finding it is possible that the articulation required by participants to report objects in their field of view may have contributed to the increased postural control difficulties experience in the Motion_SIM trial. It is challenging, however, to draw direct comparison between this and the previous articulation based research, as the previous research has all focused on the effect of articulation on postural sway in a non-moving environment. Given the extreme nature of the perturbations experienced in the present study, it is unlikely that small alterations in postural sway, caused by respiration-related effects on postural sway, would have a vast impact on balance. As such, the two components that likely added to the attentional competition were vision and comprehension. The participants had to scan their environment, therefore moving their head and no longer focusing on a fixed reference point as they may have done in Motion_NOSIM. Once objects were spotted on the screen, participants then had to process the information that was coming and try to identify the object correctly. Therefore, they were now mentally focusing on something other than postural control. This comprehension and identification was to be completed in a fairly quick amount of time as they had other objects to search for in the water.

The results of this study provide further evidence of the fact that postural control and cognitive functioning are not independent systems. The potential implications of an increased step count and increased muscle activity when adding a vigilance task to a postural control task are the increased risk of falling and/ or fatigue. Horak (2006) states that falls can result from insufficient cognitive processing to control posture while occupied with a secondary vigilance task, and the mechanism behind a fall is described as an imbalance (slips, trips, etc.) with a failure to recover equilibrium. In most cases, falls occur from an inability of the individual to adapt to the environmental conditions (Hanson, Redfern, & Mazumdar, 1999). While no falls took place in this study, individuals were clearly at increased risk of falling.

4.7.1 Limitations

When interpreting the results from the current study, the following should be considered: all participants in the data collection had no prior experience with motion simulators, working in a marine environment and to performing SAR tasks. Experienced SAR personnel may have employed advanced search techniques and may have developed compensatory mechanisms to maintain postural control

4.8 CONCLUSION

The following conclusions can be made from the results of the current study:

1. The addition of a SAR task to a demanding postural control task lead to increased levels of lower limb muscle activation across the lower limb muscles examined and increased number of steps taken
2. The current study was completed with young, healthy, naïve participants; future research should utilize experienced subject matter experts (SAR personnel) to see if the same trends would be identified.
3. It is important to note that the SAR task employed in the current study was multifaceted. Therefore, it is difficult to precisely identify the one factor that had the greatest influence on the competition for attentional resources.

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CHAPTER 5: OVERVIEW AND CONCLUSION

5.1 INTRODUCTION

The purpose of the current research project was to examine how individuals respond when working in a moving environment. Research in this field is needed to better understand how individuals perform vocational and daily living activities in moving environments. The information discovered can assist safety and industry personnel, along with human factor specialists, in providing safe work environments for individuals working at sea.

Two separate research questions were investigated. The first question examined how a SAR task is affected by varying magnitudes of sea states. The results of this study indicated that as the magnitude of the simulated sea state increased, SAR task performance decreased. When participants were exposed to high magnitude, ecologically valid, platform motions, the percentage of correctly identified targets decreased with a concurrent increase in the percentage of missed targets. Whereas, for research question number two, postural control of participants was examined while they performed a SAR task in a moving environment. The results indicate that participants exhibited increased levels of lower limb muscle activation and took more steps when completing the SAR task on the moving platform, compared to when there was no SAR task being performed. While both studies investigated different hypotheses, both suggest that there was competition for attentional resources between vigilance and postural control in young, healthy adults, in a moving environment. Participants found it more difficult to accurately perform a SAR task when balance was challenged (research question 1), and found it more difficult to maintain balance when completing the SAR task (research question 2).

This master's thesis tested the following hypotheses:

Hypothesis 1: Performance of a SAR task will decline (decrease in number of objects correctly identified, increase in number of errors committed) when conducted in a simulated moving environment. The alternative hypothesis can be accepted.

Hypothesis 2: Postural control will be challenged when a SAR task is performed in a simulated moving environment. This will be evidenced by an increase in lower limb muscle activation and number of change in support reactions observed. The alternative hypothesis can be accepted.

While the results of these two studies add to both the human factors and postural control literature, they also add new insight into the effect of dual task performance on postural control. Andersson et al. (2002) stated that any negative change in performance on either of the tasks performed in a dual-task study indicates a dual-task effect; there is a competition for central processing resources. The results from these two studies identified that both SAR task performance and postural control were negatively impacted. However, it cannot be definitively identified from this study if the SAR task negatively affected postural control or postural control negatively affected the SAR task. The results do, however, add to the existing body of literature examining the dual-task paradigm. Much of the literature has examined one-dimensional secondary tasks in both stable (Andersson et al., 2002; Mitra & Fraizer, 2004; Pellecchia, 2003; Riley et al., 2003) and moving environments (Yu et al., 2010a; 2010b; Hickey, 2016). Whereas, the current studies were unique in that both employed a complex task (SAR task) which placed demands on multiple different cognitive pathways. The SAR task was a multifaceted task. In order for it to be performed correctly, the participant had to visually search, mentally comprehend, and verbally articulate the answer to the researcher. It was loosely based on situational awareness (SA), where SA is the ability to identify, process and comprehend the critical elements of information about what is happening around you (United States Coast Guard, 1998).

