The effect of repeated exposure to a simulated moving environment on lower limb muscle co-contraction and balance.

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ABSTRACT

The use of 6 Degrees of Freedom motion platforms to induce habituation to offshore motions is a relatively new area of study. One of the biggest challenges is assessing and determining the effectiveness of the training. This is assessed by measuring muscle activity of postural control muscles in the lower limb by analyzing changes in total muscle activity over the course of a trial or using an equation to compare co-contraction between muscle pairs, termed the co-contraction index (CCI). These techniques combined allow researchers to draw conclusions regarding the use of habituation as a preventative intervention to workplace injuries that may occur in offshore environments.

The purpose of the present study was to examine changes in lower limb muscle activity and interpret the effectiveness of implementing varied motion profiles on an individual's ability to habituate to these environments.

Participants, with no previous experience in moving environments, were exposed to a total of 9, 5-minute trials of simulated motion, performed on a 6 degrees of freedom motion simulator. During trials 1, 8 and 9, muscle activation and video data were recorded. The remaining 6 trials consisted of varied motion sequences and were considered the habituation trials. Results indicated decreased total muscle activation, CCI and total number of steps taken values from pre-habituation to post-habituation trials. There were no significant changes between pre-habituation and retention trials, which were completed no longer than 48 hours after the habituation session. This indicates that longer-term effects did not occur. Frequency analysis of electromyographic data indicates there was no effect of fatigue from pre to post-habituation trials. The decrease in muscle activity seen can be indicative of decreased energy cost during postural control tasks. It is possible that this may lead to a decrease in the onset of fatigue and subsequently injury risk in maritime occupations.

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LIST OF ABBREVIATIONS AND SYMBOLS

A/P - Anterior/Posterior Direction
ANOVA – Analysis of Variance
BoS – Base of Support
CIS – Change in Support
CoM – Centre of Mass
CoP – Centre of Pressure
CCI - Co Contraction Index
DOF - Degrees of Freedom
EMG - Electromyography
iEMG - Integrated Electromyography
M/L - Medial/Lateral Direction
MIF - Motion Induced Fatigue
MII - Motion Induced Interruption
MVC - Maximum Voluntary Contraction
PRE - Pre-Habituation Data
POST - Post-Habituation Data
RET - Retention Trial after completion of Habituation Trials

Chapter 1 : INTRODUCTION

In Newfoundland and Labrador, offshore industries are major contributors to the economy. In 2017, over 5200 people were employed in the offshore oil industry, both in land-based construction and offshore operations (Advance 2030, 2018). Additionally, the number of people employed as fish harvesters was over 9000 in the same year (Professional Fish Harvesters Certification Board, 2017). Individuals employed in offshore industries such as these are subjected to working conditions which pose challenges to balance, including unfavorable, unpredictable weather or sea conditions in North Atlantic waters.

Increased challenges to balance are mitigated with a variety of postural control strategies which incorporate musculature surrounding the ankle, knee and hip joints. Occasionally, individuals may take steps in order to remain upright. Such reactions are termed change in support (CIS) strategies (Maki & McIlroy, 1997). Muscle activity in the lower limbs has also shown to be higher with the initial onset of motion compared to later trials or with experience in balance rich activities, as measured using electromyography (EMG) (Duncan, Ingram, Mansfield, Byrne & McIlroy, 2016; Ingram, Duncan, Mansfield, Byrne & McIlroy, 2016). The need for coordinated postural responses can lead to increased instability and an increase in energy consumption, which can result in increased fatigue for individuals employed in these fields (Duncan, MacKinnon, Marais & Basset, 2018). Previous research has indicated that falls account of 16% of all workplace injuries, while overexertion is the most common cause of workplace injury at 31% (Kumar, 2001).

It has been established that individuals with previous exposure to balance challenging tasks, such as direct experience in maritime environments, motion simulation experience or through balance-demanding tasks, such as dance, take less steps during motion than individuals who are naïve to such environments (Duncan et al., 2016; Ingram et al., 2016). Repeated exposure to stimuli that challenge balance, such as the tasks in motion-rich or offshore environments, can also be termed habituation. Prior research (Duncan et al., 2016) has established that individuals who engage in habituation, accomplished using identical motion profiles in subsequent trials, can decrease the number of CIS strategies implemented in order to remain upright.

This thesis consists of a secondary analysis of data that was collected from a previous study that focused on the effects of habituation to simulated wave motion on joint kinematics and kinetics. The present study extends this work, to determine the effect of exposure to simulated wave motion on the amount of muscle activity and CIS strategies employed by individuals in order to remain upright. While other studies (Duncan et al., 2016; Duncan et al., 2018b; Ingram et al., 2016, Schinkel-Ivy & Duncan, 2018) have examined the effect of repeated exposure to simulated wave motion on both muscle activation and postural responses, most of the previous studies have exposed participants to a series of identical trials. The present study is unique in that it will use a variety of motion trials to assess the impact of habitation on the above variables. For the purpose of this thesis, these non-identical exposure trials will be referred to as "varied motion profiles". As such, the proposed study aims to answer the following research questions:

1. *What impact does habituation to motion on a moving platform have on postural responses (i.e. number of steps taken) in a naïve population?*

2. *What impact does habituation to motion on a moving platform have on lower-limb muscle activation amplitude, co-contraction, and frequency content?*
3. *If habituation does occur, is there any carryover of these effects up to 48 hours following initial testing?*

It is hypothesized that with experience of varied motion profiles, the amount of co-contraction present in lower limb muscle pairings will decrease as will the overall amplitude of EMG. Similarly, the number of steps taken by participants in order to maintain balance, will be reduced. Collectively, these changes are indicative of improved balance. The amount of co-contraction was measured using the Co-Contraction Index (CCI) as previously employed by Schinkel-Ivy & Duncan (2018). The assessment of performance using CCI and EMG was reflective of an individual's ability to maintain balance in a moving environment.

Chapter 2 : REVIEW OF LITERATURE

The literature review will examine how individuals maintain postural control in stable and moving environments. It will also examine how muscle activation is altered in moving environments and the literature that currently exists related to habituation to moving environments.

The body is a system which is inherently unstable due to forces acting upon it. These forces include gravity or those which arise from movement of the body and interaction with the environment (Maki & McIlroy, 1997). For example, walking on an empty sidewalk versus a crowded sidewalk pose different challenges to balance. On a crowded sidewalk, one must continuously be aware of obstacles in their path of travel. While navigating these obstacles can prove difficult, environments which are unstable in nature pose a different set of challenges to balance due to the random nature of perturbations they create. For example, balancing while standing on a bus as the driver swerves to avoid a pothole or standing upright on a boat in adverse weather conditions would be considerably more challenging then walking on a crowded sidewalk, as the perturbation would be more random and difficult to predict. These more random, unpredictable perturbations require coordinated postural responses in order to remain upright. Such perturbations can be imposed by weather conditions or obstacles in the path of a vehicle.

Postural control strategies are implemented to oppose forces acting upon the body, in order to ensure stability and maintenance of upright stance and can include keeping the feet in place, or free movement of the feet and other limbs. Most postural control strategies require activation of musculature surrounding ankle, knee and hip joints. As a result, this activation of lower limb muscles can induce muscle co-contraction (Granata et al., 2004). The increased activity and co-contraction of muscles surrounding the ankle, knee and hip is likely one of the reasons why previous research has shown that tasks involving maintenance of upright stance in moving environments have increased energy consumption (Duncan et al., 2018a).

Previous research has concluded that individuals with prior exposure to moving environments (such as maritime experience or motion simulation experience), take fewer steps during simulated wave motion trials, than individuals who are naïve to moving environments (Duncan et al., 2016; Ingram et al., 2016). Individuals who have gained balance experience through activities where balance is essential, such as dance, have also been shown to take fewer steps during simulated wave motion (Duncan et al., 2016; Ingram et al., 2016). While dancers have an increased affinity for postural control, they take fewer steps when encountering perturbations than naïve individuals, but more than those with more specific experience to the perturbations incurred, including those experienced in working or living in maritime environments (Duncan, Langlois, Albert & MacKinnon, 2014).

Based on the literature above it is clear that habituation to a moving environment enables individuals to maintain postural control while taking fewer steps and exhibiting less center of mass (CoM) movement (Duncan et al., 2014). Regular participation in balance-related activities and habituation to moving environments could help improve balance throughout activities of daily living and therefore reduce the risk of trips and falls in moving environments. Less is known about the impact of habituation on muscle activation and co-contraction of lower limb muscles in moving environments. Similarly, relatively little is known about the retention of any learning that may take place during shorter term habituation, as may be experience during exposure to a simulated moving environment. Research examining changes in lower limb muscle activity and co-contraction is needed in order to determine if exposure to offshore motions, whether simulated or real, could reduce injury rates from falls and overexertion in those employed in the offshore. The proposed study subjected participants to repeated motion on a 6 degrees-of-freedom motion platform to determine what, if any effect, repeated exposure to balance-demanding tasks has on lower limb muscle activation and balance. In addition, the research examined whether or not any habituation that did occur was retained at least 48 hours following the last exposure to the simulated motion. It is important to understand lower limb muscle activity and co-contraction and how they change over time with repeated exposure to simulated motion, in order to prepare individuals to overcome unpredictable, random and variable magnitude perturbations which challenge balance.

