CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Aquatic Treadmill Walking at Various Water Depths in Individuals with and without
Traumatic Brain Injury

A thesis submitted in partial fulfillment of the requirements for
the degree of Master of Science in Kinesiology

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DEDICATION

To my Lord who is the source of my strength and hope.

To my parents and Eri for their love and continuous support.

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ABSTRACT

Aquatic Treadmill Walking at Various Water Depths in Individual with and without Traumatic Brain Injury

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The purpose of this study is to analyse kinematic and spatiotemporal gait characteristics of aquatic treadmill walking among three different depths of water. The difference of the underwater gait characteristic between individual with and without TBI will be compared. The study findings will help to provide more effective and scientific therapeutic exercise programs for gait restoration.

Methods: A repeated measure comparison study for two groups and three water depths for aquatic treadmill walking. Total of thirteen individuals with TBI (Mean age 43.23 ± 12.04) and fifteen individuals without history of TBI (Mean age 37.07 ± 10.87) participated in the study. All participants were tested for walking at their self-selected speed on aquatic treadmill (AquaGaiter, FERNO, Willington, OH, 2002). The water depths were adjusted by a movable floor pool (KBE, Germany, 2002) to various water depths (waist [above MSIS], chest [Xiphoid process], and neck [Cervical 7] level). The biomechanical gait characteristic, including four spatiotemporal and nine joint kinematics variables were analyzed by using underwater video capturing system (Canon GL2, NY,

2002), and motion analysis system (2D Core Ehuman software, HMA Technology Inc., Ontario, Canada).

Results: Repeated measures MANOVA showed statistically significant differences across three walking conditions in spatiotemporal and kinematic variables in both groups. NonTBI group significantly increased stride length and stride time and decreased stance/swing ratio and cadence as water became deeper. TBI group showed significant decrease in stance/swing ratio from the waist to chest level of water. Significant decrease in hip ROM and increase in plantar-flexion and ankle ROM were observed in NonTBI group while there was significant decrease in hip flexion and decrease in dorsi-flexion and ankle ROM in TBI group.

Conclusions: It is not advised to use the neck level depth water with individuals with TBI because the buoyancy effects causing too much floatation which can challenge an individual's ability to balance. Another reason is that aquatic treadmill walking at the neck level caused greater plantar flexion movement. Many individuals with TBI are already dealing with excessive plantar-flexion mostly due to spasticity. Three dimensional study is advised for further evaluation of aquatic treadmill gait training with various depths.

INTRODUCTION

Traumatic brain injury (TBI) is caused by external force damaging the brain, resulting in chronic disability (The National Institute of Neurological Disorders and Stroke, 2005). It is estimated that 5.3 million Americans currently sustain varied degrees of disability as a result of TBI, and nearly 100,000 of them have ambulatory deficits (Wilson & Swaboda, 2002). Individuals who have sustained TBI often have difficulty in activating and timing muscle contraction, which interferes with walking (Wade, Canning, Fowler, Felmingham, & Baguley, 1997). Such ambulatory impairments in people with TBI increases the risk of having the secondary complications and decreases the chance of acquiring independent activities of daily living (ADLs) (Bateman et al., 2001; Centers for Disease Control and Prevention, 2002).

Gait efficiency can be improved with goal-specific gait trainings. The primary purposes of gait training are to gain independency, achieve functional abilities for ADL, prevent second complications and ensure safety (Ochi, Esquenazi, Hirai, & Talaty, 1999). Many studies have found that treadmill-based gait training is an effective rehabilitation method for gait restoration in people with TBI and other neuromuscular disabilities (Harris-Love, Macko, Whittall, & Forrester, 2004; Hesse, Konrad, & Uhlenbrock, 1999). It has been documented that the partial weight bearing (PWB) treadmill walking improves gait efficiency as compared to conventional overground gait training by many researchers (Alton, Baldey, Caplan, & Morrissey, 1998; da Cunha et al., 2002; McNevin, Coraci, & Schafer, 2000; Threlkeld, Cooper, Monger, Craven, & Haupt, 2003). The PWB effect can be achieved by walking in water. Individuals with physical disabilities can participate in

exercise with more easiness and independence in water. For example, the buoyancy in the water can assist movement and decrease compressive forces in the joints (Bates & Hanson, 1996).

There have been a couple of studies that compared the physiological responses of overground and underwater walking (Dowzer, Reilly, Cable, & Nevill, 1999; Fujishima & Shimizu, 2003; Hall, Macdonald, Maddison, & O'Hare, 1998; Pohl, 2003; Quinn, 1994; Timothy J. Quinn, 1994). There has been no study that evaluated the biomechanical aspects of aquatic treadmill walking patterns among different water depths. Several previous studies have documented gait patterns of people with TBI (Basford et al., 2003; Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004; Esquenazi, 2004; Ochi, Esquenazi, Hirai, & Talaty, 1999; Wilson & Swaboda, 2002), but few studied underwater walking or aquatic treadmill walking in this specific population.

The purpose of this study was to investigate biomechanical characteristics of aquatic treadmill walking at various water depths in individuals with and without TBI. In addition, the differences in the underwater gait characteristics between the two groups; individual with TBI and those without TBI, were compared. The study findings were expected to provide scientific understanding of aquatic treadmill walking at various water depths and to assist clinicians to offer evidence-based gait rehabilitation programs.

Hypotheses

1. There would be significant differences in gait kinematics of aquatic treadmill walking across three different water depths in both TBI and Non-TBI groups.
2. There would be significant differences in spatiotemporal gait variables of aquatic treadmill walking across three different water depths in both TBI and Non-TBI groups.
3. There would be significant differences in all gait variables, spatiotemporal gait and kinematics of aquatic treadmill walking, between TBI and Non-TBI groups across three different water depths.

Limitations

1. The underwater motion analysis was conducted in two dimensional mode.
2. Reflective markers were attached over skin surface and tight swimming shorts, which may have caused minor movement during walking trials in the water.
3. Aquatic treadmill belt did not provide constant speed due to its mechanical constraint. It may have caused slight fluctuation upon stepping.
4. Aquatic parallel bar was used for all participants to hold onto during trials.

Delimitation

1. Only ambulatory TBI participants were recruited to this study.
2. Any hemiplegic characteristic in TBI participants was excluded.
3. All participants received five-minute trial on aquatic treadmill for familiarization.

