"THE EFFECT OF MOTION AND INVERSION ON NEUROMUSCULAR AND CARDIOVASCULAR SYSTEMS"

VARUN GROVER

"The effect of motion and inversion on neuromuscular and cardiovascular systems"

by

© Varun Grover

A thesis submitted to the

School of Graduate Studies

in partial fulfillment of the

requirements for the degree of

(Master of Science in Kinesiology)

School of Human Kinetics and Recreation

Memorial University of Newfoundland

October 2011

St. John's Newfoundland

Acknowledgements

I am indebted to my supervisor Dr. David G. Behm for his invaluable support, guidance and patience, without cooperation of his impeccable knowledge and appended help the thesis would not have been possible. My thanks extend to faculty in School of Human Kinetics and Recreation, Memorial University of Newfoundland for sharing their knowledge and assistance for success of this study.

I acknowledge thanks and gratitude to all my graduate friends and Memorial university students who in one way or another contributed and extended their valuable assistance in preparation and completion of this study.

I would like to thank my parents, Sanjeev Grover and Manju Grover and my brother, Anuj Grover for supporting and encouraging me to pursue this Master's degree in Canada.

Table of Contents

List of figures:

Figure 1: This figure illustrates differences in knee extension force (Newtons) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

Figure 2: This figure illustrates differences in elbow flexion force (Newtons) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

Figure 3: This figure illustrates differences in knee extension force (Newtons) between first and second maximum voluntary force (MVC) (main effect for time with data collapsed over position and wave motions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

Figure 4: This figure illustrates differences in vastus lateralis muscle activity (mV) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

Figure 5: This figure illustrates differences in vastus lateralis, biceps brachii, abdominals and back muscles activity (mV) between pre- and post-experimental protocol (main effect for time with data collapsed over wave motion and positions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

Figure 6: This figure illustrates differences in mean heart rate (beats per minute) between pre- and post-experimental protocol (main effect for time with data collapsed over wave motion and positions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

List of appendices:

Appendix 1 - Figures

Appendix 2 - Pictures

Appendix 3 - Equations

List of abbreviations:

A/D	Analog/Digital
Ag	Silver
AgCl	Silver chloride
ANOVA	Analysis of Variance
cm	Centimeter
dB	Decibels
E-C	Excitation – Contraction
EMG	Electromyography
Hz	Hertz
Kg	Kilogram
LAS	Lower abdominal structure
Mf	Microfarad
min	Minutes
MVC	Maximum Voluntary Contraction
ms	Milliseconds
s	Seconds
yrs	Years

1.0 Literature review

1.1 Introduction

In Canada, ocean based oil rig workers must successfully complete an escape maneuver from a simulated overturned helicopter in water, before they can start their employment (Newfoundland offshore petroleum board, 2008). To escape out of an inverted helicopter in water requires optimal functioning of the neuromuscular system. In the inverted seated position, the worker has to reorient himself quickly, coordinate his actions to remove the seat harness and push the window or door of the helicopter to escape out as quickly as possible. Along with the stress of the inverted seated position, there is an additional stress of the wave motion produced by the currents in the ocean. In the ocean, the waves and currents result in marked movement or oscillations of the vessels. Since the workers are harnessed to the seats of the helicopter, they also experience the same oscillatory wave motions as the submerged helicopter. The vestibular and central nervous systems are placed under great stress with the combination of the body in an inverted position as well as experiencing oscillatory wave motions. These factors will also induce stress on the neuromuscular system, and may result in movement impairments, due to diminished muscular performance.

An inverted body position may produce alterations in the expected neuromuscular, cardiovascular and physiologic functions seen in the upright position. The effects of inversion have not been explored extensively in the scientific literature. Only four studies have been published investigating the inversion-induced neuromuscular and cardiovascular changes. In an inverted body position there is a decrease in force output and muscle activation in both upper (Hearn et al. 2008) and lower limbs (Paddock and Behm 2009), which suggests changes in neuromuscular functioning. Neary et al. (2011a, b) found significant decreases in heart rate and cardiac output with an inverted seated position vs. upright seated and supine position.

The mechanisms during inversion that may modify human neuromuscular and cardiovascular responses may include hydrostatic pressure, vasoconstriction, hemodynamic regulation, intraocular pressure, intracranial pressure, intrathoracic or intra-abdominal pressure and respiratory functions. However these factors have not been investigated.

Unpredictable wave motion introduces an environment of uncertainty and instability. The interaction of inversion and wave motion has not been previously investigated. As these factors have the potential for fatalities, it would be important to investigate the cumulative effects of these stressors because in real life situations these factors happen simultaneously. It is not known if there are summative or plateau effects associated with these two factors.

1.2 Potential Effects of Inversion on Physiological Functioning

1.2.1 Cardiovascular system

1.2.1.1 Hemodynamic regulation

The central (heart) and peripheral circulation dynamics can be altered during an inverted body position. Inverted body position results in decreased heart rate and systolic and diastolic blood pressure (Hearn et al. 2009; Paddock and Behm 2009). But there are no studies explaining the effect of changes in peripheral blood flow pressure on cardiovascular and neuromuscular systems, in an inverted body position. The perfusion pressure at the muscle could be tested by determining the distance of the muscle from the heart. The perfusion pressure in the hand decreases by 35mmHg upon raising the arm, leading to an increase in mean arterial pressure and reduction in force output (Wright et al 1996). When the arm is lowered below the heart, the normal perfusion pressure at the hand was attained with an increase in the muscle force production (Wright et al 1996). With positive pressure of up to 50mmHg applied to the lower limbs during exercise, there is reduced muscle performance due to decreased muscle perfusion and oxygen saturation (Sundberg and Kaijser 1992). These studies indicate that force output decreases when muscle perfusion pressure decreases. Due to reduced pressure perfusion, there may be an increase in the muscle activation to maintain the force.

Increased integrated EMG has been seen with leg elevation (Hobbs and McCloskey 1987). Force production of active fibers at a given level of activation falls with decreasing muscle perfusion pressure, thus may require an increase in the muscle activity to maintain the force or to maintain balance. But there are no studies that directly support that the reduction in force production is due to reduced perfusion pressure. Reduced perfusion pressure may also induce muscle ischemia and perhaps it is the ischemia that reduces muscle force.

Local ischemia at the muscular level may result in decreased synthesis of adenosine triphosphate (ATP) (Lanza et al. 2006). The ATP synthesis requires oxygen, and oxygen saturation decreases with reduced perfusion pressure. However the reduced ATP synthesis is due to the decreased ATP demand during ischemia (Lanza et al. 2006). Less ATP during ischemia may be related to decrease in the force production, since muscle force production controls the rate of ATP synthesis. Also the force time integral is decreased with ischemic contractions, indicating more pronounced muscle fatigue (Lanza et al. 2006).

1.2.1.2 Cardiovascular parameters: Heart rate and blood pressure

The central and peripheral circulations are regulated by the central nervous system. The control centers in the medulla oblongata are responsible for the hemodynamic regulation (Mitchel and Victor 1996). These centers receive input from various receptors throughout the body and higher centers. These centers control the hemodynamics by regulating the activity of the sympathetic and parasympathetic system. The afferents from the receptors (e.g. baroreceptors, chemoreceptors) and input from the higher centers (e.g. hypothalamus) activate the medulla centers. Depending on the stimulus, the medullary control centers cause alterations in efferent sympathetic and parasympathetic activity, which in return results in changes in cardiovascular system activity, such as heart rate and blood pressure. There will also be decrease in the blood flow in the lower limb, due to gravity. The reduction in the blood flow results in decreased muscle performance (Hepple 2002).

Heart rate and systolic and diastolic blood pressure decreases with an inverted body posture (Hearn et al. 2008; Paddock and Behm 2009). These changes could be due to the alterations in the activity of central or peripheral mechanisms of the body or an interaction of both. Peripheral mechanisms may include changes in hydrostatic pressure, vasoconstriction, and change in the peripheral vascular resistance. The central factors playing a role in fluctuations of the heart rate and blood pressure in the inverted position could be symapathetic and parasympathetic nervous system and vasomotor centers. The cerebrovascular blood flow resistance decreases with -30 degree whole body head down tilt which is attributed to the reduction of the sympathetic tone or activity (Bosone et al. 2004). The decrease in the sympathetic activity causes a decrease in the heart rate (Schneider and Chandler 1973), blood pressure (Bosone et al. 2004) and total peripheral resistance (Goodman and Lesage 2002). However, Butler et al. (1991) found an increase in the total peripheral resistance with head down tilt position. The aforementioned studies suggest with few exceptions, that there is a decrease in the sympathetic activity with head down tilt position. Decreased sympathetic activity may be responsible for the decrease in the heart rate and blood pressure. There is a reactive increase of the cardiac output with the decrease in heart rate with 6 degrees of head down tilt. (Yao 1999). Stroke volume also decreases in the head down tilt position (Butler et al. 1991). Cardiac output is equal to the product of stroke volume and heart rate. The last two mentioned studies suggest that, there should be a substantial increase in the heart rate in order to increase the cardiac output with decreasing stroke volume. This conflicts with the result of previous inversion studies which reported heart rate decreases in the inverted seated position (Hearn et al. 2008, Paddock and Behm 2009, Neary et al. 2011a,b). Furthermore Neary et al. (2011a,b) reported inversion-induced cardiac output decreases. This may suggest that the cardiovascular mechanisms and the sympathetic system functioning in the inverted seated position do not work in the same fashion as in the whole body head down tilt to 6 degrees. There is no correlation between the sensitivity of both cardiac and sympathetic efferent functioning in baroreflex control of arterial pressure (Dutoit et al. 2010). Whereas Neary et al. (2011a,b) examined cardiac output, there are no studies examining variations in stroke volume during the inverted body position. As the Neary results were only published abstracts, more peer-reviewed published papers investigating cardiovascular parameters such as the relationship between cardiovascular parameters and sympathetic stimulation would be of interest. Changes in the cardiovascular parameters could be associated with peripheral reflex mechanisms such as the action of baroreceptors.