2.1 Maintenance of Upright Stance in Stable Environments

Maintenance of upright stance has been modelled as an inverted pendulum where the ankles serve as the axis of rotation (Winter, 1995). It is often quantified using center of pressure (CoP) measurements that are recorded using a force plate. The CoP is the location of the ground reaction force, which is equal and opposite to all downward forces acting on the body (Winter, 1996). Shifts in the CoP are controlled by musculature of the lower limb and are generated to ensure the body’s CoM remains inside the base of support (BoS) which is comprised of the feet and their position (Winter, 1995). For example, if an individual is standing with the feet approximately shoulder width apart, the base of support is considerably wider than if the individual was placed in tandem stance (Winter, 1996).

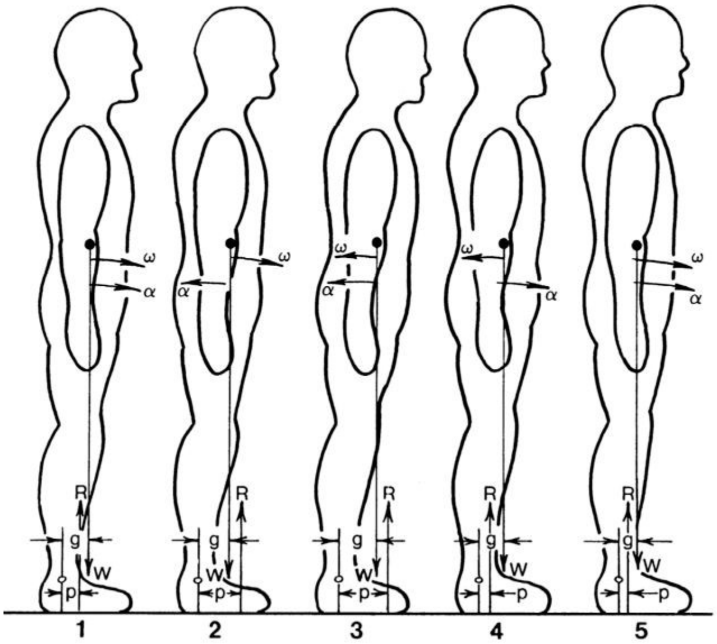

Figure 2.1: An individual in quiet stance during balance. The body acts as an inverted pendulum during upright stance. Angular velocity is created to oppose anterior/posterior shifts in balance to ensure the individual remains upright (Winter, 1995).

When balance is perturbed there are three main strategies implemented to maintain upright stance. The ankle and hip strategies require the feet to stay in one position and are termed fixed support strategies. The ankle and hip strategies are implemented by muscles surrounding the ankles or the hips to shift the CoM so that it stays within the given BoS. The last balance strategy is characterized by responses that include steps or grasping motions to extend the BoS to accommodate shifts in the CoM (Maki & McIlroy, 1997). All balance reactions coordinate to result in successful maintenance of upright stance in both stable and moving environments.

2.1.1 *Ankle Strategy*

When using the ankle strategy, plantarflexion, dorsiflexion, inversion and eversion of the ankle are used to control the bodies CoM in both anterior/posterior (A/P) and medial/lateral (M/L) directions (Winter, 1995). The muscles controlling A/P and M/L shifts about the ankle are small, therefore they tend to generate relatively small movements and thus smaller shifts in the CoP (Winter, 1995). The relationship between the CoP relative to the CoM can be used to illustrate the inverted pendulum model, which assumes the body to be an inverted pendulum that pivots about the ankle joint (Winter, 1995). For example, when anterior shifts of the CoM occur, ankle plantarflexor activity increases which causes an anterior shift of the CoP ahead of the CoM position. By shifting the CoP position ahead of the CoM, the acceleration which moves the body forward is decreased to restore equilibrium. The reverse will occur if a posterior shift of the CoM needs to be corrected (Winter, 1996). When excursions of the CoP are too large to be controlled by ankle musculature, control of balance may shift to the hip joint due to its ability to generate larger shifts of the CoM to restore balance (Winter, 1995).

2.1.2 *Hip Strategy*

A combination of hip flexors, extensors, adductors and abductors are activated when an individual uses a hip balance strategy (Winter, 1995). The hip strategy can be more efficient at shifting the CoM so that it remains within the base of support because it increases the magnitude of those shifts (Winter, 1995). For example, flexion of the hip serves to move the CoM posterior while extension shifts the CoM anterior (Winter, 1995). The shifts in CoM position created using the hip fixed support strategy are greater than those induced by ankle plantarflexion and dorsiflexion. Hip adductors and abductors serve to transfer the distribution of weight from both feet to either the left or the right, termed hip “loading” and “unloading.” Transferring of weight lifts the pelvis and increases the amount of vertical force applied to either the left or right limb, while decreasing the vertical force by the same amount on the contralateral limb (Winter, 1996).

2.1.3 *Change in Support Strategy*

A change-in-support strategy (CIS) is characterized by reactions such as stepping and grasping to change the size of the base of support in an effort to keep the CoM with the BoS (Maki & McIlroy, 1997). While it was once thought that CIS strategies were reserved for very large perturbations, it is now recognized that they are often initiated before the CoM reaches the stability limits of the BoS (Maki & McIlroy, 1997). CIS reactions can be difficult to implement because they require coordinated motion of both lower and upper extremities. For example, hand holds or surfaces that are graspable are not always present or can be restricted in their size and location (Maki & McIlroy, 1997). Compensatory stepping reactions are targeted toward the ground, which tends to remain relatively level and predictable. However, in situations such as perturbed stance or maintenance of stance in moving environments, compensatory stepping reactions require increased amounts of planning and coordination, increasing the difficulty of the reaction (Maki & McIlroy, 1997). When stepping is involved, the postural adjustment can further perturb balance of the individual. Lateral balance is lost when standing on one leg, for example, and this is an adverse effect of implementation of a change in support strategy.

Any combination of these postural control strategies can be employed in response to a perturbation. Perturbations can be encountered in a variety of settings, from walking on a crowded sidewalk to working or living in a maritime environment. Individuals learn to adapt to the demands of their environment and will adjust postural control strategies to suit their needs.

2.2 Maintenance of Upright Stance in Moving Environments

Some activities of daily living require exposure to moving environments where balance is required. For example, standing on a bus, subway, ship or sailboat prove more difficult than remaining seated in such environments or standing on stable ground. When busses or subways rapidly change direction or grind to a halt, inertia causes individuals to continue in the direction, often resulting in shifts of the CoM and necessitating the use of a change in support strategy to widen the BoS and retain the falling CoM. The same holds true for occupations at sea, such as deckhands on fishing vessels, welders on oil rigs or those who are responsible for navigation onboard vessels. In addition to the increased balance challenges created by offshore environments (Lajoie, Teasdale, Bard & Fleury, 1993) occupations such as fishing often require workers to maintain balance while performing a work-related task, like lifting or lowering loads. Dual tasking has been shown to increase forces acting on joints and result in increased risk for musculoskeletal injury (Kingma, Delleman & Van Dieen, 2003; Torner et al., 1988).

In motion rich environments, an individual's CoM is accelerated, resulting in a disturbance of balance (Duncan, MacKinnon, Albert & Antle, 2007). The onset of postural control strategies is often marked by large muscle activations and joint accelerations (Duncan et al., 2007). The activations of lower limb muscles are significantly larger during initial exposure to moving environments than in later trials (Duncan, Ingram, Mansfield, McIlroy & Byrne, 2018b). Similarly, individuals tend to spend more time implementing change in support strategies during initial exposure, and the increased number of steps taken relates to the increase in lower limb muscle activation observed (Duncan et al., 2016; Duncan et al., 2018b). Postural control strategies such as the ankle strategy involve larger contributions of ankle musculature in order to induce postural corrections and maintain balance (Horak & Nashner, 1986).

In some instances, the CoM accelerations experienced by individuals in offshore environments are too large to overcome, resulting in the abandonment of a secondary task in favor of stance maintenance. These interruptions in secondary task performance are often referred to as motion induced interruptions (MII) (Crossland & Rich, 1998). These MIIs are marked by the presence of stumbling (i.e. a change in support strategy) and/or sliding or lift off due to a momentary loss of stability due to unexpected perturbations (Duncan, MacKinnon & Albert, 2013). The rate of MII occurrence increases when the severity of motion increases (Duncan, MacKinnon & Albert, 2010). Individuals tend to take more steps in order to remain upright when motion of the environment is more severe (Duncan et al., 2016).

2.3 Habituation to Moving Environments

With repeated exposure to moving environments, individuals tend to implement change in support strategies in anticipation of a perturbation. The anticipatory control of balance serves to minimize destabilization caused by perturbations by voluntarily initiating a change in support strategy (Maki & McIlroy, 1997). For example, repeated or prolonged exposure to moving environments will result in less MII's than if an individual had not experienced a moving environment before (Duncan et al., 2016). The decrease in MII's is known as skill learning, where participants develop a skill to repeatedly overcome threats to balance (Duncan et al., 2016). Balance skills transferrable to moving environments can also be obtained in other ways. For example, recreational or professional activities such as dancing often challenge balance and these skills have shown to be transferrable to moving environments (Duncan et al., 2018b, Duncan et al., 2016).

The transferability of balance skills has been examined in two previous studies (Duncan et al., 2016; Ingram et al., 2016). In one of these studies, balance reactions were examined in three groups: individuals without any prior experience to motion simulated environments, formally trained dancers, and individuals with experience in marine environments. The authors found that the time spent implementing CIS strategies differed between these groups. The experienced maritime workers and individuals naïve to offshore motions exhibited low and high use of CIS strategies, respectively. Of interest for the present study was the fact that the formally trained dancers, who had no previous maritime experience, employed balance strategies that were more like the experienced workers than naïve individuals (Duncan et al., 2016). The authors suggested this was indicative of the dancers' ability to implement postural control strategies based on previous experiences, even if prior experience was not similar to offshore motion (Duncan et al., 2016). The same trend was found in a study by Ingram et al. (2016), however in this case participants prior experience consisted of at least one previous exposure to a simulated wave motion experiment. Individuals who had previously been exposed to nautical motions using a motion simulator were found to spend less time implementing CIS responses than those who were trained in dance or naïve to the balance tasks required (Ingram et al., 2016). The work of both Ingram et al. (2016) and Duncan et al. (2016) indicate that choice of postural response appears to be dependent on previous experience, suggesting that specificity of training impacts successful completion of the task. Previous experience in moving environments can significantly influence performance of tasks in unstable environments as it appears to aid in the development of anticipatory gains and control in response to perturbations (Duncan et al., 2016).