Independent and Dependent Variables

Independent Variables:

1. Three water depths; Waist, Chest and Neck
2. TBI group and non-TBI group

Dependent Variables:

1. Cadence (steps/min)
2. Stride length (meters)
3. Stride time (seconds)
4. Stance / Swing ratio (seconds)
5. Peak hip flexion angle (degree)
6. Peak hip extension angle (degree)
7. Peak knee flexion angle (degree)
8. Peak knee extension angle (degree)
9. Peak ankle dorsi-flexion angle (degree)
10. Peak ankle plantar-flexion angle (degree)
11. ROM of hip flexion/extension (angles)
12. ROM of knee flexion/extension (angles)
13. ROM of ankle dorsi/plantar flexion (angles)

Definition of Terms

Cadence: The number of steps taken in one minute

Comfortable Walking Velocity: Normal velocity which participants were asked to select as a preferred velocity in this study.

Gait Cycle: A complete cycle of one full stride which begins foot-strike on one side to the foot-strike on same side.

Stride Length: It is the linear distance between the heel-strike on one side to the heel-strike on same side. The stride length consists of two step lengths which is the distance by which the named foot moves forward in front of the other one.

Swing Time: It lasts from toe off on one side to the next heel contact on same side. The foot moves forwards through the air.

Stance Time: It lasts from the heel strike on one side to the toe off on same side. The foot is on the ground.

Peak Joint Angle: Maximum flexion or extension angle in a joint during movement.

Joint Excursion: Range of motion in joints during gait and measured in degrees.

LITERATURE REVIEW

Introduction

Traumatic Brain Injury (TBI) is caused by an external force damaging the brain and often results in death or chronic disability. TBI can result in short or long-term problems. It is estimated that 5.3 million Americans currently sustain varied degrees of disability as a result of TBI, and nearly 100,000 of them have ambulatory deficits (Centers for Disease Control and Prevention, 2002).

Traumatic Brain Injury

Definition and Incidence

Traumatic brain injury is defined as a sudden blow to the head, causing damage to the brain and the brain stem, disrupting the normal brain function (The National Institute of Neurological Disorders and Stroke, 2005). Every year, 230,000 people are hospitalized due to TBI. The mortality rate is 30 per 100,000 and more than 50,000 people die annually with TBI in the United States (Centers for Disease Control and Prevention, 2002).

Etiology

Individuals at the highest risk for TBI are those 15 to 30 years of age, infants six months to two years of age, young school age children, and elderly, especially those over 65 years of age (McCance & Huether, 2002). Males are more than twice likely as females to have TBI. The etiology of the primary brain injury varies. Motor vehicle accidents are the leading cause of TBI (50%), followed by falls (21%), violence (12%), and sports-related events (10%) (McCance & Huether, 2002). According to National

Center for Injury Prevention and Control, gunshot injuries result in the highest mortality rate related to TBI (Centers for Disease Control and Prevention, 2002).

TBI is classified into two categories; primary or secondary injury. A primary injury occurs as a result of an initial impact to the head which include skull fractures, intracranial hematomas, cortical contusions, lacerations, and penetrating wounds (David, 2002). The secondary injury that results from physiologic responses to primary injury are cerebral edema, hemorrhage, infection, and increased intracranial pressure (McCance & Huether, 2002). TBI can cause a wide range of functional changes affecting thinking, sensation, language and emotions (Esquenazi, 2004; O'Suilleabhain & Dewey, 2004).

The severity of the injury varies within the individuals with TBI; therefore a Glasgow Coma Scale (GCS) is used to determine mild, moderate, or severe TBI. Severe TBI is defined by GCS score of less than 9, moderate TBI is from 9 to 12, and mild TBI is greater than 12. Individuals with mild TBI may or may not lose consciousness for a very short time and symptoms include headache, lightheaded, dizziness and confusion. Individuals with moderate or severe TBI may have similar symptoms such as nausea, convulsions, seizures, slurred speech, and weakness or numbness in their arm or legs (Centers for Disease Control and Prevention, 2002).

Gait

Pohl (1991) defined gait as the time interval between two successive occurrences of one of the repetitive events of walking. Gait is defined as manner of moving the body from one place to another by alternately and repetitively changing the location of the feet with the condition that at least one foot is in contact with the walking surface (Smidt,

1990). Gait is a complex performance and sensitive to minor degrees of orthopedic deformity (Sudarsky, 2001). The main functional goals of walking are to move from one place to another, to move safely, and to move efficiently. However, impaired balance, sensation and problems with limbs can interfere with accomplishing the functional goals.

The gait cycle is divided into the stance and swing phases (Figure 1). The stance phase lasts for about 60% of the gait cycle and swing phase for about 40%. Every gait cycle starts with the initial contact and the loading response, which is 0-10% of whole gait cycle, followed by the midstance (10-30%), terminal stance (30-50%), pre-swing (50-60%), initial swing (60-73%), mid swing (70-85%), and end with terminal swing, which is 85-100% of gait cycle (Smidt, 1990).

Gait in TBI

To identify functional impairment after a TBI is critical for safety and prevention of re-injury (Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004). Therapeutic exercises are already recognized as successful tools for individuals with TBI to increase cardiovascular endurance, flexibility, muscular strength, and improve cognitive function (Driver, O'Connor, Lox, & Rees, 2004; Jankowski & Sullivan, 1990). Individuals who have sustained TBI often have difficulty activating and timing muscle contraction, which interferes with walking (Wade, Canning, Fowler, Felmingham, & Baguley, 1997). Such ambulatory impairments in people with TBI increase the risk of having second complications and decrease the chance of acquiring independent activities of daily living.

Several clinical assessments, such as Tinetti Balance Assessment, Dizziness Handicap Inventory, Optokinetic testing, showed that individuals with TBI have balance

vestibular and optokinetic reflex impairment (Basford et al., 2003). Individuals with a history of TBI have gait abnormalities characterized by a shorter stride length, slower speed, asymmetrical steps and a wider step width compared to non-TBI individuals who have an equal ratio of stance and swing phases between both legs (Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004; Ochi, Esquenazi, Hirai, & Talaty, 1999).

Spatiotemporal gait analysis of individuals with TBI was reported by Ochi et al. in 1999. The study included 172 individuals who had sustained a TBI; participants' gait variables were compared with a normal gait pattern and that of individuals with a stroke. Individuals with TBI had a faster pace in the short stance period than individuals who had sustained a stroke. There was no significant difference in the cadence or the stride time between individuals with stroke and TBI. The average walking speed, cadence, and step lengths of TBI participants were less, and the stride phase and double supported period were longer compared to that of the normal gait pattern. The results of this study were similar to the study by Alberto on spastic gait with TBI individuals.