1.2.1.3 Baroreceptors

Baroreceptors play a lead role in the acute regulation of the blood pressure with postural change (Berne and Levy 2001). They are more responsive to constantly changing pressure than to constant sustained pressure. Baroreceptors are stretch receptors, which respond to the stretch of the vessel due to increased arterial pressure at the carotid sinuses and aortic arch (Berne and Levy 2001). Small increases in central venous pressure reduce the sensitivity of baroreflex control of sympathetic activity in healthy humans (Charkoudian et al. 2004). Carotid baroreceptor-induced changes in arterial blood pressure are primarily mediated by alterations in vascular conductance and reflex-induced changes in the cardiac output are the result of carotid baroreceptor mediated changes in heart rate (Fadel 2008). Therefore the capacity of the carotid baroreceptors to regulate arterial blood pressure depends critically upon its ability to alter the tone of the vessels (Fadel 2008). Although the sensitivity of both the cardiac and the sympathetic efferents function in the baroreflex control of the arterial pressure they are not correlated in healthy men, though in women the sensitivity of both cardiac and sympathetic efferents were found to be related (Dutoit et al. 2010). Balance between the cardiac output and the sympathetically mediated vasoconstriction contributes significantly to the normal regulation of the arterial pressure in humans, as dynamic inputs from the cardiac output and stroke volume affects the baroreflex control of muscle sympathetic nerve activity in healthy normotensive humans (Charkoudian et al. 2005). According to the study performed by Wallin (2007), muscle sympathetic nerve activity and increased levels of the cardiac output share an inverse relationship. Fast changes in arterial pressure at the carotid sinus effectively changes the sympathetic outflow to the muscles and thus contributes to the compensatory blood pressure responses whereas static blood pressure control probably depends more on the baroreceptor control over the effector organs (Bath et al. 1981).

During an inverted body position, the central venous pressure may increase with pooling of blood in the upper extremity due to the effect of gravity, which may cause a reduction in the baroreceptor activity. The repercussions are still not known. The mentioned studies suggest the significant role of the baroreceptors in regulating the hemodynamics in relation to the posture of the human body, but it is still ambiguous how the baroreceptors will react to the inverted body position. The decrease in sympathetic activity during head down tilt position (Bosone 2004), may be related to the stimulation of the baroreceptors. This is plausible because cephalic pooling of blood and its subsequent increase in hydrostatic pressure with inversion would provide a strong stimulus to the baroreceptors.

Vasomotor sympathetic activity via the baroreflex also maintains arterial pressure during orthostasis. (Fu et al. 2006). Orthostatic tolerance is impaired during whole body head down tilt position. This may be due to the decrease in the tone of venous capacitance vessels (Butler et al. 1991). While attaining upright posture from a recumbent position, sympathetic activity increases. During sustained orthostasis (45 minutes) the vasoconstriction initiated by sympathetic adrenergic nerves is maintained by ongoing sympathetic activation (Fu et al. 2006). Sympathetic activity is not seen in the push pull effect (rapid change in the whole body head up tilt and head down tilt position) (Sheriff et al. 2010). The influence of sympathetic activity in orthostatic tolerance when standing upright from supine position is certain. But knowledge about the effect of sympathetic activity on orthostatic tolerance while attaining the upright seated position from completely inverted seated position is still sparse.

In relation to orthostasis, marked changes in cardiovascular system have also been seen in Trendelenburg position. The Trendelenburg position is a whole body head down tilt position at a 15-20 degree tilt used during pelviscopic surgeries (Suh et al. 2010). The effect of the Trendelenburg position on systemic and pulmonary hemodynamics in critically ill patients is not generally appreciated (Sibbald et al. 1979). Preload of both right and left ventricles of heart, and cardiac output increases whereas sympathetic vascular resistance decreases in this position (Sibbald et al. 1979). The effect could be mediated by baroreceptors stimulation, which will inhibit vasoconstrictor tone of resistance vessels. According to Ostrow et al. (1994) the Trendelenburg position does not influence hemodynamic parameters such as cardiac output and blood pressure in normovolemic or normotensive patients. However few studies performed on the effect of Trendelenburg position on cardiovascular system show conflicting results. The findings from the aforementioned studies on Trendelenburg position could provide valuable information in studying the effect of an inverted body position on the functioning of the cardiovascular system.

1.2.2 Hydrostatic pressure

The hydrostatic pressure in the upright position is controlled by various mechanisms, such as spinal and supraspinal sympathetic vasoconstriction reflexes (Henriksen 1991), which in turn stimulates the baroreceptors. Vasoarteriolar reflexes produce vasoconstriction in the cutaneous circulation in upright body posture (Vissing et al. 1997). There are other mechanisms that control pressure dynamics in the upright position, but all the mechanisms controlling the hydrostatic pressure during inverted body position are not known. Do the same mechanisms act with inversion as in the upright position? Very little research has been conducted to study the effect of variations in hydrostatic pressure on the neuromuscular system in the human body. Most of the studies are based on animal models. Heinemann et al. (1987) performed a study on rat muscles to examine the effect of increased hydrostatic pressure on acetylcholine receptors. It was seen that an increased hydrostatic pressure resulted in pulsing acetylcholine receptor release in turn reducing its effect on muscle firing rate. Geeves and Ranatunga (1987) performed a study to understand the effect of increased hydrostatic pressure on the isometric tension of a psoas single muscle fiber of the rabbit. Increased pressure was maintained for 10-20 seconds, which resulted in a 15% reduction in the isometric active tension, when the fiber was maximally calcium activated. It was hypothesized that for such a linear relationship, the decrease in force produced per cross bridge was responsible. A later investigation by Fortune et al. (1989) found that the decrease in maximum active tension is determined by amount of products of ATPase reaction. Ranatunga and Geeves (1991) carried out further investigations to analyse the difference in twitch and tetanic response to increased hydrostatic pressure. Isometric contractions were analyzed in the extensor digitorom longus muscle of the rat, in response to different hydrostatic pressures. Extensor digitorum longus muscle is comprised of fast twitch fibers (Ranatunga and Geeves , 1991). With increased hydrostatic pressure the peak tension, the time to peak and the time to half relaxation of a twitch tension were found to increase. Though in fused tetanus, the increased hydrostatic pressure resulted in decreased tension, half time of tension rise and increase in half time of relaxation. This suggests that tension potentiation is a combined result of the increase in tension rate and decrease in rate of tension relaxation which could be due to the effect of hydrostatic pressure on the mechanisms involved in excitation-contraction (E-C) coupling (Ranatunga and Geeves, 1991). The E-C coupling reaction may result in increased calcium release associated with the action potential. However, submaximal contractions or contractions at lower calcium levels resulted in increased tension, whereas maximal contractions or contractions at higher calcium levels resulted in decreased tension under the influence of increased hydrostatic pressure (Fortune et al. 1994). Thus increased hydrostatic pressure may affect calcium release and sequestration resulting in variations of twitch tension. The increased twitch tension due to the result of increased hydrostatic pressure is a result of increased release of calcium (Vawda et al. 1996). Thus we may say that high hydrostatic pressure may result in an increase in the release of calcium with increased twitch tension. The aforementioned studies indicate that impairment of MVCs may also be related to increased hydrostatic pressure.

But according to the result of Paddock and Behm (2009) the force production and muscle activation decreases in the lower limbs during inverted seated position. Thus there may be more factors affecting the neuromuscular system, which can overshadow the effect of hydrostatic pressure. In an inverted body position the hydrostatic pressure will be less in lower limbs and may be increased in the upper limbs (with more perfusion pressure) due to pooling of the blood in upper extremity as an effect of gravity. Therefore in lower limbs, the opposite effect of the increased hydrostatic pressure could be seen as the hydrostatic pressure will be less than normal. This suggests that the alteration in force production should not be similar in both upper and lower limbs, and there should be increase in the force production at lower limbs because of decreased hydrostatic pressure. There is no evidence for this response and no investigations have been performed so far relating to this subject.

1.2.3 Intraocular pressure

The Trendelenburg position results in an increase in intraocular pressure (Awad et al. 2009). Intraocular pressure increases with head down tilt position (Linder et al. 1988). A 3-fold increase in intraocular pressure is seen in the gravity inversion position (-90 degrees) with respect to intraocular pressure in upright body position (Linder et al. 1988). The elevation of intraocular pressure results in reduction of visual neurophysiologic functioning (Linder et al.

1988) and may result in poor visual feedback. During constant isometric contractions, decrease in the visual feedback results in increased force error, and can reduce force variability due to altered activation of primary agonist muscles (Baweja et al. 2009). Thus, this suggests that an increase in intraocular pressure during inverted body position may reduce muscle performance due to deficient visual feedback. Auto-regulatory processes attempt to maintain the blood flow constant to the eye, despite the increase in the ocular perfusion pressure (Schmidl et al. 2010). The head down tilt position mimics, to a degree, the inverted body position, thus physiological changes seen in this position could be related to changes seen in the inverted body position.