Previous research (see Mansfield et al., 2007; Duncan et al., 2014; Duncan et al., 2016; Ingram et al., 2016; Schinkel-Ivy & Duncan, 2018) has examined the number of steps taken as a means to quantify one's ability to remain upright. Thus, this type of analysis can provide considerable insight in to the postural control strategies required to maintain stability in an unstable environment, Greater understanding of the specific strategies implemented to maintain postural control in moving environments would occur using a detailed analysis of lower limb muscle activation. The present study will primarily focus on lower limb muscle activation during stance in moving environments. Literature in this area will now be reviewed in detail.

2.4 Muscle Activity in Moving Environments

Lower limb muscle activity in unstable environments has generally been shown to increase in comparison to the muscle activation required in stabile environments (Duncan, et al., 2018b). In particular, muscles of the ankles, knees, hips, lower back and trunk are most often affected by the onset of perturbation, likely due to the fact that these joints are used to maintain stability and upright posture (Torner, Almstrom, Karlsson & Kadefors, 1994). As was reviewed above, relating to postural control strategies, there is also evidence that muscle activation amplitudes change as habituation occurs. For example Duncan et al., (2018b) reported that after exposure to several 5-minute trials of simulated wave motion lower limb muscle activity (particularly in musculature surrounding the ankle joint) decreased somewhat. It is important to note, however, that activation still remained elevated compared to the muscle activity required when maintaining upright stance in a stable environment. The decrease in lower limb muscle activity suggests that individuals become habituated to the environment and perturbations encountered, resulting in alterations of postural control strategies. Work by Schinkel-Ivy and Duncan (2018) and Ingram et al. (2016) has also provided evidence of the impact of habituation on muscle activation. Schinkel-Ivy and Duncan (2018) found that both experienced and novice participants exhibited decreased co-contraction of lower limb muscles after completing five, 5-minute motion exposure trials on the same day. While the focus of Ingram et al. (2016) was on the effect of previous balance intense activities on motion simulator performance, their results also indicated a reduction in overall muscle activation amplitude in the naïve, dance trained and motion simulation experienced groups, following exposure to 5 identical motion simulator trials.

The findings of Duncan et al. (2018b), Ingram et al. (2016) and Schinkel-Ivy & Duncan (2018) indicate decreases in lower limb muscle activity can be interpreted as habituation to offshore motion. There have been no studies, to date, that have examined at what, if any type of retention there is of the habituation to such motions. The retention of postural control strategies is important, as it would be indicative of some longer-term change in balance behaviour that may translate to an offshore working environment. These longer-term changes in muscle activation are important as higher levels of muscle activation can contribute to motion induced fatigue (MIF) (Duncan et al., 2018a; Wertheim, 1998). Although not specifically shown in moving environments, previous research has shown that fatigue is associated with a loss of productivity, increased injury rates and higher number of human factors errors (Drowatzky & Drowatzky, 1999; Rosa, 1995). Research examining the effectiveness of habituation at producing longer term reductions in lower limb muscle activation has potential implications from a human factors and ergonomics perspective. The present study aims to identify the effects of repeated exposure to a simulated moving environment on lower limb muscle activity, changes in postural control strategies and if these effects of habituation are retained. If repeated exposure to maritime motion proves to enhance balance and lower total muscle activity and the retention of those changes occur, motion-simulated habituation can be further considered as a method of maritime pre-employment training to ensure individuals are ready for continuous exposure to such perturbations. As lower limb muscle activation will be used as a key outcome measure in this study, a brief review of electromyography analysis techniques frequently used in this type of research is presented below.

2.5 Electromyographic Data Analysis Techniques

Analysis of EMG data can be completed in several ways. For example, changes in muscle activation amplitude can be assessed using integrated or root mean square EMG, frequency analysis of EMG data can assess effects of fatigue, the amount of co-contraction present between muscle pairs can be determined and muscle activation timing can be assessed (Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2013). Previous studies examining muscle activation in moving environments have used normalized EMG amplitudes to determine the magnitude of muscle activation in a given trial (Duncan et al., 2018b). Integrated EMG (iEMG) has been used to examine the total activation of a muscle over a period of time. For example, a study examining the effect of anxiety on postural response placed individuals at varying heights either close to the edge of the step or further away from it and required them to complete a voluntary rise to toes task, where participants plantarflexed when instructed (Adkin, Frank, Carpenter & Peysar, 2002). The researchers used integrated EMG to determine the total muscle activation for a period of 250ms after the earliest onset muscle activity (Adkin, et al., 2002).

As it is also possible that some of the muscle activation changes observed following multi-trial exposure to motion trials could result from fatigue, the present study also incorporated a frequency analysis of lower limb EMG. The results of this analysis were used to assess muscle fatigue following habituation trials. Previous research examining changes in frequency content of EMG signals indicate that frequency content has been shown to decrease with the onset of fatigue (DeLuca, 1984). To the author's knowledge, no research involving habituation to simulated motions has involved frequency analysis of EMG signals to determine the presence of motion induced fatigue has been completed.

Co-contraction is defined as the simultaneous activation of antagonist muscles which contributes to increased joint stiffness (Rudolph, Axe & Snyder-Mackler, 2000). Previous studies have concluded that co-contraction surrounding the ankle joints increases when participants are instructed to minimize postural sway, inferring that co-contraction and joint stiffness are compensatory strategies to maintain upright stance following perturbations (Nelson-Wong et al., 2012). It is consistent in the literature that older adults have higher prevalence of co-contraction than young adults. Older adults often have difficulty maintaining their balance and, in some instances, can be categorized as at-risk for falls (Nelson-Wong et al., 2012).

The amount of co-contraction is quantified by calculating a ratio between antagonist pairs, also known as a co-contraction index. The co-contraction index, based on the work of Rudolph and colleagues (2000), is calculated using the following equation:

$$CCI = \sum_{i=1}^{N} \left[\left(\frac{EMG_{low_i}}{EMG_{high_i}} \right) (EMG_{high_i} + EMG_{low_i}) \right]$$

Equation 2.1: Co-contraction Index (Rudolph et al., 2000).

Unlike many co-contraction measures, the CCI does not require the assignment of antagonist or agonist roles to the muscles of interest. Instead the EMG_{high} and EMG_{low} variables indicate the muscle in the pair with the highest and lowest level of activation at any given instant in time. This lack of dependence on defining antagonist/agonist roles is important for postural control tasks where the roles of such muscles cannot be clearly identified (Nelson-Wong et al., 2012).

Schinkel-Ivy and Duncan (2018) used the co-contraction index as a method to examine lower limb muscle activity during simulated wave motion trials used to mimic working in a moving environment. Participants in the Schinkel-Ivy & Duncan study had varying amounts of experience in offshore environments and were classified as experienced (at least 6 months maritime work experience) or novice (no maritime work experience). The results of Schinkel-Ivy & Duncan indicate that novice participants had greater CCI values than the experienced group. In addition, as participants became familiar with the perturbations delivered during the study, the CCI decreased over time in both groups (Schinkel-Ivy & Duncan, 2018). One limitation of this study was the fact that the authors did not examine how much (if any) retention of postural control strategies occurred up to 48 hours following the motion habituation trials. In addition, the motion exposure trials that they used were all identical, meaning the perturbations were consistent in direction, magnitude and timing across all trials. Given the random nature of most marine moving environments it is possible that more effective habituation and retention would occur if the habituation trials were more variable. In an effort to address this limitation in the Schinkel-Ivy and Duncan (2018) paper, the present study aimed to replicate the work of these authors, while using varied motion habituation trials and the addition of a retention trial 48 hours post habituation. Specifically, unlike the Schinkel-Ivy & Duncan study, for any given subject, no two habituation trials were the same. As it is also possible that some of the muscle activation changes observed following multi-trial exposure to motion trials could result due to fatigue, the present study also incorporated a frequency analysis of lower limb EMG. The results of this analysis were used to assess for fatigue muscle fatigue following the habituation trials. The results of this study could impact the training individuals receive prior to beginning a career in offshore industry in order to reduce the prevalence of slips, trips, and falls.

2.6 Research Questions

The specific research questions were:

1. What impact does habituation to motion on a moving platform have on postural responses (i.e. number of steps taken) in a naïve population?
2. What impact does repeated exposure to varied, simulated motion trials have on lower limb muscle activation amplitude, co-contraction, and frequency content?
3. If habituation to motion simulation does occur, is there any carryover of these effects up to 48 hours following initial testing?

It is hypothesized that with implementation of a habituation protocol, naive individuals would exhibit better balance (i.e. they would step less), decreases would be observed in co-contraction levels and overall EMG amplitude, with no evidence of changes in the frequency content of the EMG signal. Additionally, it is hypothesized that there will be some carryover of those effects as evidenced by continued reductions in EMG amplitude and co-contraction 48 hours post the habituation session.

Chapter 3 : METHODOLOGY

This thesis consists of a secondary analysis of data that was collected to examine the effects of habituation to simulated wave motion on joint kinematics and kinetics. This thesis extends this work, by examining electromyographic data to examine the impact of simulated motions on muscle activity and postural control strategies employed by individuals in order to remain upright in these environments.