Esquenazi (2004) identified the clinical pattern of motor dysfunction with TBI patients. He noted individuals with TBI often have excessive hip flexion throughout the stance phase, adducted thigh in the swing phase, and a stiff knee on the affected side in the pre and the initial swing. He also concluded that there was a lack of full knee extension in the terminal swing phase, an equinovarus foot in the stance phase, and a hyperextension of the first metatarsal in the early and mid stance phase. This hyperextension of the first metatarsal greatly affected the gait pattern of the individual by disrupting the weight bearing ability of the foot. These deviations in the gait mechanics

Figure 1. Gait cycle

resulted in an impaired balance, an insufficient limb clearance causing the individual to trip and fall, as well as a hip hiking gait, a shortened step length, and limb instability.

In another study, Chou (2004) investigated the kinematics of center of mass (COM), walking speed, center of pressure (COP), and stride length with TBI individuals. The study showed that the TBI group had a slower walking speed, and shorter stride length than the healthy individuals. There was a greater medio-lateral distance between their COM and COP which caused instability in maintaining dynamic balance when they were stepping over the obstacles.

Wade et al. (1997) found that individuals with TBI tend to sway antero-posterior and medio-lateral directions while walking and have poor balance ability while walking. She also found that the slower walking speed and shorter stride length exaggerated the antero-posterior COM motion in TBI individuals.

Basford et al. (2003) also reported that TBI individuals reduce their sagittal plane movement to maintain their balance. Gait efficiency can be improved with goal-specific gait training. The primary purposes of gait training are to gain independence, achieve functional abilities for ADL, prevent second complications and ensure safety (Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004; Ochi, Esquenazi, Hirai, & Talaty, 1999).

Aquatic Exercise and TBI

Aquatic exercise can benefit individuals with physical disability (Driver, O'Connor, Lox, & Rees, 2004; McNevin, Coraci, & Schafer, 2000). Water significantly reduces the compressive force on the joint. Exercise in the water provides resistance as

bodies move through the water, countered sufficiently by the effect of buoyancy (Bates & Hanson, 1996).

Driver et al. (2004) evaluated the effects of an aquatic program on physical fitness components of individuals with TBI, who were randomly assigned to either a control or experimental group. The experimental group, eight individuals with TBI, participated in one-hour aquatic exercise sessions, three times a week, for eight weeks. Cardiovascular endurance, body composition, muscular strength, muscular endurance, and flexibility were measured at pre- and post-program. The results showed a significant increase in range of motion, muscular endurance, strength and sub maximal cycle time and wattage. It provided evidence that the aquatic exercise therapy resulted in an increase of fitness components of individuals with TBI.

Aquatic exercise also increases vital capacity, due to the increase of pressure on the lungs by the water (Bates & Hanson, 1996). Shallow breathing is common among individuals with TBI and it causes rapid fatigue and decreased ability to complete ADLs. An aquatic exercise effectively increases vital capacity and the ability to perform tasks without rapid fatigue, which results in more confidence and independence in individuals' lives (Driver et al., 2004).

Partial Weight Bearing Gait Training

Previous research stated that partial weight bearing (PWB) walking improves gait and balance efficiently and increases walking speed (McNevin, Coraci, & Schafer, 2000; Threlkeld, Cooper, Monger, Craven, & Haupt, 2003). Partial weight bearing walking can be achieved by using suspension or walking in the water. The gait comparison of non-supported and PWB walking revealed significant improvements in gait variables during

PWB walking for individuals with neuromuscular disability (Alton, Baldey, Caplan, & Morrissey, 1998; McNevin, Coraci, & Schafer, 2000).

A kinematic gait comparison study was performed by Threlkeld et al. (2003). The study outcome revealed different kinematic gait patterns among different percentages of body weight support (BWS). Distorted kinematic patterns were observed with the support level of 50 and 70% BWS, while lesser distortions of gait were observed with the support level of 10 and 30% BWS. Cadence significantly increased while step length and double limb support decrease during BWS walking.

Wilson et al. (2002) found improvements in the gait ability of TBI individuals after eight weeks of PWB therapy. Two participants showed improvements in muscle strength, standing balance, and a decrease in spasticity. Because of little number of participants, this study lacked validity and reliability of the results; however it succeeded in terms of introduction of use of PWB therapy.

Aquatic Treadmill

The PWB effect can be achieved by walking in the water. Because the buoyancy in the water acts to support body weight, assist movement, and decrease compressive force in the joints, individuals with physical disabilities are able to perform a variety of tasks without fear of falling or weakness (Bates & Hanson, 1996; Driver, O'Connor, Lox, & Rees, 2004). Fifty percent of the body weight is supported when the water is at the waist level, 70-75% at the chest, and 90% at the neck level (Bates & Hanson, 1996).

Many studies have found that treadmill based training is an effective rehabilitation mode for gait restoration in people with TBI and other neuromuscular disabilities (Harris-Love, Macko, Whittall, & Forrester, 2004; Hesse, Konrad, &

Uhlenbrock, 1999). There have been some studies that evaluated the difference of the physiological responses and gait patterns between land walking and underwater walking (Kato, Onishi, & Kitagawa, 2002; Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2005; Pohl, 2003).

Pohl et al. (2003) found differences in the physiological responses between overground treadmill and underwater treadmill at two different depths in six healthy students with no physical disability. The study also proved that there is a significant decrease in stride frequency when water depth is increased from the thigh level to waist level. Further investigation into the kinetics of the gait cycle in the water was suggested.

Miyoshi et al. (2005) reported the functional roles of lower limbs while walking in the water, and identified that the function of the ankle joint moment is to maintain stability against gravity, the knee joint moment is to absorb the impact force during gait, and the hip joint moment is to force the body forward against the water resistance throughout the stance phase. This study also proved that the rehabilitative exercise in the water is effective since it minimized joint loading.

Kato et al. (2002) presented a study to determine the kinematic characteristic of underwater treadmill walking and running and compared the same exercise on land with healthy trained males with no physical disability. He found that participants used a greater knee joint flexion when walking in the water to overcome the resistance of the water. Furthermore, the nonsupport phase was shorter, and the stride frequency was higher in the water than on land. This study provided useful information to understand the gait characteristics of both walking on land and in the water.

Gait Analysis

Gait analysis is performed to assess motor performance, to define disorders of walking, to estimate the magnitude of the observed deviation, and to provide valuable information about the effect of therapeutic interventions (Davis, 1997; Ebersbach & Poewe, 2001). There are several methods of gait analysis. The simplest method is observational gait analysis, by observing individual's walking, measuring speed, step length, and number of steps using a stopwatch. More advanced and consistent analysis can be done with motion analysis, which can be done by capturing body segments with a video camera system that tracks bony landmarks. Although three-dimensional analysis usually requires expensive and complicated equipment, movement measurement analysis can be performed faster and cheaper providing valid information (Ebersbach & Poewe, 2001).