Endsley (1995) provides a hierarchical model of SA which has three main elements: Level 1 SA: perception; Level 2 SA: comprehension; and Level 3 SA: projection. Perception (level 1 SA) implies that the work environment should be continually monitored for sensory information and detect changes in stimuli (Sneddon, Mearns, & Flin, 2006). Perception can be seen as the building block of SA (Sneddon et al., 2006). To achieve high SA, the operator must first perceive the relevant elements in the environment. Accurate perception of the environment requires a high level of concentration, attention to detail, and vigilance. If external factors (i.e. motion) negatively influence perception, SA is compromised, and critical elements may be missed or ignored (Sneddon et al., 2006; United States Coast Guard, 1998). Comprehension (level 2 SA) involves the interpretation, storage and retention of the incoming information to form a picture of the situation/objects/events (Sneddon et al., 2006). Projection (level 3 SA) occurs as a result of the combination of levels 1 and 2. It is the ability to use information from the environment to predict possible future circumstances and/or events. Correctly identifying possible future circumstances is vital in allowing the best decision to be made regarding appropriate courses of action to take to meet goals. Using this SA paradigm to better understand SAR performance highlights the complexity of the task.

If we break the SAR task into components, the first component is vigilance (SA: perception). The importance of vision to postural control has been very well documented (Andersson et al., 2002; Nashner et al., 1989; Woollacott et al., 1986). Postural stability decreases when there is a loss of visual input, or in conditions that alter the quality or type of visual input (Hunter and Hoffman, 2001). It has also been shown that variability in postural sway decreases when looking at nearby objects as opposed to distant objects (Lee & Lishman, 1975; Stoffregen et al., 2000). For the current studies, participants examined targets at various locations and distances from their central point of reference. The results from these studies add to the literature in that postural control decreased when the type of visual input was altered. Throughout the five-minute trial, the visual input (scenery) was constantly changing as the participants were searching for objects in the water. Additionally, the results potentially add to Lee & Lishman (1975) and Stoffregen et al. (2000) findings that postural sway decreases when targets were closer as opposed to more distant. The objects in the water varied in visual distance from the participant. Some of the objects were visually closer and "easier" to see, whereas others were visually farther away and more "difficult" to locate. However, it is difficult to say definitively that this factor affected postural sway as the effect of target distance from the participant was not analyzed.

The second component of the SAR task was comprehension; the participant had to correctly identify the object they saw in the water. It was found that the number of correctly identified objects decreased as motion increased, which is similar to Andersson et al. (2002) findings. They found a similar negative effect in that the performance of a silent mental arithmetic task (counting backward in multiples of seven) was impaired when balance was perturbed by stimulation of the calf muscles. However, the current results contradict Vuillerme et al. (2000) findings. They found that center of pressure (COP) displacements decreased during and after performing a secondary reaction time (RT) task. The RT task was to verbally indicate the LED colour (either red or green) as fast as possible. However, comparison of results of the current study to those of Vuillerme et al. (2000) are difficult to make because their study was completed in a stable environment.

Verbal articulation was the final component of the SAR task; this is similar to the SA projection level. In the Vuillerme et al. (2000) study, they discussed that verbal articulation of responses to the researcher may have had an impact on postural control. Similarly, Yardley et al. (1999) indicated that sway path increased when participants were asked to perform an articulation task, and not during a silent task. The production of speech requires the coordination between articulatory and respiratory processes (Conrad & Schönle, 1979). The duration of expiration during speech is approximately ten times longer than during quiet respiration, producing changes in respiration patterns, which in return can produce changes in postural control (Conrad & Schönle, 1979). Based on these findings, it is possible that the articulation required by participants in the current study may have contributed to the increased postural control difficulties experienced in the Motion_SIM trial. However, it is difficult to draw direct comparisons between this study and previous articulation-based literature, as the previous research has all focused on the effect of articulation on postural sway in a non-moving environment. Given the extreme nature of the perturbations experienced in the present study, it is unlikely that small alterations in postural sway, caused by respiration-related effects on postural sway, would have an impact on postural control.

The complexity of both postural control and the SAR task employed in the current study make it challenging to draw direct comparisons to previous dual-task literature. The literature already presents several discrepancies due, in part, to the numerous types of cognitive tasks and postural stance positions employed (Dault et al., 2001; Mitra & Fraizer, 2004). However, the results of this study provide further evidence of the fact that postural control and cognitive functioning are not independent systems. It appears that there is a limit for attentional capacity and that both posture and a cognitive task cannot be performed optimally at the same time. That the dual-task effect is present and that there is a competition for central processing resources.

5.2 FUTURE DIRECTIONS

The current research has indicated the potential of a dual-task effect occurring between posture and a concurrent secondary task (SAR task). Given the complexity of the SAR task examined, it is difficult to precisely identify the one factor that had the greatest influence on the competition for attentional resources. Future research should consider breaking down the complex task into its components (vigilance, comprehension, verbal articulation) in an effort to see if there is one particular aspect of the task that contributes to the task performance and balance deficits observed. As well, future research should utilize experienced subject matter experts (SAR personal) to see if similar trends would be identified.

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