3.1 Participants

Twelve participants (6 male, 6 female) between the ages of 20 – 40 years, with no prior experience working in offshore environments, were recruited. Additional exclusion criteria included: susceptibility to motion sickness, regular participation (i.e. greater than once every six months) in recreational yoga, dance or similar activities that may enhance balance, balance problems, and musculoskeletal injuries or impairments which would prevent them from safely exercising. Data collection occurred on the Challenging Environment Assessment Laboratory's six degrees of freedom (DOF) lab, located at Toronto Rehabilitation Institute in Toronto, Ontario, Canada.

3.2 Electromyography

EMG data was collected using a Noraxon Ultium EMG system (Noraxon, Scottsdale, Arizona USA) at a frequency of 1000 Hz from a total of five lower limb muscles bilaterally. The muscles examined included the following: tibialis anterior (TA), peroneus longus (PL), medial gastrocnemius (MG), vastus lateralis (VL) and the hamstrings (HAM). To reduce noise, the attachment sites for electrodes were shaved to remove hair and swabbed with a rubbing alcohol pad to remove dirt or oil on the skin. Participants then completed maximum voluntary contractions (MVC) for all the muscles listed above, which were done in order to normalize in-trial EMG data to each participant's maximum (Table 3.1). Following EMG preparation and the completion of MVCs, participants completed motion simulation trials.

Table 3.1: Procedure for Maximum Voluntary Contractions of lower limb muscles

Muscle	Procedure
Tibialis Anterior	Participants were asked to sit on a table with their feet not touching the ground. The researcher asked participants to forcefully pull their toes toward their knees. The researcher applied resistance to prevent this motion.
Medial Gastrocnemius	Participants were asked to stand on one foot. The researcher asked participants to plantarflex while the researcher applied resistance by pushing down on the participant's shoulders.
Peroneus Longus	Participants were asked to sit in a long sitting position. The researcher asked participants to forcefully evert their foot against resistance applied by the researcher.
Vastus Lateralis	Participants were asked to sit on a table with their feet not touching the ground. The researcher asked participants to forcefully straighten their knee, pushing as hard as they could. The researcher applied resistance to the lower leg to prevent this motion.
Long-Head Biceps Femoris (Hamstrings)	Participants were asked to sit on a table with their feet not touching the ground. The researcher asked participants to forcefully bend their knee, pushing as hard as they could. The researcher pushed on the lower leg to try and prevent this motion.

3.3 Experimental Setup

All data collection took place on a 5m x 5m Stewart motion platform capable of producing 6 DOF motion. The platform was located in the Challenging Environments Assessment Laboratory at the Toronto Rehabilitation Institute in Toronto, Ontario, Canada. The motion platform was enclosed to limit visual cues from the surrounding stable environment (Duncan, MacKinnon & Albert, 2013).

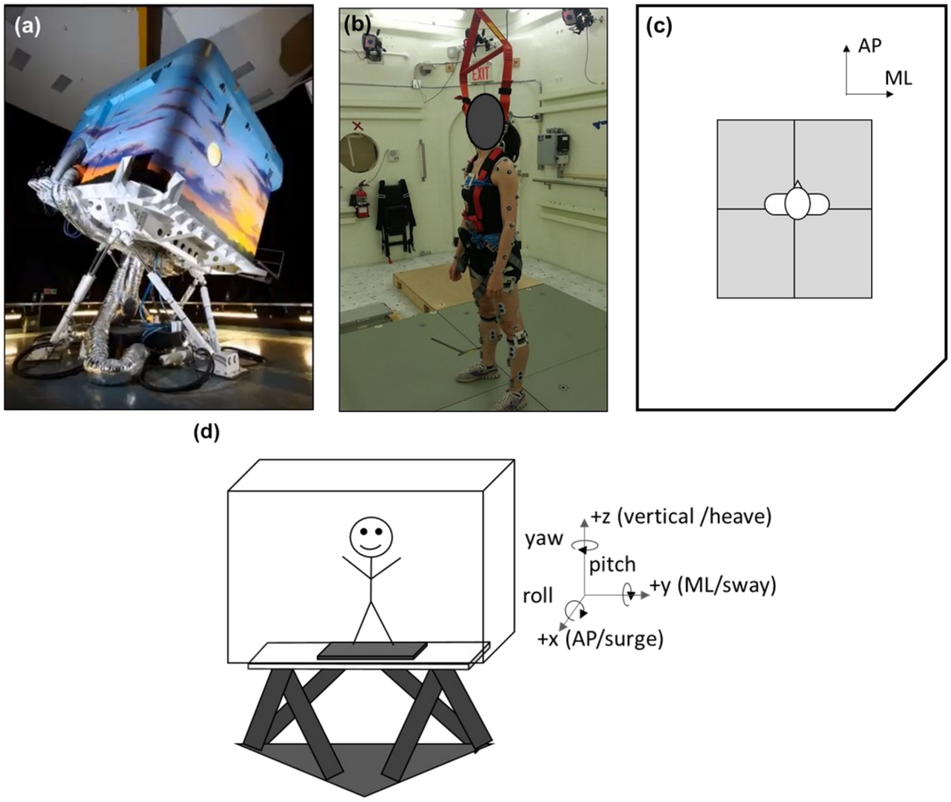

Figure 3.1: Experimental environment. (a) The CEAL: a 5m x 5m laboratory that is secured to a 6 DoF Stewart Platform. (b) Inside the laboratory: a participant stands in the middle of the platform instrumented with motion capture markers and electromyographic data electrodes while wearing a safety harness. (c) Participants stood in the middle of the platform and were unable to reach the walls but were free to move within the 2.4 m x 2.4 x area. (d) Participants always stood facing forward (+x) (C. A. Duncan, personal communication July 31, 2019).

Waveforms used to create the motion of the platform were constructed using linear wave theory based on time series data collected from offshore vessels. Motions during all trials were similar to those incurred on a mid-size commercial fishing vessel in moderate North Atlantic seas and were based upon the linear motion equations outlined by Duncan and colleagues (2015) (Table 3.2)

Table 3.2: Equations used to create platform motion

$\text{Roll} = 0.8(6 \sin (1.050t) + 1.25 \sin (0.11t + 0.5))$
$\text{Pitch} = 0.8(2.5 \sin (1.76t + 0.5) + \sin (t) - 1.5))$
$\text{Heave} = 0.1(5 \sin (1.595t + 2) + 15 \sin (1.21t))$
$\text{Surge} = 0.1(7.8 \sin (0.649t + 4.8) + 7.8 \sin (0.825t + 3.8) + 0.5))$
$\text{Sway} = 0.1 (18 \sin (0.583 t + 5) + 9 \sin (1.122t + 5.4) - 0.25)$

3.4 Protocol

During motion trials, participants were instructed to move their feet whenever necessary to maintain balance, but to return to a shoulder width, toes forward stance when balance was regained. Although the motion platform was capable of producing motions in 6 DOF, only 5 DOF were used (roll, pitch, heave, surge and sway) as per Schinkel-Ivy & Duncan (2018) (Figure 3.2). As yaw is not typically experienced in wave induced motions, it is typically not included in these types of studies. Habituation trials were broken into six, 5-minute motion trials with a 1-minute rest period in between (Table 3.3). Prior to the habituation trials participants were exposed to a 5-minute, 5 DOF motion trial that was used to establish participants baseline response of motion.

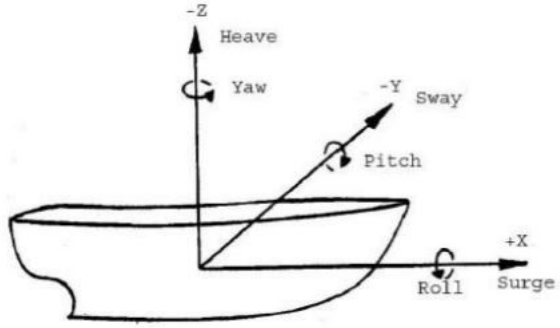

Figure 3.2: Schematic of 6 DoF ship motions

Six habituation trials followed, involving exposure to a variety of motions. The order of which these motions were presented was identical for all participants (Table 3.2). The Pre- and Post-habituation trials consisted of the same motion profile and were used to examine the potential effects of habituation and learning on balance and lower limb muscle activation. The habituation trials began with two trials of unidirectional motion (one pure pitch and one pure roll). This was followed by one trial combining pitch and roll motions at half magnitude. Next, a trial of 5DOF motion at half intensity was administered, followed by another trial of pitch and roll motions (delivered at full magnitude with 10% less frequency). The last habituation trial consisted of 5 DOF motions delivered at full magnitude and 10% less frequency. 48-hours after completion of this session, participants returned to the lab, were prepared for EMG in the same way as the previous session and completed one, 5-minute retention trial using 5 DOF motion, similar in magnitude but different from PRE-POST testing trials. During all motion trials, EMG was collected for the full duration of the trial. A video camera also captured participant motion during the trial. These videos were used to quantify the number of steps participants took during each of the trials.

Table 3.3: List of trials to explore habituation to wave motions. Each trial was 5 minutes in duration.