A few studies have compared the physiological responses of overground and underwater walking (Driver, O'Connor, Lox, & Rees, 2004; Pohl, 2003), but few have analyzed biomechanical characteristics of underwater treadmill walking. Several previous studies have documented gait patterns of people with TBI (Basford et al., 2003; Esquenazi, 2004; Ochi, Esquenazi, Hirai, & Talaty, 1999; Wilson & Swaboda, 2002), but few have studied underwater walking or aquatic treadmill walking in this specific population.

The purpose of this study was to examine kinematic and spatiotemporal gait parameters of aquatic treadmill walking at three different depths of water. The study would provide valuable scientific evidence for understanding underwater walking

patterns in healthy adults and individuals with TBI. The findings would be helpful in developing effective gait training programs.

METHODS

Participants

There were fifteen individuals with Traumatic Brain Injury (13 male, 2 female, mean age 45.23 ± 11.58 years) and fifteen healthy individuals (10 males, 5 female, mean age 37.07 ± 10.87 years) without a history of TBI in the study. Participants with TBI had a mean of 12.67 ± 10.59 post-TBI years. Detail information of each subject is summarized in Table 1. All participants were recruited from the Center of Achievement at California State University, Northridge.

Inclusion Criteria for Participants

1. 2 years or more post-TBI (For TBI group)
2. Age 25 – 60 years
3. Ability to walk with or without an aid (without physical assistance from another person)
4. Ability to cooperate with the testing procedures
5. No surgery within the last six months
6. No significant musculoskeletal problems from conditions other than TBI
7. No significant hemiplegic characteristics in their movements

Exclusion Criteria for Participants

1. Recent surgery within the last six months
2. Orthopedic or peripheral nerve injuries to their lower limbs
3. Unable to cooperate with testing procedures
4. Severe uncontrolled seizures
5. Non-ambulatory

6. Severe visual impairment

7. Acute illness

Table 1 Subject physical characteristics information

Group	Subject ID	Gender	Age	Weight (kg)	Height (cm)
NTBI	1	F	54	77.01	167.6
	2	F	47	54.36	160.0
	3	F	40	61.16	160.0
	4	F	28	56.63	172.7
	5	F	25	58.89	160.0
	6	F	40	60.70	165.1
	7	M	26	84.71	172.7
	8	M	56	88.34	180.3
	9	M	49	110.99	180.3
	10	M	26	61.16	167.6
	11	M	27	81.54	177.8
	12	M	36	66.14	152.4
	13	M	25	88.61	185.4
	14	M	42	86.07	180.3
	15	M	35	83.81	167.6
TBI	1	F	43	52.55	162.6
	2	F	53	70.67	160.0
	3	M	62	106.91	180.3
	4	M	36	87.88	190.5
	5	M	35	96.49	188.0
	6	M	56	77.28	175.3
	7	M	50	83.81	167.6
	8	M	44	90.1	182.9
	9	M	32	74.75	175.3
	10	M	50	78.37	170.2
	11	M	30	89.24	175.26
	12	M	64	61.16	165.1
	13	M	33	87.43	175.26
	14	M	27	85.62	177.8
	15	M	33	87.43	182.9

Setting

The study was performed at the Center of Achievement at California State University, Northridge. The water temperature was set range 90-93 degree in Fahrenheit throughout the testing trials. The participants were asked to walk in the water on the aquatic treadmill at three different water depths; waist level (approximately 50% body weight support), chest level (approximately 70-75% body weight support), and neck level (approximately 90% body weight support) (Bates & Hanson, 1996). The water depths were changed using a movable floor pool (KBE Bauelemate, GmbH & Co., Germany, 2002).

Instrumentation

An aquatic treadmill (AquaGaiter™, FERNO, Ohio, 2002) was used in the movable floor pool. Two digital video cameras (Canon GL, 2002) with underwater housing (Equinox, Michigan, 2002) were positioned on left and right side of an aquatic treadmill to capture underwater walking in the sagittal plane (2 meters away from the treadmill). Aquatic parallel bar (AquaSprint, San Louis Obispo, CA, 2005) was used for all participants to hold onto while walking on the aquatic treadmill. The captured video data were edited with the digital video editing software (Arc Soft Show Biz software, Arc Soft, 2005) and then imported to motion analysis software (Human @ motion, Ontario, Canada, 2005) for digitization and data analysis procedures. The dark markers were attached at bony landmarks in the lower extremities of each participant.

Test Procedures

Data collection procedures are presented in Table 2. The test procedure was explained to participants, and an informed consent form was obtained. All participants were asked to wear bike shorts over their tight fitting swimsuits. Black adhesive markers (15mm in diameter and 0.1mm thickness seal) were attached on both sides of the lower extremities at the following anatomical landmarks: the midpoint on the iliac crest between the anterior and posterior superior iliac spines, the greater trochanter, the lateral femoral condyle, the lateral malleolus and the fifth metatarso-phalangeal joint (Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2005) (Figure 2). A five-minute practice trial was given to all participants prior to the testing trials at waist level of water. During practice trial, participants selected their comfortable walking speed, which were applied to all testing trials. Three two-minute testing trials were captured at each water depth. Two-minute resting time was given to all participants after completing each trial.

All participants held onto an aquatic parallel bar, which was stabilized by research assistants, for postural stability with no weight support effect. The safety of all participants was ensured by positioning a lifeguard throughout each testing procedure. Two digital video cameras (Canon GL, 2002) were placed into underwater housings (Equinox, Michigan, 2002) and secured on aquatic wheelchairs which were positioned at two meters away on both sides of the aquatic treadmill (AquaGaiterTM, FERNO, Ohio, 2002). The aquatic treadmill was calibrated using two white tapes, 0.9 meter a part, on the side of the treadmill. To synchronize the two video cameras, red flash light were used during testing trials (Figure 3).

Data processing procedures are presented in Table 3. Captured video was imported to computer. Total of two strides were randomly selected and edited with video editing software (Arc Soft Show Biz software). Edited video was imported and digitized using motion analysis software (Human ® motion, Ontario, Canada, 2005).

Statistical Analysis

The outcome of this study were analyzed by performing repeated measures multivariate analysis of variance (MANOVA) with one between subject factor (TBI and Non-TBI groups) and one within subject factor (three levels of water depths: waist, chest and neck level).

First, it was hypothesized that there would be significant differences in gait kinematics of aquatic treadmill walking across three different water depths in both TBI and Non-TBI groups.

Second, it was hypothesized that there would be significant differences in stride time, stance / swing ratio, stride length and cadence among three different water depths in both TBI and Non-TBI groups.