1.2.4 Respiratory system

Respiratory system may also experience increased work load in inverted body position. With inversion, the inspiratory muscles may have to produce more force to push the diaphragm against gravity. Also there may be an increase in intrathoracic or intra-abdominal pressure which may result in increased stress on the thoracic cage and diaphragm. This stress may result in early fatigue of the respiratory muscles, and may leave the person breathless. Also there may be variation in the gaseous exchange at the alveolar level. With head down body tilt, the sympathetic activity decreases (Bosone 2004). The sympathetic system is responsible for bronchodilatation (Van der Velden and Hulsmann 1999). Thus a decrease in sympathetic activity may result in increased secretion in the lungs via bronchial glands. Constriction of bronchial muscles restricts the oxygen supply to the muscle which results in alterations in the coupling of phosphocreatine hydrolysis and oxygen uptake in contracting muscle, which by determining the rate of inorganic phosphate (Pi) accumulation may affect calcium release (Hepple 2002). A decrease in oxygen supply to the muscle also results in a reduction in the levels of creatine phosphate (Brechue et al 1995). During submaximal contractions there is a parallel decline and maintenance of force with not only fluctuations of blood flow but also due to alterations in oxygen supply (Hepple 2002). Thus any decrease in the efficiency of the respiratory system may result in decrease oxygen saturation, which may directly affect the muscle activation and muscle optimal force production especially with prolonged contractions which have a greater reliance or susceptibility to oxygen deficits.

1.3 Effect of wave motion on human body

As discussed earlier, in oceans, the waves and currents result in marked movement or oscillations of the vessels. When a helicopter is submerged in the ocean it also experiences oscillatory movements and since the workers are harnessed to the seats of the helicopter, they also experience the same oscillatory wave motions as the submerged helicopter. This wave motion may affect motor task performance by altering neuromuscular mechanisms. There are no studies performed so far to suggest how wave motion under such circumstances affects motor task abilities in humans.

1.3.1 Instability

Unpredictable wave motions as found on marine vessels lead to uncertainty, affecting the neuromuscular and cardiovascular responses for the individuals experiencing this wave motion. With wave motion, the trunk and the abdominal muscles may have a significant role while performing tasks using upper and lower limbs in the inverted seated position, as the muscles have to maintain the stability of the body. The EMG activity of the contralateral trunk and abdominal muscles increase when isometric contractions of bicep brachii are performed in the inverted seated position (Hearn et al. 2008), though minimal EMG activity in trunk muscles and abdominal muscles was seen when the contralateral biceps brachii was relaxed. Such activity of the trunk and abdominal muscles could be the result of the instability while performing any task. The stability of the spine is increased by the co-activation of the spine flexor and extensor muscles (Arokoski et al. 2001). Instability decreases force, as more work is performed by **the** body's stabilizing muscles to maintain joint stability. When instability was introduced to the wrist joint, muscle force and activity decreased (Kornecki et al. 2001). When using an unstable pendulum like device for pushing movements Kornecki and Zschorlich (1994) observed 20-40% force output decrement. Resistance training promotes strength gain (Behm and Sale 1994) however under unstable conditions the ability to exert force is reduced (Anderson and Behm 2004). Significant decreases were found in velocity, squat depth, and maximum concentric and eccentric power upon performing squats on unstable surfaces (Drinkwater et al. 2007). There is usually a decrease in force production in conjunction with the increased limb muscle activation, which suggests switching over from muscle mobilizing to stabilizing functions (Anderson and Behm 2004). Behm et al. (2002) found that force production by leg extension, plantar flexion and isometric chest press decreased on physioball (unstable surface) whereas no significant difference was found between stable and unstable condition for limb and chest muscle activation during isometric chest press. The aforementioned studies suggest that under unstable conditions muscle force is not isolated to the prescribed motor task rather it divides into stabilizing and motor task, thus resulting in decreased external force production. The body may also act by stiffening the muscles around a joint to limit movement for more stability. This may also limit force production as the body will produce a greater proportion of isometric force than concentric.

With instability the body adopts a stiffening pattern (Carpenter et al. 2001) thus affecting muscle force production (Adkin et al. 2002). This suggests that instability produces decreased motor performance. The wave motion produced with submerged helicopters and in military jets produces an environment of wave motion uncertainty with responses which may be similar to those found with instability exercises. Although the person is harnessed to the seat, the combined effects of inverted seated posture and wave motion may result in profound uncertainty for the vestibular and neuromuscular systems.

Above mentioned conditions result in alteration in balance (instability), coordination, spatial orientation which is regulated by vestibular system in human body (Schubert M.C and Herdman S.J, 2001).

1.3.2 Vestibular system

With wave motion, vestibular functioning should also be affected, as the vestibular system is responsible for posture maintenance, stabilization of visual images, spatial orientation (Schubert M.C and Herdman S.J, 2001) with balance and coordination of the body. The vestibular system also regulates the sympathetic activity. Vestibular afferent activation in response to impulses from higher centers and receptors in the body (for altered hemodynamics) results in vestibulosympathetic activation (Kerman et al 2000, a). In relation to the position of the body and innervations of particular sympathetic nerves, vestibular sympathetic reflex activation may result in a change in the local blood flow (Kerman et al. 2000, b). These studies suggest that vestibular system stimulation leads to alterations in hemodynamic patterning via sympathetic nervous system. Also anatomical and functional connections between vestibular and autonomic systems (sympathetic and parasympathetic systems) contribute to postural sway (Balaban and Porter 1998). This indicates that changes in the posture will also put more demand on the vestibular as well as autonomic systems. "The extensive convergences of vestibular and autonomic information in both vestibular and autonomic brain regions are consistent with the concept that vestibular and visceral information (for example, blood pooling and visceral proprioception) are used to form a central representation of gravito-inertial parameters during movement. This representation can influence neural circuitry involved in postural control, cardiovascular control, and perception of the spatial, vertical and wave motional or affective responses" (Balaban and Porter 1998).

1.3.3 Sympathetic System Responses

Instability may result from altered postures or wave motion adversely affecting the ability to perform skillful tasks. With the postural adjustments, both peripheral and central mechanisms are involved (Ivanenko et al. 2000). Feedback from somatosensory, vestibular and visual inputs are provided by efferent and afferent signals within the sensorimotor system (Kollmitzer et al. 2000) and anticipatory postural adjustments (Slijper and Latash 2000) contribute to the balance of the body. The impulses are sent by efferent nerves to adjust the posture by controlling the muscle contractions and ensure optimal coordination of the contracting muscles. Sympathetic activity constricts the vessels in the muscles in response to upright standing or orthostatic intolerance (Wallin and Sundlof 1982). The sympathetic response to constriction of vessels is also accompanied by a sudden increase in the heart rate (Furlan et al. 2001). Stimulation of sympathetic nervous system results in hyper-alertness, increased heart rate, blood pressure, respiratory rate and increase in the blood flow to the muscles. This suggests that altered sympathetic activity due to the wave motion and inverted body position may affect the ability to activate the motor neurons. The central nervous system becomes increasingly stressed in the inverted body position. With an increase in the intracranial pressure in head down tilt position (Bosone 2004), the human neuromuscular system may be affected, but the effects have not been investigated previously. The compound result of increased intracranial pressure and increased or decreased sympathetic activity might affect the neural outflow to the motor neurons adversely affecting the ability to fully activate motor neurons, and thus affecting maximal force output or the ability to sustain submaximal contractions. Inhibition of the sympathetic system will result in decrement of all these parameters. Acute head down body tilt results in lowering of the sympathetic nervous system activity (Bosone 2004). Sympathetic system is also responsible for the fight or flight reaction. In the inverted body position, especially during the real life threatening situations, these responses may result in increased sympathetic outflow. Thus the precise response of sympathetic activity during the inverted body position with wave motion is still debatable.

In a threatening situation, the flight or fight reactions of the sympathetic system are activated and should result in increased heart rate and blood pressure, providing better perfusion to the vital organs and muscles. This fact conflicts with the findings of Hearn et al. (2008) and Paddock and Behm (2009) studies, which reported a decrease of the heart rate, systolic and diastolic blood pressure during inverted body position. It could be assumed that sympathetic system activity was decreased in the inverted seated position due to mechanisms which overshadow the fight or flight reaction or the highly controlled conditions in these studies were not ecologically valid (as both the studies did not have conditions precipitating fight or flight reactions in participants). Hence the deliberate and slow movement or transition into inversion may not actually simulate the real life situation and with this controlled environment, eliminates the effect of emergency i.e. flight or fight reactions. No studies have been performed so far to study the sympathetic system activity response with wave motion and an inverted body position. The only known study performed by Bosone (2004) shows a decrease in the sympathetic nervous activity with head down body tilt but without any wave motion. Sympathetic activity inhibition will result in decreased heart rate (Sundblad 2000), blood pressure (Bosone 2004) and total peripheral resistance (Goodman and Lesage 2002). Vestibulosympathetic reflex activity could be more responsible for sympathetic system activity inhibition than the effect of cardiopulmonary baroreceptors in the head down body tilt position (6-8.5 degree) (Kawanokuchi et al. 2001). The effect on sympathetic system activity in the inverted body position is still unclear, but it certainly has a significant effect over the cardiovascular and neuromuscular mechanisms and performance in the inverted body position.