Trial Number	Testing Motion Profile	Testing Day
1	Pre-exposure trial (PRE): Full Motion, 5 DoF	1
2	Pure Roll (Full Magnitude)	1
3	Pure Pitch (Full Magnitude)	1
4	Pitch and Roll (Half Magnitude)	1
5	5 DOF (Half Intensity)	1
6	Pitch and Roll (Full Magnitude, 10% Less Frequency)	1
7	5 DOF (Full Magnitude, 10% Less Frequency)	1
8	Post – exposure trial (POST): Full Motion, 5 DoF – with the same motion profile as the Pre-Exposure Trial	1
9	Retention Trial (RET) – 5 DoF Full Motion	2

3.5 Data Analysis

Prior to any processing, all EMG data was low-pass filtered (20Hz) to remove motion artefact (DeLuca, 1997). Any signal offset was removed by subtracting the baseline signal from each of the trials. EMG data was normalized to the maximum for each muscle following recommendations provide by Burden (2010). The root mean square (RMS) was calculated using EMG collected during the MVC trials. A 100ms moving window was used for this root mean square calculation. The RMS EMG was then examined to determine the maximum activation for each muscle. The EMG values of the task were divided by the maximum EMG from the MVC trial to yield a value expressed as a percentage of the MVC. The data was then be integrated using trapezoid rule. Data from the Pre, Post and Retention trials was integrated across the full 5-minute trial. Further analysis included calculation of the CCI. This calculation was done using the equation provided in the review of literature (equation 2.1) as per Schinkel-Ivy and Duncan (2018). For the CCI calculation, normalized EMG data was down-sampled to 50 Hz. The data was then full wave rectified and low pass filtered at 10Hz to create a linear envelope. After this process, the CCI formula was applied (equation 2.1) for the entirety of the 5-minute trial, allowing researchers to assess changes in CCI values between trials. The CCI calculations were completed using a custom program written in Matlab v.R2018b (The MathWorks, Inc., Natick, MA, USA). The muscle pairings for CCI data are included in Table 3.4 and are based on the methods of Schinkel-Ivy and Duncan (2018). The CCI calculations were completed for Pre, Post and Retention trials only. Mean and median frequency data was analyzed to determine what, if any effect fatigue played in changes to muscle activity. After being subjected to RMS, the data was partitioned into one-minute intervals and a Fast Fourier Transform was performed.

Table 3.4: Lower limb musculature pairings for co-contraction index equation

Shank Pairings	Shank-Thigh Pairings	Thigh - Pelvis Pairings
Tibialis Anterior - Peroni	Tibialis Anterior – Vastus Lateralis	Vastus Lateralis – Hamstrings
Tibialis Anterior – Medial Gastrocnemius	Peroni – Vastus Lateralis	
Peroni – Medial Gastrocnemius	Peroni – Hamstrings	

Video data was used to determine the number of steps (CIS strategies) participants took was counted. A step was defined as any occurrence when a participant moved their foot from its original position or when a participant needed to grab the guard rail for support. If a participant performed a second step within one second of the initial step, only one step was counted. This was in accordance with definitions and analysis provided by Duncan et al. (2016).

3.6 Statistical Analysis

As this thesis used a repeated measures design and differences between conditions were examined, Mauchly's test for sphericity was completed. If the sphericity assumption was violated (i.e. Mauchly's test was significant), the appropriate correction was applied to ensure a valid F-ratio was reported in the results (Field, 2009).

3.6.1 *Number of Steps*

A one-way repeated measures analysis of variance (ANOVA) was completed to examine the impact of repeated exposure to simulated motions on the number of steps taken during a trial. Time was used as a factor which had three levels: PRE, POST and RET trials.

3.6.2 *Muscle Activation Amplitude and CCI*

A one-way repeated measures ANOVA was completed. Time was used as a factor over three levels: PRE, POST and RET trials. This calculation was completed for each muscle on both the left and right limb and also for each of the CCI muscle pairs on the right and left sides.

3.6.3 *Frequency*

A two-way repeated measures ANOVA was completed when statistically analyzing frequency data. Time was used as a factor, examining differences between PRE and POST trials. Minute-to-minute analysis was also completed. For example, the frequency of each muscle during the first minute of the PRE trial was compared to minutes 2, 3, 4 and 5. The minute-to-minute analysis was also completed for the POST trial. This analysis was completed for each muscle on both the left and right limb.

Chapter 4 : RESULTS

During data analysis some of the data was removed from statistical analysis due to technical issues with signal quality. Muscles affected include peroneus longus, vastus lateralis and hamstrings data. Specifically, the peroneus longus data was removed from one participant, vastus lateralis data was removed from 3 participants and hamstring data was removed from 10 participants. This will account for any variance in degrees of freedom.

4.1 Number of Steps

Analysis of video data indicated that there was a significant effect of time for the total number of steps taken ($F_{(2,26)} = 46.383$, $p < .001$). Post-hoc tests showed there were significantly more steps taken in PRE trials than post ($p < .001$), in PRE trials than RET ($p = .001$) and RET trials compared to POST ($p = .004$). See Figure 4.1.

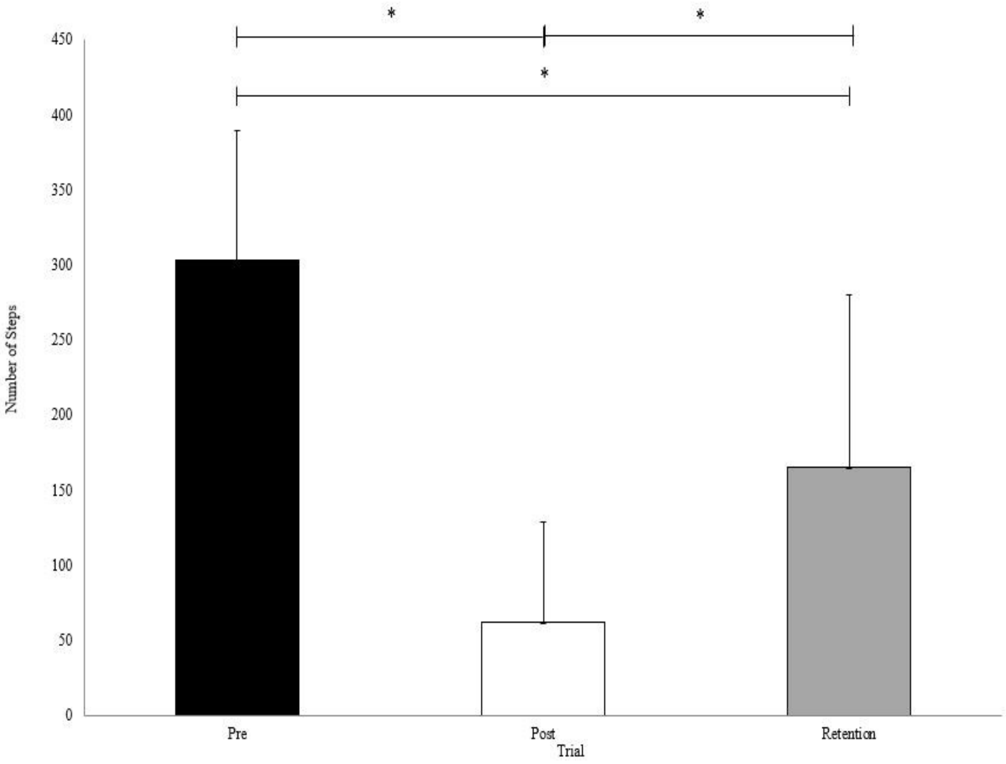

Figure 4.1: Results for the total number of steps taken in PRE, POST and RET trials. Asterisk (*) denotes significance (p < .05)

4.2 Co-Contraction Index

Results of the CCI analysis are provided in Figure 4.2 (right limb) and 4.3 (left limb). There was a significant effect of time for CCI values of the right limb for the following muscle pairs: RTA/RPL ($F_{(2,12.5)}=5.752, p = .029$), RTA/RG ($F_{(2,24)}=13.478, p = .001$), RPL/RG($F_{(2,14.37)} = 13.528, p < .001$), RTA/RVL($F_{(1.09,8.72)} = 5.287, p = .046$), RPL/RVL($F_{(2,9.01)} = 4.990, p = .049$), RTA/RH($F_{(2,6)} = 8.770, p = .019$), RG/RH($F_{(2,6)} = 110.797, p = .010$), and RVL/RH($F_{(2,6)} = 10.615, p = .011$). Bonferroni post-hoc comparisons revealed CCI values were higher in PRE trials than POST for the following pairs: RTA/RPL ($p < .001$), RTA/RG ($p < .001$), RPL/RG ($p < .001$), RTA/RVL ($p < .001$) and RPL/RVL ($p < .001$). CCI values were significantly higher between RET and POST trials for pairings of RTA/RG ($p = .032$), and RPL/RG ($p = .010$). Post-hoc comparisons between PRE and RET trials proved not to be statistically significant.