Third, it was hypothesized that there would be significant differences in spatiotemporal gait and kinematics variables between TBI and Non-TBI groups across three different water depths.

Human Subject Review

This study was approved by the Institutional Review Board of California State University, Northridge. Potential risks to participants, including fatigue, dehydration or

fall on the treadmill, were minimized by providing close monitoring, scheduled water break, aquatic parallel bar and active spotting by research assistants. The safety of all participants was ensured by positioning a lifeguard throughout each testing procedure. All the procedures, risks and benefits of the study were explained to all participants before they participated in the study. Informed consent (Appendix A) was obtained from participants and participants were permitted to withdraw from the study at anytime for any reason.

Table 2: Data Collection Procedures

	Testng Procedures
1. Pre-test Administration	<ul style="list-style-type: none">▪ Informed consent▪ Explanation of testing protocol
2. Participant Preparation	<ul style="list-style-type: none">▪ Tight swimsuit▪ Aqua shoes.▪ Marker attachment▪ Measure participants' leg length
3. Data Collection	<ul style="list-style-type: none">▪ 5 min aquatic treadmill walking warm up.▪ Familiarization▪ Selection of comfortable speed.▪ Three two-min walking at three depths of water.▪ Two-min resting time between each trials.

Table 3. Data Process Procedures

1. Data Process	<ul style="list-style-type: none">▪ Edit video with Showbiz software▪ Gait digitization with HUMANTM software
2. Data Analysis	<ul style="list-style-type: none">▪ Export spatiotemporal and kinematic data from HUMAN software to Microsoft Excel software▪ Draw kinematic graphs

Figure 2. Marker attachment and locations: the midpoint on the iliac crest between the anterior and posterior superior iliac spine, the greater trochanter, the lateral femoral condyle, the lateral malleolus, the midpoint of calcaneus bone and the fifth metatarsal-phalangeal joint (Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2005)

Figure 3: The set up for aquatic treadmill walking trials. Two digital video cameras with underwater housing were positioned on left and right side of participants to capture underwater walking in sagittal plane (2 meters away from the treadmill). The red light was used to synchronize both cameras.

RESULTS

The purpose of this study was to investigate the biomechanical characteristics of aquatic treadmill walking at three different water depths in individuals with and without TBI. The biomechanical differences were examined in two categories including spatiotemporal and kinematic gait variables. There were four spatiotemporal variables (cadence, stride length, stride time, and stance/swing time ratio) and nine lower limb sagittal plane joint kinematic variables (peak flexion/extension angles and excursions of the hip, knee and ankle joints). In addition the differences in gait characteristics between individuals with TBI and those without TBI were compared. Thirteen TBI and fifteen Non-TBI participants completed the data collection on (Table 4). Six of the participants in TBI group used a walker as an assistive device; while seven had no assistive device during daily overground walking (Table 5). Etiologies of brain injury in this study were a motor vehicle accident (9), fall (1), a blow from external objects (2) and violence (1).

It was hypothesized that there would be significant differences in spatiotemporal variables among three water depths in both groups. Both groups revealed significant differences in spatiotemporal variables in including stride length, stride time, cadence and stance/swing ratio (all P s < .05).

The second hypothesis was that there would be significant changes in kinematic variables among three water depths in both groups. Both groups showed significant changes in hip flexion, hip ROM, ankle dorsi flexion, plantar flexion and ankle ROM (all P s < .05).

Finally, it was hypothesized that there would be significant group differences. Significant group interactions were found in peak hip flexion, hip extension, ankle dorsi flexion and ankle ROM (all P s < .05).

Biomechanical Analysis

Biomechanical variables of aquatic treadmill walking among three water depths were analyzed with four spatiotemporal variables (stride time, stride length, stance / swing ratio, and cadence) and nine kinematics variables (peak joint angles of flexion and extension and ROM in the hip, knee and ankle joints). A repeated measures multivariate analysis of variance (MANOVA) was used to analyze the biomechanical differences. Results of spatiotemporal differences are summarized on Table 6 and differences kinematic differences on Table 7.

Statistical analysis for Non-TBI group showed significant differences among three water depths in seven variables: stride time ($F= 17.757, p < .001$) (Figure 4), stride length ($F= 17.402, p < .001$) (Figure 5), stance swing ratio ($F= 39.384, p < .001$) (Figure 6), cadence ($F= 15.336, p < .001$) (Figure 7), hip flexion/extension excursion ($F= 22.861, p < .001$) (Figure 9), peak ankle plantar-flexion ($F= 10.985, p < .001$) (Figure 11), and ankle dorsi- / plantar-flexion excursion ($F=12.517, p < .01$) (Figure 12). Non-TBI group significantly increased stride length and stride time by 8%, and decreased cadence by 8% during aquatic treadmill walking at the neck level as compared to the chest level at a matched walking speed. In addition, stance/swing ratio significantly decreased by 6% from the waist level to the chest level, 23% from the chest level to neck level of water. The results also revealed that the Non-TBI group significantly decreased hip excursion by

17%, increased ankle plantar flexion by 12% and ankle excursion by 17% at the neck level as compared to the chest level.

Statistical analysis for the TBI group showed significant differences among three water depths in four variables: stance swing ratio ($F=6.822, p < .023$) (Figure 6), peak hip flexion ($F= 11.564, p < .001$) (Figure 8), peak ankle dorsi-flexion ($F= 27.94, p < .001$) (Figure 10), and ankle dorsi- / plantar-flexion excursion ($F=2.188, p < .021$) (Figure 12). TBI group significantly decreased stance/ swing ratio by 17.5% at the chest level when compared to the waist level. Peak hip flexion was significantly decreased by 9.1% from the waist to the chest level. Ankle excursion was decreased by 3.6% from the waist to the chest level and by 8.7% from the chest to the neck level in TBI group. In addition, peak ankle dorsi-flexion was decreased by 42% at the neck level compared to the chest level.

Group Difference Analysis

A repeated measures MANOVA with one between-subject factor (TBI and Non-TBI groups) and one within-subject factor (three levels of water depths: waist, chest and neck levels) was used to evaluate the group interactions. The purpose of this statistical analysis was to determine which group demonstrated greater differences in each dependent variable across three water depths. The results of the repeated measures MANOVA are presented in Table 8.

Significant group interactions were found in four variables including peak hip flexion ($F = 7.170, p < .002$) (Figure 13), peak hip extension ($F = 5.179, p < .009$) (Figure 14), ankle dorsi-flexion ($F = 24.321, p < .001$) (Figure 15), and ankle dorsi-/ plantar-flexion excursion ($F = 5.418, p < .007$) (Figure 16). The TBI group showed greater

differences during aquatic treadmill walking among three water depths in peak hip flexion and extension, as compared to Non-TBI group. On the other hand, Non-TBI group had greater differences in peak ankle dorsi-flexion and excursion than TBI group. No significant group interaction was found in the knee kinematic variables.