1.4 Conclusion

All the mechanisms discussed affect the neuromuscular mechanisms and cardiovascular mechanisms of the body either directly or indirectly through relayed pathways. The cardiovascular system may react with changes in heart rate and blood pressure and the response could be produced by baroreceptors activity or due to changes in peripheral and central circulations due to change in body posture. Such alterations to the cardiovascular system could be because of altered central nervous system activity (may be due to increased intracranial pressure) or due to shift in hydrostatic pressure gradient as pooling of blood is more pronounced in upper limbs and less in lower limbs, unlike the upright posture. As per earlier mentioned studies intraocular pressure and respiratory rate also appears to increase with inverted seated posture.

The force loss and decrease in motor performance efficiency could entirely be due to inverted seated posture or due to effect of wave motion or due to effect of both together acting on the body simultaneously. The wave motion may alter vestibular system response and in lieu may cause sympathetic activity to increase. This may result in altered neuromuscular responses and cardiovascular system activity.

Hearn et al. (2008) and Paddock and Behm (2009) studied the muscle activation and force production in upper and lower limb respectively, and found both parameters decreased in both limbs, thus suggesting that aggregation of alterations produced in all the cardiovascular and central neural pathways mechanisms has decreased the output and efficiency of the neuromuscular system. Neary et al. (2011 a, b) found contradictory results with no significant force reduction in upright vs. supine vs. inverted seated position, though the studies result support the finding of significant decrease in heart rate of Hearn et al. (2008) and Paddock and Behm (2009) studies.

The above two mentioned studies were performed to analyze the effect of inverted seated position on the force production and muscle activation, relating to the escape maneuver preformed by ocean based oil rig workers, from the overturned helicopter submerged in the sea water. The four studies examining inversion (Hearn et al. 2008; Paddock and Behm 2009; Neary et al. 2011 a, b) may lack full ecological validity. First all the studies discuss the effects on force production and muscle activation in upper and lower limb, but separately, though in a real life situation the upper and lower limbs act simultaneously. Secondly, the experiments in the studies (Hearn et al. 2008; Paddock and Behm 2009; Neary et al. 2011 a, b) were performed with the chair positioned stationary with the subjects in the inverted seated position, which is not a similar case in realistic conditions when the helicopter is submerged. As discussed above, in oceans there is high water current causing vessels to oscillate, thus the worker also bears the same wave motion. To get results which are more ecologically valid, there is a need to study the neuromuscular system and cardiovascular response during inverted seated position with chair in wave motion simulated to the wave motions of the vessel in ocean water, while analyzing the force production and muscle activation in both upper limb and lower limb at the same time. This procedure would give a more realistic picture and better insight to the changes in the neuromuscular and cardiovascular system during real life situation with ocean based oil rig workers under the rare circumstances of drowning of the helicopter in the ocean.

1.5 References – Literature review

1. Adkin A.L, Frank J.S, Carpenter M.G, Peysar G.W (2002). Fear of falling modifies anticipatory postural control. Exp Brain Res 143 (2): 160-170
2. Anderson K.G, Behm D.G (2004). Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res 18(3): 637-640
3. Arokoski J.P, Valta T, Airaksinen O, Kankaanpaa M (2001). Back and abdominal muscle function during stabilization exercises. Arch Phys Med Rehabil 82(8): 1089-1098
4. Awad H, Santilli S,Ohr M, Roth A, Yan W, Fernandez S, Roth S, Patel V (2009). The effects of steep trendelenburg positioning on intraocular pressure during robotic radical prostatectomy. Anesth Analg 109(2): 473-478
5. Balaban C.D, Porter J.D (1998). Neuroanatomic substrates for vestibulo-autonomic interactions. J Vestib Res. 8(1): 7-16
6. Bath E, Lindblad L.E, Wallin B.G (1981). Effects of dynamic and static neck suction on muscle nerve sympathetic activity, heart rate and blood pressure in man. J Physiol 311: 551-564
7. Baweja H.S, Patel B.K, Martinkewiz J.D, Vu J, Christou E.A (2009). Removal of visual feedback alters muscle activity and reduces force variability during constant isometric contractions. Exp Brain Res 197(1): 35-47
8. Behm, D.G., Button, D., Power, K, Anderson, K, and Connors, M. (2002). Relative muscle activation with ice hockey actions. Can. J. Appl. Physiol. 27 (Suppl): S5
9. Berne R.M. and Levy M.N (2001). Principles of physiology: C.V. Mosby Publishers, Toronto Ontario, 188-197

10. Bosone D, Ozturk V, Roatta S, Cavallini A, Tosi P, Micieli G (2004). Cerebral haemodynamic response to acute intracranial hypertention induced by head-down tilt. Funct Neurol 19(1): 31-35

11. Brechue W.F, Ameredes B.T, Barclay J.K, Stainsby W.N (1995) Blood flow and pressure relationships which determine VO_{2max}. Med Sci Sports Exerc 27(1): 37-42

12. Butler G.C, Xing H.C, Northey D.R, Hughson R.L (1991). Reduced orthostatic tolerance following 4 h head-down tilt. Eur J Appl Physiol Occup Physiol 62(1): 26-30

13. Carpenter M.G, Frank J.S, Silcher C.P, Peysar G.W (2001). The influence of postural threat on the control of upright stance. Exp Brain Res 138 (2): 210-218

14. Charkoudian N, Joyner M.J, Johnson C.P, Eisenach J.H, Dietz N.M, Wallin B.G (2005). Balance between cardiac output and sympathetic nerve activity in resting humans: role in arterial pressure regulation. J Physiol 568(Pt 1): 315-321

15. Charkoudian N, Martin E.A, Dinenno F.A, Eisenach J.H, Dietz N.M, Joyner M.J (2004). Influence of increased central venous pressure on baroreflex control of sympathetic activity in humans. Am J Physiol Heart Circ Physiol 287(4): H1658-1662

16. Drinkwater E.J, Pritchett E.J, Behm D.G (2007). Effect of instability and resistance on unintentional squat-lifting kinetics. Int J Sports Physiol Perform 2(4): 400-413

17. Dutoit A.P, Hart E.C, Charkoudian N, Wallin B.G, Curry T.B, Joyner M.J (2010). Cardiac baroreflex sensitivity is not correlated to sympathetic baroreflex sensitivity with in healthy, young humans. Hypertension 56(6): 1118-1123

18. Fadel P.J (2008). Arterial baroreflex control of the peripheral vasculature in humans: rest and exercise. Med Sci Sports Exerc 40(12): 2055-2062

19. Fortune N.S, Geeves M.A, Ranatunga K.W (1989). Pressure sensitivity of active tension in glycerinated rabbit psoas muscle fibres: effects of ADP and phosphate. J Muscle Res Cell Motil 10(2): 113-123
20. Fortune N.S, Geeves M.A, Ranatunga K.W (1994). Contractile activation and force generation in skinned rabbit muscle fibres: effects of hydrostatic pressure. J Physiol 474(2): 283-290
21. Fu Q, Shook R.P, Okazaki K, Hastings J.L, Shibata S, Conner C.L, Palmer M.D, Levine B.D (2006). Vasomotor sympathetic neural control is maintained during sustained upright posture in humans. J Physiol 577(Pt 2): 679-687
22. Furlan R, Magatelli R, Palazzolo L, Rimoldi A, Colombo S, Porta A (2001). Orthostatic intolerance: different abnormalities in the neural sympathetic response to a gravitational stimulus. Auton Neurosci 90(1-2): 83-88
23. Geeves M.A, Ranatunga K.W (1987). Tension responses to increased hydrostatic pressure in glycerinated rabbit psoas muscle fibers. Proc R Soc Lond B 232: 217-226
24. Goodman L.S, LeSage S (2002). Impairment of cardiovascular and vasomotor responses during tilt table simulation of "push-pull" maneuvers. Aviat Space Environ Med 73(10): 971-979
25. Hearn J, Cahill F, Behm D.G (2009). An inverted seated posture decreases elbow flexion force and muscle activation. Eur J Appl Physiol 106(1): 139-147
26. Heinemann S.H, Stuhmer W, Conti F (1987). Single acetylcholine receptor channel currents recorded at high hydrostatic pressures. Proc Natl Acad Sci USA 84(10): 3229-3233

27. Henriksen O (1991). Sympathetic reflex control of blood flow in human peripheral tissues. Acta Physiol Scand Suppl 603: 33-39

28. Hepple R.T (2002). The role of O_2 supply in muscle fatigue. Can J Appl Physiol 27(1): 56-69

29. Hobbs S.F, McCloskey D.I (1987). Effects of blood pressure on force production in cat and human muscle. J Appl Physiol 63(2): 834-839

30. Ivanenko Y.P, Solopova I.A, Levik Y.S (2000). The direction of postural instability affects postural reactions to ankle muscle vibration in humans. Neurosci Lett 292(2): 103-106

31. Kawanokuchi J, Fu Q, Cui J, Niimi Y, Kamiya A, Michikami D, Iwase S, Mano T, Suzumura A (2001). Influence of vestibulo-sympathetic reflex on muscle sympathetic outflow during head-down tilt. Environ Med 45(2):66-68

32. Kerman I.A, Emanuel B.A, Yates B.J (2000a). Vestibular stimulation leads to distinct hemodynamic patterning. Am J Physiol Regul Integr Comp Physiol 279(1): R118-125

33. Kerman I.A, McAllen R.M, Yates B.J (2000b). Patterning of sympathetic nerve activity in response to vestibular stimulation. Brain Res Bull 53(1): 11-16

34. Kollmitzer J, Ebenbichler G.R, Sabo A, Kerschan K, Bochdansky T (2000) Effects of back extensor strength training versus balance training on postural control. Med Sci Sports Exerc 32(10): 1770-1776