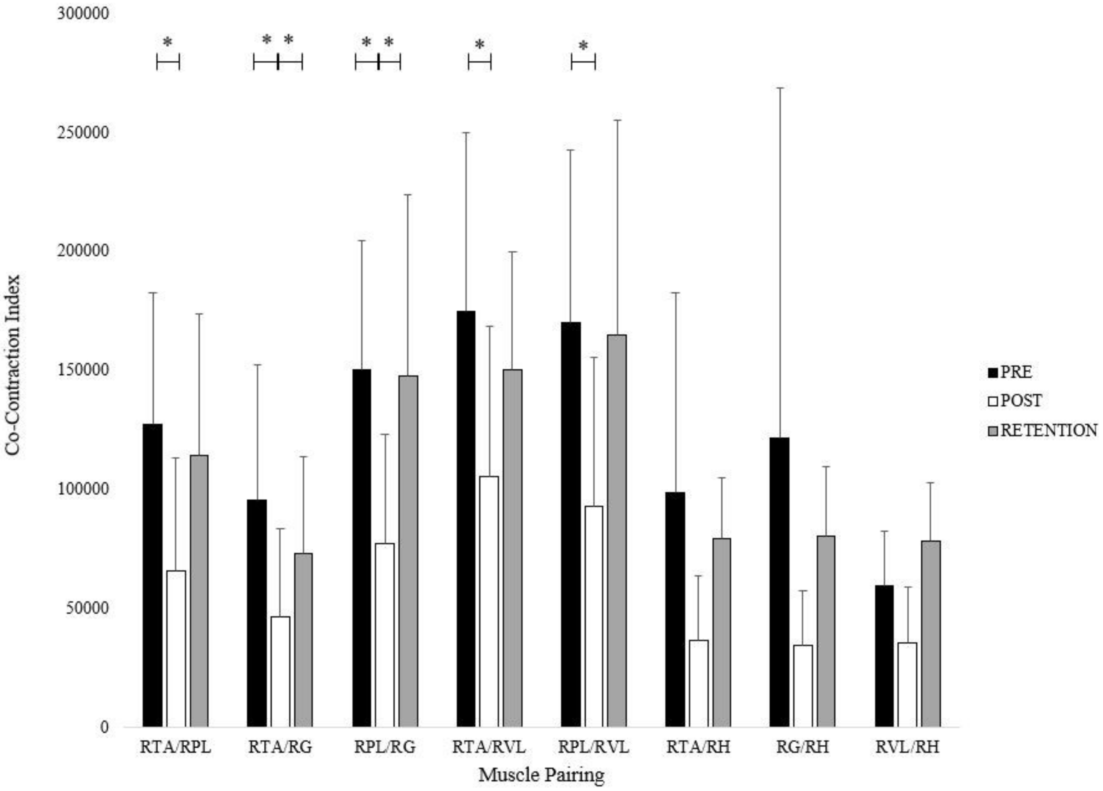

Figure 4.2: Co-Contraction Index data for right lower limb musculature. Asterisk (*) denotes significance (p < .05)

The CCI results for left limb were different than from the right. A significant effect of time was observed for pairings of LTA/LPL ($F_{(2,22)} = 19.155, p < .001$), LTA/LG ($F_{(2,24)} = 20.454, p < .001$), LPL/LG ($F_{(1.19,13.145)} = 10.849, p = .004$), LTA/LVL ($F_{(2,14)} = 8.962, p = .003$), and LPL/LVL ($F_{(2,12)} = 7.066, p = .009$). Bonferroni post-hoc comparisons indicated PRE trials were significantly greater than POST trials for LTA/LPL ($p < .001$), LTA/LG ($p < .001$), LPL/LG ($p < .001$), LTA/LVL ($p = .008$) and LPL/LVL ($p = .011$). RET trials were greater than POST trials for LTA/LPL ($p < .001$), LTA/LG ($p < .001$), LPL/LG ($p = .002$), LTA/LVL ($p = .006$) and LPL/LVL ($p = .023$). No significant differences were found between PRE and RET conditions.

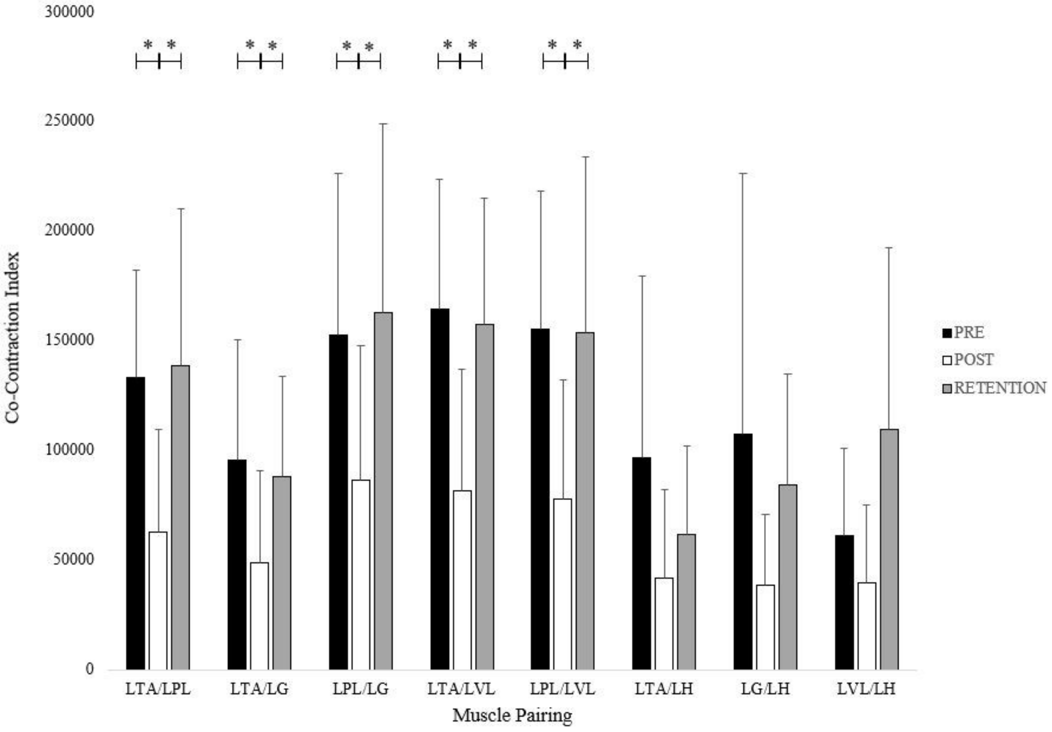

Figure 4.3: Co-Contraction Index results for left lower limb musculature. Asterisk (*) denotes significance (p < .05)

4.3 EMG Amplitude

Integrated EMG analysis of the right limb (see Figure 4.4) indicated a significant effect of time for RTA($F_{(2,22)}=6.975$, $p = .005$), RPL($F_{(2,22)}=4.947$, $p = .017$) and RG($F_{(2,24)}=14.154$, $p < .001$). Post-hoc analysis revealed that PRE trials had significantly more activation than POST trials for RTA ($p = .007$) and RG ($p = .001$). RET trials were greater than POST for all muscles but significance was only found for RTA ($p = .019$)

and RG (p = .001).

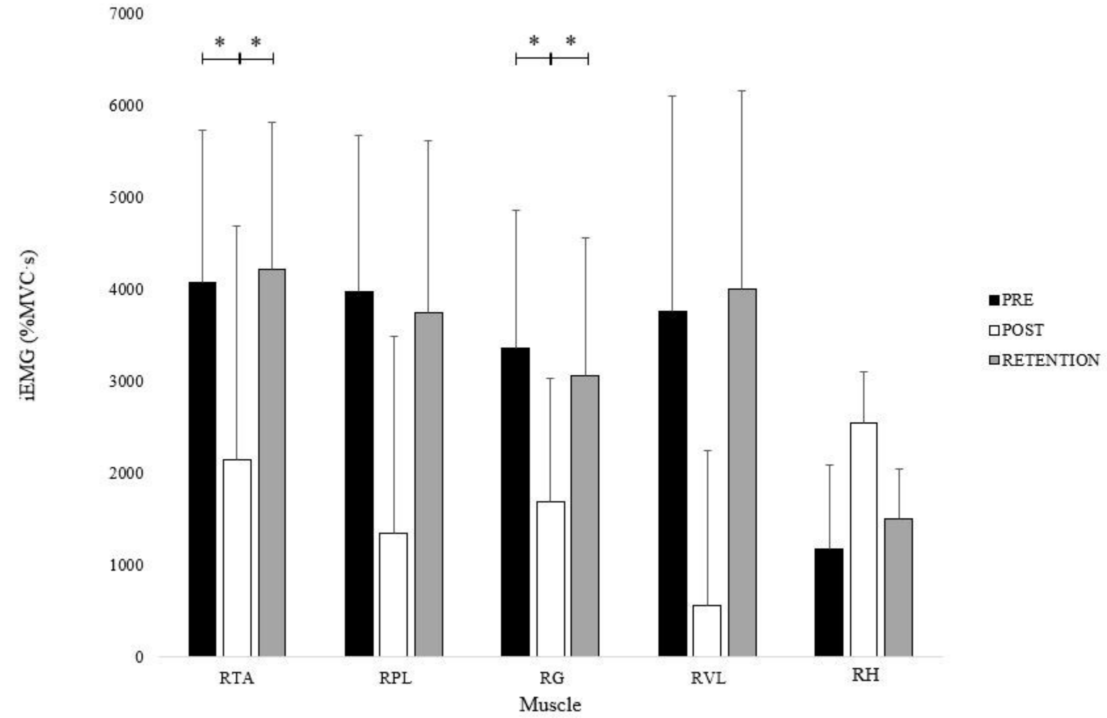

Figure 4.4: Integrated EMG results for right lower limb musculature. Asterisk (*) denotes significance (p < .05)

The iEMG analysis of left lower limb musculature showed changes similar to the right limb (see Figure 4.5). Significant effects were found for LTA($F_{(2,24)}$=8.925, p = .001), LPL($F_{(2,22)}$=13.679, p = .002), LG($F_{(2,24)}$=5.639, p = .010) and LVL($F_{(2,24)}$=5.754, p = .015). Bonferroni post-hoc tests indicated that iEMG PRE was significantly greater than POST in LTA (p = .006) and LPL (p < .001). The iEMG during RET trials was significantly greater than POST for LTA (p = .008), LPL (p = .001), LG (p = .011) and LVL (p = .025) muscles. There were no statistically significant differences between PRE and RET trials.