Table 4.

Summary of subject physical characteristics in NonTBI and TBI groups

	NTBI		TBI	
	Mean	SD	Mean	SD
Age (years)	37.07	10.87	43.23	12.04
Weight (kg)	76.67	16.23	80.77	15.03
Height (cm)	170.01	9.57	174.68	9.4
Post-TBI	N/A	N/A	12.67	10.59
Males:Females	9:6		13:2	
Total	15		15	

NTBI = Non TBI Group, TBI = TBI Group

Table 5

Summary of walking aids in TBI group

TBI Group	Sample Size	Functional Walking Aids	
		No aids	Walker
Female	1	0	1
Male	12	7	5
Total	13	7	6

TABLE 6.

Spatiotemporal Variables - NonTBI & TBI Group

Group	Variables	Mean (SD)			Statistical Comparison	
		W	C	N	F	p
NTBI	Stride Length	0.75 (.12)	.76 (.12)	.81 (.12) *	17.402	0.000 *
	Stride Time	1.64 (.20)	1.66 (.26)	1.81 (.31) *	17.757	0.000 *
	S/S	1.50 (.19)	1.41 (.19) *	1.08 (.31) *	39.384	0.000 *
	Cadence	74 (8.73)	74 (10.36)	68 (12.43) *	15.336	0.000 *
TBI	Stride Length	.36 (.17)	.41 (.33)	.42 (.28)	1.868	0.176
	Stride Time	2.74 (.78)	2.87 (.64)	2.92 (.47)	0.544	0.587
	S/S	2.34 (.60)	1.93 (.55) *	1.97 (.72)	6.822	0.023 *
	Cadence	48 (17.81)	44 (9.72)	43 (6.99)	1.583	0.226

* p< .05

NTBI = Non-TBI group, TBI = TBI group

W = Waist, C = Chest, N = Neck level of water

S/S = Stance / Swing ratio

Figure 4.

Comparison of stride time among three depths of water in both groups.

W = Waist level, C = Chest level, N = Neck level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 5.

Comparison of stride length among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 6.

Comparison of stance/swing time ratio among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 7.

Comparison of cadence among three depths of water in both groups

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

TABLE 7.

Peak Joint Angle Comparison among Three Depths of Water - NonTBI & TBI Group

Group	Variables	Mean (SD)			Statistical Comparison	
		W	C	N	F	p
NTBI Group	Hip Flex	37.59 (8.25)	37.80 (8.79)	35.74 (8.21)	2.85	0.075
	Hip Ext	3.69 (10.63)	3.97 (12.33)	8.53 (9.32)	3.801	0.072
	Hip ROM	33.90 (8.19)	32.96 (8.00)	27.21 (7.54)*	22.861	0.000*
	Knee Flex	70.37 (5.24)	69.65 (7.26)	67.76 (8.97)	2.59	0.093
	Knee Ext	11.10 (5.15)	9.99 (5.55)	10.10 (4.96)	0.104	0.901
	Knee ROM	59.27 (4.32)	59.66 (6.32)	57.66 (9.25)	2.534	0.153
	Ankle DF	13.62 (5.39)	14.11 (3.57)	14.48 (4.83)	0.232	0.795
	Ankle PF	46.10 (6.00)	46.90 (6.30)	52.37 (6.15)*	10.985	0.000*
	Ankle ROM	32.48 (8.84)	32.39 (6.54)	37.89 (7.14)*	12.517	0.000*
TBI Group	Hip Flex	55.91 (14.80)	50.77 (14.30)*	47.41 (15.87)	11.564	0.000*
	Hip Ext	14.51 (14.99)	12.80 (17.33)	14.97 (14.70)	2.421	0.110
	Hip ROM	41.41 (10.31)	37.96 (9.47)	32.44 (15.72)	6.955	0.004
	Knee Flex	64.26 (13.31)	63.06 (16.20)	61.35 (17.09)	3.359	0.052
	Knee Ext	15.16 (10.73)	14.50 (10.48)	17.76 (10.29)	0.111	0.896
	Knee ROM	49.10 (16.26)	48.55 (17.91)	43.59 (11.95)	3.213	0.058
	Ankle DF	-12.16 (6.99)	-15.66 (7.78)	-22.24 (10.02)*	27.94	0.000*
	Ankle PF	47.38 (13.88)	49.61 (11.27)	53.22 (15.87)	4.624	0.140
	Ankle ROM	35.22 (11.40)	33.95 (12.17)*	30.98 (8.67)*	2.188	0.021*

* p< .05 NTBI = Non-TBI group, TBI = TBI group

RT = Right limb, LT = Left limb

W = Waist, C = Chest, N = Neck level of water

Figure 8.

Comparisons of peak hip flexion among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 9.

Comparisons of hip flexion / extension ROM among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 10.

Comparisons of ankle dorsi-flexion among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 11.

Comparisons of ankle plantar-flexion among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Figure 12.

Comparisons of ankle dorsi-/plantar-flecion ROM among three depths of water in both groups.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Statistically significant $p < .05$

Table 8.

The repeated measure MANOVA results for the interaction (groups x conditions) analysis

Variables	Repeated measure MANOVA Results					
	Group		Conditions		Group X Condition	
	F	P	F	P	F	P
Stride time	52.017	*0.000	3.003	0.058	0.039	0.962
Stance/swing ratio	22.550	*0.000	11.689	*0.000	2.196	0.121
Stride length	36.382	*0.000	11.262	*0.000	1.318	0.276
Cadence	49.330	*0.000	7.658	*0.001	0.355	0.703
Hip Flex	17.856	*0.000	13.975	*0.000	7.170	*0.002
Hip Ext	8.716	*0.007	1.415	0.252	5.179	*0.009
Hip Exc	3.230	0.084	20.592	*0.000	1.050	0.357
Knee Flex	1.459	0.238	5.991	*0.005	0.376	0.689
Knee Ext	7.084	*0.013	0.167	0.847	0.081	0.922
Knee Exc	9.270	*0.005	5.803	*0.005	0.612	0.546
Ankle DF	3.342	0.079	20.703	*0.000	24.321	*0.000
Ankle PF	0.117	0.735	11.229	*0.000	1.239	0.298
Ankle Exc	3.681	0.066	3.929	*0.026	5.418	*0.007

* Significantly different $p < 0.05$

flex=flexion, ext=extension, exc=excursion

DF=dorsiflexion, PF=plantarflexion

Figure 13.