35. Kornecki S, Kebel A, Siemienski A (2001). Muscular co-operation during joint stabilisation, as reflected by EMG. Eur J Appl Physiol 84(5): 453-461

36. Kornecki S, Zschorlich V (1994). The nature of the stabilizing functions of skeletal muscles. J Biomech 27(2): 215-225

37. Lanza I.R, Wigmore D.M, Befroy D.E, Kent-Braun J.A (2006). In vivo ATP production during free-flow and ischaemic muscle contractions in humans. J Physiol 577(Pt 1): 353-367

38. Linder B.J, Trick G.L, Wolf M.L (1988). Altering body position affects intraocular pressure and visual function. Invest Opthalmol Vis Sci 29(10): 1492-1497

39. Mitchell J.H, Victor R.G (1996). Neural control of the cardiovascular system: insights from muscle sympathetic nerve recordings in humans. Med Sci Sports Exerc 28(10): S60-69

40. Neary J, Salmon D.M, Pritchett E, Behm D.G (2011a). Effects of an inverted body position on arm maximal voluntary contract force and cardiovascular parameters. Proc Physiol Soc 23: PC84

41. Neary J, Salmon D.M, Pritchett E, Behm D.G (2011b). Effects of an inverted body position on muscle force and cardiovascular parameters. European College of SportSciences

42. Newfoundland and Labrador offshore petroleum board (2008). http://www.cnlopb.nl.ca/safe_about.shtml

43. Ostrow C.L, Hupp E, Topjian D (1994). The effect of trendelenburg and modified trendelenburg positions on cardiac output, blood pressure and oxygenation: A preliminary study. Am J Crit Care 3(5): 382-386

44. Paddock N, Behm D (2009). The effect of an inverted body position on lower limb muscle force and activation. Appl Physiol Nutr Metab 34(4): 673-680

45. Ranatunga K.W, Geeves M.A (1991). Changes produced by increased hydrostatic pressure in isometric contractions of rat fast muscle. J Physiol 441: 423-431

46. Schmidl D, Garhofer G, Schmetterer L (2011). The complex interaction between ocular perfusion pressure and ocular blood flow-relevance for glaucoma. Exp Eye Res 93(2): 141-155

47. Schneider M.F, Chandler W.K (1973). Voltage dependent charge movement of skeletal muscle: a possible step in excitation-contraction coupling. Nature 242(5395): 244-246

48. Schubert M.C, Herdman S.J (2001) Vestibular disorders. Page 822-824 in O'Sullivan S.B and Schmitz T.J, editors. Physical Rehabilitation. 4th edition. F.A.Davis Company, Philadelphia

49. Sheriff D.D, Nadland I.H, Toska K (2010). Role of sympathetic responses on the hemodynamic consequences of rapid changes in posture in humans. J Appl Physiol 108(3): 523-532

50. Sibbald W.J, Paterson N.A, Holliday R.L, Baskerville J (1979). The trendelenburg position: hemodynamic effects in hypotensive and normotensive patients. Crit Care Med 7(5): 218-224

51. Slijper H, Latash M (2000). The effects of instability and additional hand support on anticipatory postural adjustments in leg, trunk and arm muscles during standing. Exp Brain Res 135 (1): 81-93

52. Suh M.K, Seong K.W, Jung S.H, Kim S.S (2010). The effect of pneumoperitoneum and trendelenburg position on respiratory mechanics during pelviscopic surgery. Korean J Anesthesiol 59(5): 329-334

53. Sundberg C.J, Kaijser L (1992). Effects of graded restriction of perfusion on circulation and metabolism in the working leg; quantification of a human ischaemia-model. Acta Physiol Scand 146(1): 1-9

54. Sundblad P, Spaak J, Linnarsson D (2000). Haemodynamic and baroreflex responses to whole-body tilting in exercising men before and after 6 weeks of bedrest. Eur J Appl Physiol 82(5-6): 397-406

55. van der Veleden V.H, Hulsmann A.R (1999). Autonomic innervation of human airways: structure, function and pathophysiology in asthma. Neuroimmunomodulation 6(3): 145-159

56. Vawda F, Ranatunga K.W, Geeves M.A (1996). Effects of hydrostatic pressure on fatiguing frog muscle fibres. J Muscle Res Cell Motil 17(6): 631-636

57. Vissing S.F, Secher N.H, Victor R.G (1997). Mechanisms of cutaneous vasoconstriction during upright posture. Acta Physiol Scand 159 (2): 131-138

58. Wallin B.G (2007). Interindividual differences in muscle sympathetic nerve activity: a key to new insight into cardiovascular regulation? Acta Physiol 190(4): 265-275

59. Wallin B.G, Sundlof G (1982). Sympathetic outflow to muscles during vasovagal syncope. J Auton Nerv Syst 6(3): 287-291

60. Wright J.R, McCloskey D.I, Fitzpatrick R.C (2000). Effects of systemic arterial blood pressure on the contractile force of human hand muscle. J Appl Physiol 88(4): 1390-1396

61. Yao Y.J, Wu X.Y, Sun X.Q, Hao W.Y, Wie Y.B, Cao X.S (1999). Effects of 24 h -6 degrees head-down tilt bed rest on cardiovascular function and response to orthostatic stress. Space Med Med Eng (Beijing) 12(6): 401-405

The effect of motion and inversion on neuromuscular and cardiovascular systems

by

Varun Grover

(Master of Science in Kinesiology)

School of Human Kinetics and Recreation

Memorial University of Newfoundland

St. John's Newfoundland

2.0 Abstract

The purpose of the study was to analyze the effect of inversion with wave motion on the functioning of cardiovascular and neuromuscular systems. Cardiovascular system was assessed by measuring the heart rate response and neuromuscular system was analyzed by measuring maximum voluntary contraction (MVC) force and electromyography (EMG). Force production and electromyographic (EMG) activity for elbow flexors and knee extensors were measured along with muscle activation of trunk and abdominal muscles. Heart rate was measured before and after each experimental procedure. All the parameters were tested in upright and inverted seated position with wave motions. Both positions were combined with 3 sets (pitch, roll and random, all combined with heave) wave motions and were selected randomly. Pitch, roll and heave are types of wave motion, where random was combining all the three types of wave motion together. Each experimental procedure lasted 1 minute and subjects performed two isometric MVCs for the right elbow flexors and right knee extensors at beginning and at the end of one minute. Results showed that wave motion induced significantly less knee extension MVC force (Pitch = 8%; Roll = 13.4%; Random = 13.5%, $p < 0.0001$) and significant less elbow flexors MVC force (Pitch = 21.1%; Roll = 26.7%; Random = 25.1%, $p < 0.0001$). A main effect for time showed that there was a significant drop in EMG activity with the second MVC (compared to first MVC) for vastus lateralis (15.4 %, $p = .0024$), biceps brachii (11.7 %, $p = .05$), lower abdominal structure (LAS) and external obliques muscles (12.5 %, $p = .034$). A significant increase in heart rate (18.1 %, $p = .0001$) was seen post experimental procedures in upright seated position compared to before the start of the procedure. The results were evaluated by keeping position, time and wave motion as factors. The aforementioned results suggest significant neuromuscular impairments and heart rate responses with wave motion and inversion

combined over time. The results of this study provide both basic physiological mechanisms and applications to life threatening situations such as submerged helicopters subjected to wave motions as well as overturned vehicles among other situations.

3.0 Introduction

The human body is primarily adapted to upright posture. In rare circumstances, humans have to experience inverted postures, such as in car accidents, and jet planes rolling in the sky. Similar circumstances may be seen when ocean oil rig workers are transported to their workplaces in helicopter. In the event of a landing on the water, the workers have to reorient the body as fast as possible, remove harness and kick out the window or door in order to escape. The workers are under continuous stress of an inverted seated posture and high ocean water current, which keeps moving the helicopter, making an escape more difficult. There have been very few studies investigating the effects of an inverted seated posture on motor activity performance and no studies integrating both an inverted posture and movement. It would be important for both the safety of personnel and scientifically, to investigate the physiological effects of inversion and wave motion on physical performance.

An inverted seated posture decreases elbow flexion force and muscle activation (Hearn et al. 2009) and also decreases lower limb muscle force and activation (Paddock and Behm 2009). The studies involved inversion of the subjects in a specially designed inversion chair. Maximum voluntary contractions were performed in each study, to measure the force output. There was a decrease in the force output, mostly due to an effect on the central neural component, as there was a relative increase in co-contractions. Cardiovascular changes were also observed (decreased heart rate and systolic and diastolic blood pressure), and the role of the sympathetic system was suggested for these changes. The most significant finding of these studies was the impairments in neuromuscular functions in an inverted seated position. Neary et al. (2011 a,b) investigated the differences in force and cardiac parameters between upright, supine and inverted seated postures. They reported no significant changes in force production. Similar to the previous inversion studies, Neary et al. found inversion-induced decreases in heart rate as well as cardiac output. However it can be argued that the above studies were not fully ecologically valid, as the inversion of helicopters due to forced landings in water would involve wave motions. Following the findings of aforementioned studies, to ensure greater relevance or validity, the effects of inversion should be studied in conjunction with wave motion.

The objective of the present study is to determine the effect of an inverted position with wave motion on muscle force, activation and cardiovascular functions.

3.1 Hypothesis

It is hypothesized that there will be a decrease in muscle force in upright and inverted seated posture with wave motion compared to without wave motion, and an increase in heart rate in upright seated position with wave motion as compared with inverted seated position with wave motion.