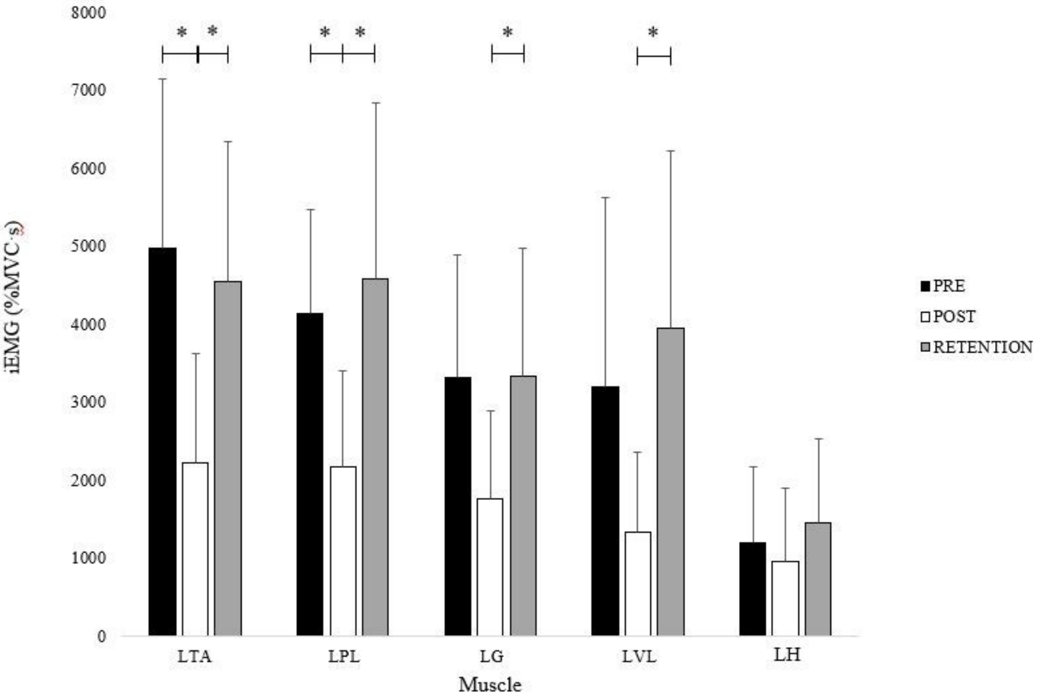

Figure 4.5 Integrated EMG results for left lower limb musculature. Asterisk (*) denotes significance (p < .05)

4.4 Fatigue Assessment

Changes in mean and median frequency were assessed to determine the impact of fatigue. Results of this analysis revealed no significant main effect of time on either mean ($F_{(2,24)}$=.554, p = .582). or median frequency ($F_{(2,22)}$= 2.127, p = .143). There were also no significant interaction effects.

Chapter 5 : DISCUSSION

The purpose of the present study was to determine the effects of habituation to simulated offshore motion on the number of steps taken, lower limb muscle activation including amplitude, co-contraction, and frequency content. The retention of any changes in muscle activation or co-contraction that occurred was also examined. While previous research by Schinkel-Ivy and Duncan (2018) has examined muscle activation amplitude and co-contraction in participants who were exposed to identical habituation trials, the present research sought to determine how participants would respond when non-similar habituation and pre/post habituation motion trials were used. In addition, the present research examined EMG frequency content to assess potential that muscle fatigue may be contributing to the observed changes in muscle activation following repeated exposure to simulated motion. In addition, it examined whether there was any evidence of retention of changes in muscle activation resulting from habituation trials up to 48 hours later (Table 3.3).

To establish the effects of non-similar habituation on postural control and muscle activation individuals were exposed to a series of simulated motions using a 6 DOF motion platform. Electromyographic data was collected from five bilateral lower limb muscles. The results of the study include that participants took significantly fewer steps and exhibited reduced iEMG amplitude and CCI in many muscles and muscle pairs from PRE to POST. However, there was no evidence of carryover of these habituation effects when compared to data collected 48 hours following the habituation trials. Mean and median EMG frequency data were analyzed to determine the presence of fatigue between PRE and POST trials. As there were no significant differences between frequency data it is assumed that decreases in CCI and iEMG were likely not impacted by the onset of fatigue. These findings have implications for real-world occupations and are specifically applicable to those who work in moving environments. The details of these implications are discussed in further detail as follows.

5.1 Muscle Activation Amplitude and CCI

This study aimed to expand on the work of Schinkel-Ivy & Duncan (2018) by examining habituation to assess the effects of implementing varied motion profiles (see Table 3.2) on lower limb muscle activation. The findings of this study agree with those of Schinkel-Ivy & Duncan (2018) in that repeated exposure to motion trials resulted in both decreased CCI and decreased muscle activation amplitude. However, the results also add to the larger body of research by showing that habituation can occur even when repeated motion trials have varied motion characteristics. The analysis of frequency data concluded that local muscle fatigue does likely not contribute to the observed changes. Prior to examining these results in detail, it is important to highlight the differences observed in the CCI values between the present study and those of Schinkel-Ivy and Duncan. Generally, the CCI magnitudes from the present study were higher when compared to those of Schinkel-Ivy and Duncan. Although the type of participants (i.e. naïve to motion rich environments) and motion profiles used for the PRE and POST trials were essentially the same, the motion platforms used differed markedly. Schinkel-Ivy and Duncan used a Moog 6 DOF motion platform with a 2m by 2m base that participants stood on. Although enclosed on the front and two sides by tarpaulin, the back was open. The platform used for the present work was a fully enclosed capsule with a base measuring 5m by 5m. Participants stood in a marked a 2.4m by 2.4m square when inside the capsule. Its design meant participants had no reference to the non-moving world when standing in the capsule. Similarly, due to the relationship between linear and angular motion (Knudson, 2007), the larger size of the platform meant larger linear displacements, and thus perturbations experienced by participants, were likely larger. It is felt that the net effect of these two factors contributed to the higher CCI values in the present study compared to Schinkel-Ivy and Duncan's work. Despite the differences in CCI magnitude between Schinkel-Ivy and Duncan (2018) and the present study, the general trends observed were the same in both, with CCI decreasing in the POST trial. A decrease in CCI demonstrates a decrease in the activity of one or both muscles in the pair. Muscle co-contraction is a strategy that can be used to enhance both joint stability (Ford et al., 2008; Lewek et al., 2005), and postural stability (Ritzmann et al., 2016; Nagai et al., 2012). It has also been identified as a strategy used to maintain stability and reduce errors when learning new skills (Heald et al., 2018; Osu et al., 2002; Ford et al., 2008). Similarly, researchers have confirmed that a reduction in co-contraction occurs as individuals become more comfortable with the new skill (Osu et al., 2002; Schinkel-Ivy and Duncan 2018) and also following balance training (Mansfield et al., 2017; Nagai et al., 2012). The reduction in CCI observed in the present study therefore suggests that participants likely found the task of remaining balanced on the moving platform less challenging following the habituation trials.

The decreased muscle activation and number of steps taken during the POST trials provides support for the fact that that participants likely found balancing during the POST trial less challenging. During POST trials participants exhibited significantly reduced iEMG in most muscles. Two previous authors (Duncan et al., 2018b; Ingram et al., 2016), examining individuals with varying levels of experience in simulated moving environments, have reported that participants with more experience have lower muscle activation during simulated motion trials. Duncan et al. and Ingram et al. go on to suggest the decrease in muscle activation during motion trials is due to the fact that they are less challenged by the balance task.

The decrease in number of steps taken (see Figure 4.1) during the POST trials provides further evidence that the balance challenge was reduced following habituation. Numerous authors have reported fewer stepping responses in individuals as they adapt to perturbations (see for example McIlroy and Maki 1995; Yungher et al., 2012). Similarly, experienced offshore workers, who are presumably more comfortable with the balance demands of a moving environment, have been reported to take less steps than naïve individuals during simulated wave motion (Duncan et al., 2016). The decrease in the number of steps that experienced offshore workers take compared to naïve individuals would further suggest an apparent relationship between decreased balance challenge and number of steps taken. Collectively the EMG amplitude and step count data provide further evidence to suggest that participants were more balanced during the POST trials suggesting that some degree of habituation occurred during the study.

This improved balance would also suggest participants were at a reduced risk of falling during the POST trials. Work by Nelson-Wong et al. (2012) provides support for this suggestion that fall risk was reduced in participants. In their study Nelson-Wong et al. (2012) examined healthy seniors maintaining balance in a stable environment. They administered the Four-Square Step Test for dynamic balance to determine if an individual was at risk of falling. The results of this study report that individuals who were found to be at risk using the Four-Square Step Test demonstrated significantly higher levels of co-contraction than those who were not at risk (Nelson-Wong et al., 2012). Although this work examined healthy seniors it does provide some evidence of the link between CCI and fall risk.

5.2 Implications for Fatigue and Injury Risk

In addition to the possible reduction in fall risk associated with improved balance following habituation it is also important to consider the potential impact that reduced CCI and EMG amplitude may have on fatigue and task performance. The energy cost associated with being in a motion rich environment is substantially higher than when performing the same task in a stable environment (Duncan et al., 2018a). Dobbins, Rowley and Campbell (2008) have outlined how the motion induced fatigue experienced from working in such environments is at least partly due to the increased muscular demand needed to maintain stability. As such, if high levels of co-contraction and muscle activation are sustained, fatigue will likely occur more quickly. For example, Kumar (2001) has discussed sustained differential loading of muscles as being concurrent with increased risk of injury.