Group interaction of the peak hip flexion comparisons between two groups among three depths of water.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Significantly different within group among three depths of water ($p < .05$)

☆☆ Significant group interaction ($p < .05$)

Figure 14.

Group interaction of the peak hip extension comparisons between two groups among three depths of water.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆☆☆ Significant group interaction ($p < .05$)

Figure 15.

Group interaction of the peak ankle dorsi-flexion comparisons between two groups among three depths of water.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Significantly different within group among three depths of water ($p < .05$)

☆☆ Significant group interaction ($p < .05$)

Figure 16.

Group interaction of the ankle dorsi- / plantar-flexion excursion comparisons between two groups among three depths of water.

W = Waist, C = Chest, N = Neck Level

TBI = Traumatic Brain Injury Group, NTBI = Non Traumatic Brain Injury Group

☆ Significantly different within group among three depths of water ($p < .05$)

☆☆ Significant group interaction ($p < .05$)

DISCUSSION

The purpose of this study was to determine the biomechanical differences in aquatic treadmill walking among three different water depths in individuals with and without TBI. Four spatiotemporal and nine joint kinematic variables were analyzed based on aquatic treadmill walking data at three depths of water (waist, chest, and neck).

The first hypothesis of this study was that there would be significant differences in gait kinematics of aquatic treadmill walking across three different water depths in both TBI and Non-TBI groups. Second, it was hypothesized that there would be significant differences in spatiotemporal gait variables of aquatic treadmill walking across three different water depths in both groups. Third hypothesis was that there would be significant group differences in all gait variables across three different water depths.

All three hypotheses in the research were supported by the results of gait analysis of aquatic treadmill walking at different water depths. It was revealed that both TBI and Non-TBI groups showed significant differences in kinematic variables. The comparison of spatiotemporal variables also showed significant differences among three depths of water in both groups. In addition, there were significant group interactions when aquatic treadmill walking patterns were compared at three depths of water.

There were some limitations and assumptions in this study. Limitations of this study included the placement of markers on the subjects' skin and marker movements. The movements of the skin may not precisely represent motions of the each joint. The aquatic treadmill had a tendency of slight deceleration upon stepping down on the belt during testing trials. It might have affected continuous stepping response and gait balance. Data were analyzed with the HUMAN motion analysis program which was

assumed to measure accurate and reliable spatiotemporal and kinematic gait variables. Eleven out of thirty participants (three from the TBI and eight from the Non-TBI group) had never walked on an aquatic treadmill before the testing trials. Although all participants received a five-minute familiarization trial on aquatic treadmill there might have been some training effect difference from their previous experiences. All participants in both groups were asked to hold onto an aquatic parallel bar for safety while walking on the aquatic treadmill. One researcher was designated to perform marker attachment, video editing, data processing and analysis to eliminate the issues with inter-tester reliability.

Spatiotemporal Gait Variables

Spatiotemporal gait variables included stride time, stride length, stance/swing ratio, and cadence. Non-TBI group used longer stride length (0.82 ± 0.12 meters) and stride time (1.80 ± 0.31 seconds) when water became deeper to the neck level whereas TBI group did not show significant differences in them. Non-TBI group demonstrated significant decrease in stance / swing ratio from the chest level (1.41 ± 0.19 seconds) to the neck level (1.08 ± 0.31 seconds) and TBI group also showed a significant decrease in stance / swing ratio from the waist level ($2.34 \pm .60$ seconds) to the chest level ($1.93 \pm .55$ seconds). Cadence was significantly decreased in Non-TBI group when water level changed from the chest (74 steps/minutes) to the neck level (68 steps/minutes). No significant change of cadence was found in TBI group among three depths of water. These changes can be explained in association with the properties of water.

The significant increase of stride time at the neck level can be explained with the effect of buoyancy which played a role lifting their body weight upward allowing people to have longer single limb phase during stance. Participants also seemed to have difficulty to propel their limbs forward due to water resistance and drag force. The drag force was pulling the limbs backward as participants were trying to accelerate the swing and caused delay in swing phase resulting in longer stride time. The longer swing time resulted in significant decrease in stance/swing ratio. Individuals took longer time to complete a stride against water resistance. While they were having longer swing time, the belt under the swinging foot kept moving and forced them to make longer strides. The longer stride time affected participants to take significantly less cadence which is step counts per minute.

The changes in gait variables of this study shared a similar trend with several previous studies that used PWB set up. It was documented that there was a decrease in cadence and an increase in stride length from no body weight support to 50 % body weight support treadmill walking in healthy individuals (Threlkeld, Cooper, Monger, Craven, & Haupt, 2003). As water gets deeper, body weight support increases accordingly. It was reported that at the waist level, approximately 50%, at the chest level, approximately 70-75%, and at the neck level, approximately 90% of body weight are supported (Bates & Hanson, 1996; Driver, O'Connor, Lox, & Rees, 2004). The similar findings in spatiotemporal gait variables from Non-TBI participants seem to be contributed by the weight support effect of aquatic walking mostly due to buoyancy. Even though TBI group did not show significant differences in stride time, stride length and

cadence, the results showed similar trends as Non-TBI group. A larger sample size may be able to convert those trends into statistical significance.

In this study, individuals with TBI demonstrated shorter stride length, slower self-selected comfortable walking speed compared to individuals without TBI. These findings were consistent with those of the previous research conducted for overground and aquatic walking (Chou, Kaufman, Walker-Rabatin, Brey, & Basford, 2004; Ochi, Esquenazi, Hirai, & Talaty, 1999).

Kinematic Variables

In general, both TBI and Non-TBI groups showed some alterations in the hip and ankle kinematics across the different water depths. Non-TBI group showed significant changes across three water depths in hip excursion (Figure 17), ankle plantar flexion and ankle excursion (Figure 21). TBI group showed significant changes in hip flexion (Figure 18), ankle dorsi-flexion, and ankle excursion (Figure 22). There were no significant differences in the knee kinematics across three depths of water in both groups (Figure 19 & Figure 20).

The peak hip flexion was significantly decreased as the water became deeper from the waist to the chest level in TBI group (Figure 18). Non-TBI group showed only a trend to use less peak hip flexion (Figure 17). The increased water resistance in deeper water can contribute to the limitation in their hip flexion in TBI group. Overcoming water resistance and drag force in deeper water seemed to be more challenging for people with TBI.