4.0 Methodology

4.1 Subjects

Twelve subjects (7 males, 5 females) with mean age of 22.8 ± 2.1 (yrs), mean weight of 71.6 ± 8.7 (kgs) and mean height of 174.9 ± 4.8 (cms), from Memorial University of Newfoundland volunteered for the study. All subjects were healthy with no history of cardiopulmonary, neurological, cognitive problems, sensory deficits, cold intolerance, or hypersensitivity. Subjects did not have any recent traumatic lesion (in last 6 months) and no previous history of any hypertensive or cerebral related conditions or serious injury. A verbal overview of procedure and purpose of the study was given to all subjects. A signed Physical Activity Readiness Questionnaire (from Health Canada, Canadian Society of Exercise Physiology) was collected from all subjects before participation. All subjects signed written informed consent form before their participation in the study. Subjects were instructed to not smoke, drink alcohol, or exercise at least 6 hours prior to testing and to not eat food for at least 2 hours prior to testing (Health Canada Canadian Society for Exercise Physiology 2004). This study was approved by the Human Investigation Committee of the Memorial University of Newfoundland.

4.2 Experimental Procedure

An introduction session was given to all subjects, which allowed them to get accustomed with the protocol under both upright and inverted seated positions and with the movements of the motion platform (for all 6 wave motion patterns). Subjects warmed up by pedaling on a cycle ergometer set at 1kp and between 70- 80 revolutions per min for 5min. Another warm up session was performed before testing, which includes submaximal isometric elbow flexor contractions in an upright seated position. Each participant came twice for experimental procedure with a gap of 1 day at least in-between the two testing days. Force production was measured on first day in both positions but without wave motion to collect control data. On second day six conditions were allocated to the subject (two positions and three different wave motions for each position). These six experimental conditions were randomly allocated.

During the test, subjects performed two isometric maximum voluntary contractions (MVCs) each of the right elbow flexors and right knee extensors (within one minute; at beginning and at the end of one minute), when seated in the chair respectively in the upright and inverted positions. During both upright and inverted positions, the MVCs were performed when the subject was placed in either of the position (upright or inverted) and 60s later. For the first set of MVCs, if the subject was not able to produce force equal to or above 95% of the previous muscle contraction, the subject had to perform the MVC again and a rest of two minutes was provided to the subjects between each trial (Hearn et al. 2009). The inverted position was maintained for one minute, and after each trial in the inverted position, subjects were rotated back to upright position for rest (Hearn et al. 2009).

4.3 Equipment

4.3.1 Inversion chair

Subjects sat in a specially designed inversion chair (Technical Services; Memorial University of Newfoundland) that secured the occupant in an upright or completely inverted position with the help of straps fastened at shoulder, waist and groin. The chair can be rotated over a 360^0 range. The chair was mounted on a wave motion platform.

4.3.2 Motion Platform

The motion platform can move in 6 degrees of wave motion. Three wave motions are produced in linear axes (surge, sway, and heave) and three in rotational axes (roll, pitch and yaw). It is an electric motion platform (series 6DOF 2000E) with a 1000Kg payload, manufactured by MOOG systems group (www.moog.com). The motion platform was installed at Memorial University of Newfoundland. Motions in roll (roll + heave), pitch (pitch + heave) and random (pitch + roll + heave) patterns were simulated while subjects were placed in both upright and inverted chair positions. For each trial, upright and inverted positions and the sequence of the 3 pattern movements of the wave motion platform were selected randomly.

4.4 Elbow flexors force

Subjects sat in an inversion chair (Technical Services; Memorial University of Newfoundland) in upright posture against the backrest of the chair with forearms supinated and elbows flexed at 90^0, resting on the padded supports on the arms of the chair. An isometric elbow flexor MVC was performed, by pushing against the padded strap fastened around the wrist, and the force production was measured by Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, Ontario). During data analysis, the resting arm weight was subtracted from the force output readings of the inverted MVC since in the upright position the elbow flexors had to overcome the mass of the arm associated with the pull of gravity (Hearn et al. 2009).

4.5 Knee extensors force

Subjects sat on the inversion chair with both hips and knees flexed at 90 degrees. The subject performed an isometric leg extension by pushing the leg against the strap fastened around the ankle, and force was measured **by** a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., Don Mills, Ontario), attached to the strap by a tight wire. (Paddock and Behm 2009). The non-contracting leg was also placed in a strap so that it did not dangle while inverted.

The forces measured by the strain gauge, were amplified (Biopac Systems Inc. DA 100 and analog to digital (A/D) converter MP100WSW; Holliston, MA) and monitored on a computer (Dell Inspiron 6000, St John's, Newfoundland) at a sampling rate of 2,000 Hz. A commercial software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA) was used to analyze the digitally converted analog data.

For ecological validity, concurrent contractions of the right elbow flexors and knee extensors were used. Subjects were instructed to flex the right elbow and extend right knee at the same time by pulling as hard and fast as possible against the padded strap for duration of approximately 4 seconds. A difference between resting position and the highest force amplitude was analyzed to measure the peak force.

4.6 Electromyography (EMG)

Muscle activation of the biceps brachii, triceps, vastus lateralis, semitendonosis, external obliques, internal obliques, rectus abdominus and lower lumbar erector spinae (LLES) were recorded via EMG analysis during resting and isometric right elbow flexion and right knee extension MVCs. First, the skin was prepared for surface electrodes placement by shaving the area, followed by rubbing with sand paper and then an alcohol swab to clean. Two surface EMG recording electrodes (Ag/AgCl discs and 10 mm in diameter) were placed approximately 3 cm apart over the mid-portion of the right biceps and triceps muscle bellies, with a ground electrode for each muscle group placed on the clavicle (Hearn et al. 2009). Two similar surface electrodes were placed 2 cm apart over the mid-belly of the vastus lateralis and the semitendinosis in alignment with the muscle fibers. The electrodes were wrapped to ensure no movement during inversion. The anterior superior iliac spine to the patella, and the gluteal fold to the knee fold were measured initially and the halfway mark was recorded then, so that for each successive session, the surface electrodes were consistently placed (Paddock and Behm, 2009). The external oblique electrodes placed approximately 15 cm lateral to the umbilicus and at the transverse level of the umbilicus; transverse abdominis or lower abdominal structure (LAS) electrodes are placed below the external oblique electrodes and just superior to the inguinal ligament (McGill et al. 1996) and two similar electrodes were placed on the lumbar region to measure lower lumbar erector spinae (LLES) muscle activity. EMG activity was sampled at 2,000 Hz, with a Blackman 61 dB band-pass filter between 10 and 500 Hz, amplified (bi-polar differential amplifier, input impedance = 2 Mf, common mode rejection ratio[110 dB min (50/60 Hz), gain 9 1,000, noise[5 lV), and analog to digitally converted (12 bit) and was stored on a personal computer for further analysis (Dell Inspiron 6000). An intergral of the EMG was analyzed over a 3 second period which included the peak force.

4.7 Heart rate

Heart rate was monitored in both upright and inverted seated positions. Heart rate was monitored with a Polar A1 monitor (Woodbury, NY). Heart rate was monitored before and after each trial.

4.8 Statistical analysis

All data analysis was performed using a 3 way repeated measures ANOVA (2x4x2) (GB-STAT for MS Windows, Version 7.0, Silver Springs, MD) with position (upright and inverted seated), wave motions (control, pitch, roll, random) and MVC event (1^{st} and 2^{nd} MVC) as factors. Differences were considered significant at $p<0.05$. If significant EMG and force differences were detected, a Bonferroni (Dunn's) procedure was used to identify the interaction. Data are reported as mean ± SD.

5.0 Results

There were no significant main effects for body position (upright versus inverted), however there were significant main effects for wave motion and time for neuromuscular measures. Wave motion significantly impaired knee extensors and elbow flexors force and increased activation of the vastus lateralis, biceps brachii and transverse abdominis and external obliques. Wave motion also significantly increased heart rate in the upright position. A significant main effect for time showed a decrease in all EMG measures and increase in heart rate.

5.1 Neuromuscular responses

5.1.1 MVC kinetics

Wave motion induced significantly less knee extension MVC force (Pitch = 8%; Roll = 13.4%; Random = 13.5%, $p < 0.0001$) compared to control event (figure 1). Similar significant wave motion-induced decreases were seen with elbow flexors MVC force (Pitch = 21.1%; Roll = 26.7%; Random = 25.1%, $p < 0.0001$) on comparing with control event (figure 2). There were no significant changes in knee extensors force and elbow flexors force with change in the position (upright and inverted). A main effect for time demonstrated a significant decrement in knee extensors force from the first to the second MVC ($p = 0.05$) (2.7 % decrement) (figure 3) and no such significance was seen in elbow flexors force.

5.1.2 Electromyography

A main effect for wave motion indicated that the EMG activity of vastus lateralis was significantly less with the roll wave motion (13.3 %, $p = .0085$) than pitch and random wave motions (figure 4). A main effect for time showed that there was significant drop in EMG activity with the second MVC (compared to first MVC) for both vastus lateralis (15.4 %, p = .0024) and biceps brachii (11.7 %, p = .05) muscles (figure 5). The average EMG activity for LAS and external obliques muscle was greater for the first MVC than the second MVC and significantly dropped by 12.5 % during the second MVC (p = .034). A similar trend (p = .062) was seen in lower lumbar erector spinae (LLES) muscle activity (16.2 % drop in second MVC from 1st MVC) (figure 5).

5.2 Heart rate

There was a trend (6.8 %, p = .09) for a decrease in heart rate with the inverted seated position with wave motion (comparing to upright seated position with wave motion). A significant increase in heart rate (18.1 %, p = .0001) was seen post wave motion in upright seated position (figure 6) as compared to pre-wave motion.