Given the unpredictable nature of moving environments, the differential loading of postural muscles is examined using CCI. Kumar (2001) indicates that when repetitive, differential loading of muscles occurs, the result is fatigue. This in turn may decrease movement efficiency and contribute to unnatural movement at the joint, potentially increasing the risk of injury (Duncan et al., 2018a; Kumar, 2001; Nelson-Wong et al., 2012). The decrease in co-contraction values from PRE to POST trials in the present study would therefore likely result in decreased energy cost and possibly reduced motion induced fatigue if they were maintained over the long-term.

5.3 Possible Mechanisms for Observed Changes

In addition to considering the possible benefits of the observed changes in balance and muscle activation, it is also helpful to consider the mechanisms underlying why these changes occurred. Previous research involving individuals who had undergone repeated exposure to trips showed an increased affinity to recover from trips when compared to a control group. More specifically, participants showed decreased maximum trunk angles and a decreased time to reach maximum trunk angles when comparing PRE to POST exposure (Bieryla, Madigan & Nussbaum, 2007). Similar results were present in the current study, where participants took significantly less steps in POST trials compared to both PRE and RET (Figure 4.1). It is possible that exposure to the motion trials enabled participants to anticipate and react to perturbations as they varied in magnitude, frequency and direction. These modified postural reactions to simulate motions may be derived based on the effectiveness of postural responses, a phenomenon known as central set (Horak, Diener & Nashner, 1989). Central set is a concept where prior experience with perturbations and the effectiveness of previous postural responses may allow individuals to modify postural control strategies in response to a perturbation (Horak et al., 1989). More specifically, central set sends commands down to both sensory and motor systems regarding the anticipated perturbation (Schmidt, 1982). If central set does indeed impact automatic postural responses, then responses to the same stimulus delivered multiple times would be changed (i.e. outcome measures such as muscle activity would decrease) (Horak et al.,1989). Schinkel-Ivy and Duncan had findings to that effect in their 2018 study, where they saw decreases in co-contraction between the first and last trials. The findings of Schinkel-Ivy & Duncan may indicate that central set is altered after habituation to moving environments occurs.

Further to the alteration of central set, individuals who have completed habituation using varied motion profiles will likely be able to successfully select a postural control strategy, due to the range of experience gained throughout the habituation trials (Duncan et al., 2016; Maki & McIlroy, 1997). Previous studies have examined the effect of habituation specificity on postural responses. In 2016, Duncan and colleagues found that individuals who had been exposed to balance rich activities such as dancing did not adapt as quickly to motion rich environments as individuals who had spent time seafaring. Duncan's finding indicates that individuals who had prior experiences, which were specific to the stimulus incurred during testing, had a greater ability to anticipate and coordinate appropriate balance reactions. In the current study, the motion trials used for habituation were similar to the POST trial (i.e. performed on the same motion platform and incorporating motions in the same directions) however they were not identical as they were in the Schinkel-Ivy and Duncan (2018) paper. The fact that habituation still occurred suggested specificity of training does not necessarily extend to motion profiles used, but rather is linked to the delivery method for the perturbations.

5.4 Habituation Trial Characteristics

Although not a direct focus of the current work, the results do provide insight to how the type of habituation trials impacts the adaptations that occur. By comparing the current results with those of Schinkel-Ivy and Duncan (2018) some insight into the effect of variability of habituation trials can be gained. Schinkel-Ivy and Duncan (2018), exposed a total of 25 participants (12 participants had no prior experience in offshore or motion simulated environments, 13 participants had at least 6 months of maritime work experience) to 5 identical motion trials. They reported reductions in CCI of approximately 49% (±4.4) from trial 1 to trial 5. This reduction in CCI represented the average decrease in CCI across all muscle pairs examined. In the present study, the percentage decreases ranged from 35% to 71% across all muscle pairs, with an overall average decrease of 46%. The percent decrease would suggest that identical and variable habituation protocols produced similar adaptations in participants. This direct comparison should be done with caution however, as the motion platforms used for both studies differed. As discussed above, Schinkel-Ivy and Duncan employed a relatively small platform (2m x 2m) meaning the magnitude of the linear perturbations that participants were subjected to were likely smaller than those of the present study.

As training magnitude and specificity (Mansfield, Peters, Liu & Maki, 2007; Freyler, Krause, Gollhofer & Ritzmann, 2016) both impact training effect, it is possible that the adaptation observed in the current study was due to the relatively higher magnitude perturbations. Future research should test both methods of habituation on the same platform to determine definitively the impact of training trial characteristics on outcomes.

5.5 Retention

In addition to examining the short-term habituation which occurred, this study also aimed to determine if there was any retention of the habituation. This portion of the research arose directly from the work of Duncan et al. (2014). As well as reporting trial to trial decreases in number of steps taken and total time spent stepping following exposure to simulated wave motion n, these authors also indicated the adaptations were carried over to testing done a minimum of 48 hours later. Despite efforts to replicate this carryover finding of Duncan et al. (2014), data from the RET trials did not indicate any significant carryover in the reduction in CCI, EMG amplitude and number of steps taken. The conflict in findings between the present study and Duncan et al. (2014) is likely due to differences in the amount and type of motion trials participants were exposed to in the two studies. The work by Duncan et al. (2014) examined 12 male and 12 female participants and subjected them to 10, 5-minute trials on day one of testing. This higher volume of trials (compared to the 8 done in the present study) may have resulted in more learning happening. As volume of training is one aspect known to impact training effectiveness (Mansfield et al., 2007) it could indicate more trials were needed in the present study to have a longer-term effect.

The second difference between the present study and Duncan et al. (2014) was the nature of the trials. Duncan et al. (2014) had participants complete four different tasks (i.e. standing in parallel stance; standing in tandem stance; lifting and lowering a load, holding a load), spread over the 10 trials. In the present study, participants were only asked to stand in a parallel stance. It is possible that the varied nature of the tasks completed in the Duncan et al. (2014) study resulted in more overload and thus better retention of the habituation that occurred. Factors in the design of the habituation program (including the number of trials participants are subjected to and the tasks completed during motion simulation trials) will assist in the development of further research studies in order to address long-term effects of perturbation training.

5.6 Future Directions for Research

The present research was carried out as part of a much larger body of research aimed at examining the factors that contribute to the increased fall risk observed in those who work in offshore industries, and developing risk reduction strategies for use in this environment. One intervention that has been previously suggested is to implement a habituation program for new offshore workers in order to prepare them for the balance challenges they will face offshore. Results of the present research suggest that such a program may indeed be worth considering. Prior to implementing such a program, more research aimed at testing the design and efficacy of such a program is needed. Perhaps one of the first studies which should be completed is a replication of the present study with the addition of a control group. The results of such a study will provide a better indication of the amount of retention individuals have following exposure to varied motion profiles. Dependant on the results of such a study, researchers would be better equipped to test the effects of manipulating study characteristics such as the length of the program.

5.7 Limitations

There were several limitations in the study. The first stemmed from the challenges encountered with EMG data collection. During data analysis, a large portion of the data from hamstrings muscles was rendered unusable due to the amount of noise in the signal. There was not enough hamstring data of sufficient quality to have any statistical findings, therefore it was excluded from the results. Had we been able to include the hamstring data, it would have allowed us to better assess CCI findings around the knee and hip joints. This would have better illustrated the effect of habituation on postural control strategy employed, such as the hip strategy, in response to perturbations.

The study also lacked a control group. Having a control group would have allowed researchers to further compare the effects of habituation on lower limb muscle activation. By comparing individuals who received habituation training to those who did not, researchers would be able to draw further conclusions about the effectiveness of habituation.

When designing the study the decision was made to not randomize the order of the habituation trials. As a result, it is possible that the changes observed in muscle activation and number of steps were due solely to the fact that the POST trial was always proceeded immediately by the most challenging habituation trial (5DOF, full magnitude, 10% less frequency (see Table 3.3). If this were the case, it would have substantial implications related to the design of future training programs. A study, randomizing the habituation trials, is needed to determine if there is an optimal order for habituation trials.

The sample size of 12 participants was low. This low sample size would have reduced the power of the study. Higher participant numbers would have given the study more power to detect change, which would have had the greatest impact when assessing difference between RET and the PRE/POST trials. An examination of the results (Figures 4.2, 4.3, 4.4, 4.5), suggests that this would not have been likely, however, given the very small differences in magnitude between the RET trials and all others.

Chapter 6 : CONCLUSION

The present study aimed to address a gap in the literature surrounding how individuals adapt to repeated exposure to simulated motion. In particular it examined how exposure to repeated and variable motion trials affected lower limb muscle activation amplitude, co-contraction and frequency content. It was novel in the fact that it also examined the retention of any changes 48 hours post exposure. Results of the study gives us the understanding that exposure to variable motion profiles resulted in a decrease in muscle activity from the beginning to the end of a testing session. Similarly, decreased co-contraction surrounding lower limb joints such as the ankle and knee was also observed. Results of the frequency analysis indicated that these muscle activation changes were likely not related to muscle fatigue, as there were no changes in the frequency content of the EMG signals. It is suggested that the muscle activation and step count changes that were observed were indicative of participants experiencing a reduced balance challenge in the POST trials. The fact that these changes were not evident in the retention trial that occurred 48 hours post exposure, suggests that no long-term changes in behaviour were created.

From an ergonomic perspective, reductions in co-contraction and total muscle activation can lead to reduced incidence of fatigue and therefore reduced risk of injury due to slips, trips and falls (Kumar, 2001). However, research is still needed to ensure that habituation trials, similar to the ones in this study, are effective in initiating motor learning and retention of balance skills learned throughout the duration of habituation. Future studies should consider implementing a longer exposure period and also the inclusion of a control group to more effectively examine changes arising from exposure. This would further the knowledge and literature surrounding balance training and habituation as an essential component of job readiness in offshore environments in order to reduce incidence and risk of injury.

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