6.0 Discussion

The results of the study suggest significant impairment in neuromuscular and cardiovascular activities with wave motion, whether in an upright or inverted seated position. Prior studies investigating inverted seated positions have reported decreases in force output in upper (Hearn et al 2008) and lower limbs (Paddock and Behm 2009). The present study's results were incongruent to the previous inversion studies. However there were significant force decrements in both upper and lower limb when wave motion was incorporated. To the authors' knowledge this is the first study to document wave motion-induced decreases in limb force output.

6.1 Effect of wave motion

The decrease in upper and lower limbs' force during wave motion could be due to alterations in central and peripheral pathways. The wave motion in the present study could constitute an unstable environment for the subjects. Although the harness and support secured the subjects to the chair, the wave motion (vestibular response) and inversion (poor base of support) would have created an environment of uncertainty and instability for the subjects. A number of studies have reported decreases in force, power and movement velocity with instability (Behm et al. 2010a,b). Anderson and Behm (2005) suggested that the decrease in force was associated with increased limb muscle activation, which suggests a transition from muscle mobilizing to stabilizing functions. Conversely, Kornecki et al. (2001) found a decrease in the EMG activity in association with impaired wrist joint muscle force, when introduced to instability. Anderson and Behm (2004) measured isometric and dynamic contractions under stable and unstable conditions for upper extremity muscles, using a Swiss ball as an unstable platform. They found no significant change in EMG activity between stable and unstable protocols though they found significant decrease in force production during unstable conditions. Studies such as Anderson and Behm (2004) and Kornecki et al. (2001) implementing unstable environments have produced a variety of EMG responses (increases, decreases, no change). The present study found no significant change in limb EMG activity with wave motion overall, however there was a specific impairment with the roll wave motion compared to pitch and random wave motions for vastus lateralis muscle (figure 5).

Whereas there was a drop in limb EMG activity over time, trunk EMG activity decreased over the 1-minute intervention period whether upright or inverted. The core is a kinetic link that helps transfer of torques and angular momentum between the lower and upper extremities (Behm et al. 2010a,b, 2011). Based on the instability resistance exercise and vestibular system literature, it is suggested that in the present experiment, instability induced by wave motion may also have been responsible for a significant decrease in force production.

In addition, co-contractile activity may increase when subjected to wave motion and its resultant instability. Behm et al. (2002b) reported that unstable plantar flexion and leg extension contractions had 30% and 40% greater antagonist activity than under stable conditions respectively. When uncertainty exists in the required task, antagonist activity has been reported to be greater (De Luca and Mambrito 1987; Marsden et al. 1983). Increased co-contractions are reported to help improve balance (Engelhorn 1983) and mechanical impedance (opposition to a disruptive force) (Hogan 1984). However, it would also contribute to force impairments during unstable wave motion conditions by providing greater resistance to the intended wave motion. It could be viewed as perplexing that force reductions occurred with no significant decrease in agonist EMG activity as the EMG-force relationship is typically linear or near linear (Edwards and Lippold 1956, DeVries 1968, Wataneabe and Akima 2009). Although there was no significant change in limb agonist EMG activity, the possibility of co-contractions could diminish agonist force output. Unfortunately, this is speculative as co-contractile activity was not monitored in the present study.

Furthermore wave motion could lead to alterations in vestibular system activity, as it is responsible for balance. The vestibular system is responsible for stabilization of the visual images on the fovea of retina during head movement (vestibule-ocular reflex) to allow clear vision, for maintaining postural stability especially during head movement and for providing information for spatial orientation (Schubert and Herdman 2001) The vestibular system is associated with sympathetic activity regulation. Anatomical and functional connections between vestibular and autonomic systems (vestibulosympathetic activation) contribute to the control of postural sway (Balaban and Porter 1998) and hemodynamics (Kerman 2000). Vestibular sympathetic reflex activation can limit local blood flow (Kerman et al. 2000), which might play a role in the force reductions with wave motion in the present study.

Wave motion significantly increased heart rate in the upright seated position. The aforementioned wave motion-induced vestibulosympathetic reflex response may also be related to the increased heart rate. The sympathetic system influences the activities of heart rate (Schneider and Chandler 1973), blood pressure (Bosone et al. 2004) and total peripheral resistance (Goodman and Lesage 2002). The increase in stabilizing contractions and co-contractions may increase energy needs, positively affecting heart rate.

A trend was observed for a decrease in heart rate in the inverted seated position compared to upright seated position which is congruent with the findings of Hearn et al. (2008) and Paddock and Behm (2009). Recent studies by Neary et al. (2011a,b) using inverted seated postures also found significant decreases in heart rate. The similar trend for bradycardia but with a lack of statistical significance in the present study may be attributed to the additional wave motion component. The wave motion-induced heart rate increase could have partially offset the inversion-induced bradycardia.

This trend for inversion-induced bradycardia could be due to the alterations in central (sympathetic and parasympathetic nervous system and vasomotor centers) or peripheral mechanisms (hydrostatic pressure, vasoconstriction, and change in the peripheral vascular resistance). Dynamic inputs from the cardiac output and stroke volume affect the baroreflex control of muscle sympathetic nerve activity in healthy normotensive humans (Charkoudian et al. 2005). Baroreceptor activity is responsible for regulation of blood pressure with postural change (Berne and Levy 2001). However, small increases in central venous pressure reduce the sensitivity of baroreflex control of sympathetic activity in healthy humans (Charkoudian et al. 2004). This reduced sensitivity might suggest that in an inverted seated position, peripheral mechanisms could have more pronounced effects on decreasing the heart rate.

6.1.1 Type of Wave motion

Significantly less EMG activity was observed with the roll wave motion compared to random and pitch wave motions. This is the first study to investigate limb force and activation responses to these types of wave motion. With pitch and random wave motions, subjects can more readily observe the movement of the wave motion platform. As the roll wave motion occurs on a frontal plane, the ability to visually follow the wave motion platform is more inhibited. The vestibular system and in particular the vestibulo-ocular reflex works to maintain visual fixation during head movements (Berne and Levy 1983). As the vestibular nerve innervates the vestibular nuclei of the medulla and pons which in turn innervate extraocular motor nuclei, the cerebellum and spinal motoneurons through the vestibulospinal tract (Berne and Levy 1983), the inability to fixate could impair muscle performance.

6.2 Fatigue Effects over Time

The overall decrease in the force and EMG activity of all the tested muscles from the pre-contraction to post-contraction (main effect for time) suggests a fatigue effect. The significant force decrement in knee extensors in upright position is congruent with Neary et al. (2011, b) who reported significant decreases in elbow flexors force and EMG activity with a 30s MVC in all postures. It is a common finding in the literature that muscle EMG activity decreases with sustained maximal voluntary contractions (MVC) (Behm 2004, Bilodea et al. 2003). The decrease in muscle activity with sustained MVC is attributed to decreased recruitment of higher threshold motor units and the muscle wisdom effect (Behm 2004). The muscle wisdom effect refers to the decrease in motoneuron firing frequency, which occurs in relation with the slowing temporal parameters of the fatiguing muscle (Behm 2004).

6.3 Conclusions

It may be concluded that in an inverted seated position with wave motion, the decrease in force and muscle activity with an increase in heart rate could be attributed to the wave motion-induced perception of uncertainty and instability.

The study illustrates the suppressive effect of wave motion on the efficiency of human performance of a motor task. It may be inferred that an individual's neuromuscular response to an unstable moving environment inhibits muscular performance. The present study illustrates that the effects of wave motion were generally more encompassing than the effects of posture (upright and inverted).

References

1. Anderson K.G, Behm D.G (2004). Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res 18(3): 637-640
2. Anderson K, Behm D.G (2005). The impact of instability resistance training on balance and stability. Sports Med 35(1): 43-53
3. Balaban C.D, Porter J.D (1998). Neuroanatomic substrates for vestibulo-autonomic interactions. J Vestib Res. 8(1): 7-16
4. Behm, D.G., Button, D., Power, K, Anderson, K, and Connors, M. (2002). Relative muscle activation with ice hockey actions. Can J Appl Physiol 27 Suppl: S5
5. Behm D.G (2004). Force maintenance with submaximal fatiguing contractions. Can J Appl Physiol 29(3): 274-290
6. Behm D.G, Drinkwater E.J, Willardson J.M, Cowely P.M (2010a). The use of instability to train the core musculature. Appl Physiol Nutr Metab 35: 91-208
7. Behm D.G, Drinkwater E.J, Willardson J.M, Cowely P.M (2010b). Canadian society for exercise physiology position stand: The use of instability to train the core in athletic and nonathletic conditioning. Appl Physiol Nutr Metab 35(1): 109-112
8. Behm D.G., Drinkwater E.J., Willardson J.M., Cowley P.M. (2011). The role of instability rehabilitative resistance training for the core musculature. Strength Cond J 33(3): 72-81
9. Berne R.M. and Levy M.N. principles of physiology: C.V. Mosby Publishers, Toronto Ontario, 188-197, 1983

10. Bilodeau M, Schindler-Ivens S, Williams D.M, Chandran R, Sharma S.S (2003). EMG frequency content changes with increasing force and during fatigue in the quadriceps femoris muscle of men and women. J Electromyogr and Kinesiol 13(1): 83-92

11. Bosone D, Ozturk V, Roatta S, Cavallini A, Tosi P, Micieli G (2004). Cerebral haemodynamic response to acute intracranial hypertention induced by head-down tilt. Funct Neurol 19(1): 31-35

12. Charkoudian N, Joyner M.J, Johnson C.P, Eisenach J.H, Dietz N.M, Wallin B.G (2005). Balance between cardiac output and sympathetic nerve activity in resting humans: role in arterial pressure regulation. J Physiol 568(Pt 1): 315-321

13. Charkoudian N, Martin E.A, Dinenno F.A, Eisenach J.H, Dietz N.M, Joyner M.J (2004). Influence of increased central venous pressure on baroreflex control of sympathetic activity in humans. Am J Physiol Heart Circ Physiol 287(4): H1658-1662

14. De Luca C.J, Mambrito B (1987). Voluntary control of motor units in human antagonist muscles: coactivation and reciprocal activation. J Neurophysiol 58(3): 525-542

15. DeVries H.A (1968). "Efficiency of electrical activity" as a physiological measure of the functional state of muscle tissue. Am J Phys Med 47(1): 10-22

16. Edwards R.G. and Lippold O.C (1956). The relation between force and integrated electrical activity in fatigued muscle. J Phys 132(3): 677-681

17. Engelhorn, R. (1983). Agonist and antagonist muscle EMG activity pattern changes with skill acquisition. Res Q Exerc Sport, 54(4): 315–323

18. Goodman L.S, LeSage S (2002). Impairment of cardiovascular and vasomotor responses during tilt table simulation of "push-pull" maneuvers. Aviat Space Environ Med 73(10): 971-979

19. Health Canada (2004). The Canadian physical activity, fitness and lifestyle approach. 3rd ed. Canadian Society for Exercise Physiology, Health Canada Publishers, Ottawa, Ont.

20. Hearn J, Cahill F, Behm D.G (2009). An inverted seated posture decreases elbow flexion force and muscle activation. Eur J Appl Physiol 106(1): 139-147

21. Hodges P.W, Bui B.H (1996). A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. Electroencephalogr Clin Neurophysiol 101(6): 511-519

22. Hogan, N. 1984. Adaptive control of mechanical impedance by coactivation of antagonist muscles. IEEE Trans Automat Contr 29(8): 681–690

23. Kerman I.A, Emanuel B.A, Yates B.J (2000). Vestibular stimulation leads to distinct hemodynamic patterning. Am J Physiol Regul Integr Comp Physiol 279(1): R118-125

24. Kerman I.A, McAllen R.M, Yates B.J (2000). Patterning of sympathetic nerve activity in response to vestibular stimulation. Brain Res Bull 53(1): 11-16

25. Kornecki S, Kebel A, Siemienski A (2001). Muscular co-operation during joint stabilisation, as reflected by EMG. Eur J Appl Physiol 84(5): 453-461

26. Marsden, C.D, Obeso, J.A, Rothwell, J.C (1983). The function of the antagonist muscle during fast limb movements in man. J Physiol 335: 1–13.

27. McGill S, Juker D, Kropf P (1996). Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. J Biomech 29(11): 1503-1507

28. MOOG Inc. (www.moog.com)

29. Neary J, Salmon D.M, Pritchett E, Behm D.G (2011a). Effects of an inverted body position on arm maximal voluntary contract force and cardiovascular parameters. Physiol Soc 23: PC84

30. Neary J, Salmon D.M, Pritchett E, Behm D.G (2011b). Effects of an inverted body position on muscle force and cardiovascular parameters. European College of SportSciences

31. Paddock N, Behm D (2009). The effect of an inverted body position on lower limb muscle force and activation. Appl Physol Nutr Metab 34(4): 673-680

32. Perrine J.J, Edgerton V.R (1978). Muscle force-velocity and power-velocity relationships under isokinetic loading. Med Sci Sports 10(3): 159-166

33. Schneider M.F, Chandler W.K (1973). Voltage dependent charge movement of skeletal muscle: a possible step in excitation-contraction coupling. Nature 242(5395): 244-246

34. Schubert M.C Vestibular disorders. Page 1000-1002 in O'Sullivan S.B and Schmitz T.J, editors. Physical Rehabilitation. 5th edition. F.A.Davis Company, Philadelphia

Appendices

Appendix 1-figures

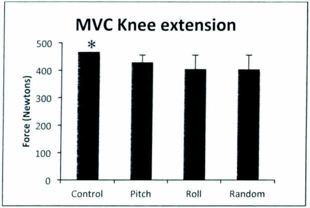


Figure 1: This figure illustrates differences in knee extension force (Newtons) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level, representing significant knee extension force difference between control event and each wave motion event.

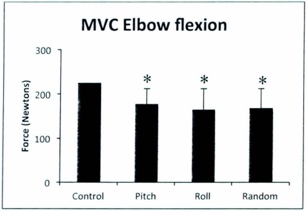


Figure 2: This figure illustrates differences in elbow flexion force (Newtons) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level, representing significant elbow flexion force difference between control event and each wave motion event.

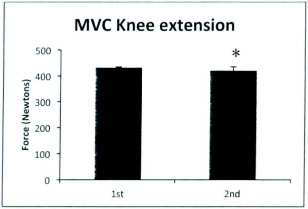


Figure 3: This figure illustrates differences in knee extension force (Newtons) between first and second maximum voluntary force (MVC) (main effect for time with data collapsed over position and wave motions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level.

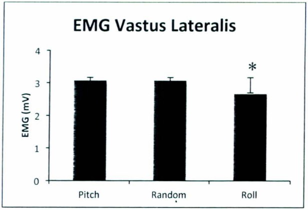


Figure 4: This figure illustrates differences in vastus lateralis muscle activity (mV) between wave motion conditions (main effect for wave motion with data collapsed over position and time). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level, representing significant difference in EMG between roll wave motion event and other 2 wave motion events.

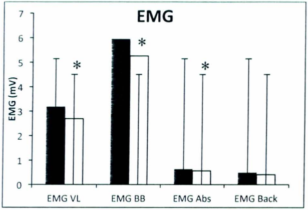
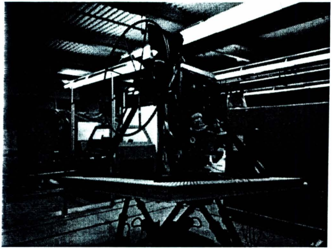


Figure 5: This figure illustrates differences in vastus lateralis, biceps brachii, abdominals and back muscles activity (mV) between 1st MVC- and 2nd MVC (main effect for time with data collapsed over wave motion and positions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level, representing significant EMG differences between 1st and 2nd MVC for the vastus lateralis, biceps brachii and abdominal muscles.

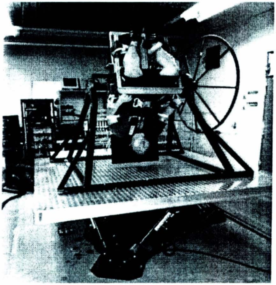
Figure 6: This figure illustrates differences in mean heart rate (beats per minute) between pre- and post-experimental protocol (main effect for time with data collapsed over wave motion and positions). Columns represent means and bars indicate standard deviations. Asterisk (*) indicates significant differences at the $p<0.05$ level, representing significant difference in HR between pre and post experimental procedures for upright seated position.

Appendix 2 - Pictures

Picture 1: Subject in upright seated position on inversion chair mounted on the wave motion platform.



Picture 2: Subject in inverted seated position on inversion chair mounted on the wave motion platform.



Appendix 3 – Equations and raw data

Equations used for wave motion profiles:

Equation 1: Roll = 6 sin(1.09825t) + 1.25 sin(0.115t + 0.5)

Equation 2: Pitch = 2.5 sin(1.84t + 0.5) + sin & #12310 ; (0.15t & #12311;) - 1.5

Equation 3: Heave = 5 sin(1.6675t + 2) + 15 sin(1.265t)

Equation 4: Surge = 7.8 sin(0.6785t + 4.8) + 7.8 sin(0.8625t + 3.8) + 0.5

Equation 5: Sway = 18 sin(0.6095t + 5) + 9 sin(1.173t + 5.4) - 0.25

Raw_Data:

1stMVC event

Upright	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Pitch	432.01	186.042	3.204	6.708	0.695	0.561
Roll	388.427	173.356	2.667	5.087	0.831	0.45
Random	371.177	172.156	2.949	5.311	0.519	0.415

Inverted	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Pitch	450.918	179.454	3.464	5.927	0.64	0.442
Roll	444.932	163.824	3.081	5.975	0.545	0.542
Random	430.406	169.339	3.729	6.76	0.628	0.537

Position	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Upright	397.205	177.184	2.94	5.702	0.682	0.475
Inverted	442.085	170.872	3.425	6.221	0.604	0.507

2ndMVC event

Upright	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Pitch	403.814	184.959	2.627	4.756	0.68	0.441
Roll	377.883	178.158	2.526	4.576	0.589	0.448
Random	384.359	177.911	2.55	5.111	0.642	0.426

Inverted	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Pitch	430.322	178.263	2.985	5.718	0.611	0.403
Roll	404.961	162.7	2.378	5.489	0.421	0.394
Random	428.349	172.518	3.082	5.198	0.464	0.358

Position	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Upright	388.685	180.342	2.567	4.814	0.637	0.438
Inverted	421.21	171.16	2.815	5.468	0.499	0.385

Total Average
(1stMVC event + 2ndMVC event)

Position	Force Quads	Force Biceps	EMG Quads	EMG Biceps	EMG Abs	EMG Back
Upright	392.945	178.763	2.753	5.258	0.659	0.456
Inverted	431.647	171.016	3.12	5.844	0.551	0.446