Non-TBI group used significantly less hip ROM at the neck level of water (27.21 ± 7.54 degree) compare to chest level (32.96 ± 8.00 degree) (Figure 17). TBI group also showed a similar trend in the hip ROM, but the differences were not statistically significant. The decreased hip ROM can be explained by water resistance and buoyancy effect. Participants could not propel their hip forward against increased resistance in deeper water. In addition, the buoyancy can force individuals to keep their body in an upright position elevating their center of mass. This can create an environment that challenges the dynamic balance of participants. With challenged balance their total hip movement tends to be less confident resulting in a decreased ROM.

In TBI group, peak ankle dorsi-flexion was decreased from the chest level (-15.66 ± 7.78 degrees) to the neck level (-22.24 ± 10.02 degrees) during stance phase. Non-TBI group showed an increase in their peak plantar-flexion angle from the chest level (46.90 ± 6.30 degrees) to the neck level (52.37 ± 6.15 degrees). TBI group probably could not overcome the water resistance and the drag force. Non-TBI group increased their peak plantar-flexion as water became deeper while they were walking on their toes at the neck level. The belt of the treadmill seemed to drag their foot backward at the toe off phase. Both groups had no clear heel strike at the neck level.

There was significant change in ankle ROM in both groups. TBI group showed significant decreases in ankle ROM from the waist level (35.22 ± 11.40 degrees) to the chest level (33.95 ± 12.17 degrees) and from the chest level to the neck level (30.98 ± 8.67 degrees). In contrast, there was a significant increase in ankle ROM with Non-TBI group from the chest level (32.39 ± 6.54 degrees) to neck level (37.89 ± 7.14 degrees). The ankle kinematic graphs are presented in Figure 21 and 22. The ROM was decreased

in TBI group as water became deeper because of the decrease in dorsi-flexion at the ankle joint. The water resistance and the drag force played a role making individuals with TBI limit ankle ROM. On the other hand, people without TBI increased their ankle ROM because they were able to take advantage of the treadmill belt during stance and overcome water resistance and drag force during swing.

It was assumed that individuals might have more freedom to use greater movements as water becomes deeper thanks to the effect of buoyancy. However this study findings indicate that individuals from both TBI and Non-TBI groups used less hip excursion when water level became deeper from the chest to the neck level. The drag force, eddy turbulence, and water resistance may have counteracted or even overpowered the effects of buoyancy resulting in less hip ROM. Another possible explanation is that the buoyancy effects may cause too much difficulty in balancing and people can not propel their hip forward with confidence. In addition, individuals with TBI are often observed to have excessive hip flexion throughout the stance phase during overground walking and they tend to reduce their sagittal movements to maintain balance (Esquenazi, 2004). In the water, TBI group did not show excessive hip flexion mainly due to the buoyancy allowing them stand upright and also aquatic parallel bar provided for safety and stability which prohibited them from having a crouched position.

The absence of significant changes in knee kinematics during the stance phase can be explained with the findings from previous research by Miyoshi et al (2005). The research group analyzed the functional role of lower limbs while walking in the water and identified that the function of the knee joint movement is to absorb the impact force during the initial gait cycle. This can explain why there were no significant changes in

knee kinematics in the present study. Thanks to the buoyancy effect and its PWB effect, individuals did not need to utilize the shock absorbing function of their knee joints at foot strike. The change in the water depth from the waist to the neck level may have not imposed significantly more demand of the shock absorbing function from the knee. The results demonstrated no significant differences in knee kinematics during swing phase as well. The anatomical structure of the lower extremity may contribute to the result as well. The shank of the lower extremity has less surface area as compared to the thigh area. The knee movement does not seem to get as much water resistance as the hip that needs to swing the larger thigh surface.

The results of group interaction showed that TBI group had greater change as water became deeper. Individuals with TBI already have altered motor behaviors due to the nature of their disability (Ochi, Esquenazi, Hirai, & Talaty, 1999). The impaired motor characteristics can limit their ability to adapt to a new task or environment, such as walking on an aquatic treadmill in deeper depth of water. This limitation in their motor adaptation seems to make an adjustment more difficult which result in not being able to make any adaptation to different water depths.

Figure 17.

Hip kinematics in Non-TBI group among three depths of water.

Figure 18.

Hip kinematics in TBI group among three depths of water.

NonTBI Knee Kinematics

Figure 19.

Knee kinematics in Non-TBI group among three depths of water.

Figure 20.

Knee kinematics in TBI group among three depths of water.

NTBI Ankle Kinematics

Figure 21.

Ankle kinematics in Non-TBI group among three depths of water.

TBI Ankle Kinematics

Figure 22.

Ankle kinematics in TBI group among three depths of water.

Clinical Significance

As discussed earlier, there is no previous study which compared biomechanical differences in walking among three water depths. The results from this study revealed that walking on the aquatic treadmill at different depths of water affects gait patterns in both people with and without TBI. It is recommended to consider the differences when providing gait training at the neck level of water for individuals with TBI. The increased buoyancy effects at the deeper water can create too much floatation which can challenge balance during gait. In addition, clinicians and researchers are suggested to pay closer attention to the findings in the ankle kinematics when using the aquatic treadmill for gait training and analysis. It is not advised to use the neck level depth water for people with TBI because many of them are already dealing with excessive plantar-flexion mostly due to spasticity and muscular contracture. When clinicians use an aquatic treadmill as a gait training method, they should gradually progress their clients from a deeper depths to the waist level since walking at the waist level shows similar gait kinematics patterns to overground walking.

Future Research

The results of this research have created additional research questions which can be addressed in the future studies. First, this study only focused on two-dimensional biomechanical analysis hence it did not allow researcher to determine kinematic variables in the frontal and transverse planes. A future investigation can be conducted in three dimensions to have more comprehensive understanding of aquatic treadmill walking at various water depths. Second, this investigation included participants with TBI who use

various assisted devices on overground walking. Further research is suggested to determine biomechanical variables on the aquatic treadmill walking with individuals who use the same assisted device on land.

Finally, this investigation compared aquatic treadmill walking among three depths of water only with individuals with TBI and Non-TBI. It would be valuable to apply a similar research method to individuals with other physical disabilities to extend the understanding of aquatic gait patterns which will allow clinicians to design more scientific and evidence-based rehabilitation program in the future.

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APPENDIX A

California State University, Northridge **Aquatic Treadmill Walking at Various Water Depths in Individuals with and without Traumatic Brain Injury.**

INFORMED CONSENT FORM

You are invited to participate in a study titled "Aquatic Treadmill Walking at Various Water Depths in Individuals with and without Traumatic Brain Injury (TBI)" conducted by Mai Narasaki, a graduate student in the Department of Kinesiology. The study will be conducted under the supervision of Dr. Taeyou Jung and other research committee members at the Center of Achievement / Brown Center at California State University, Northridge. The purpose of this study is to investigate characteristics of aquatic treadmill walking at different depths of water among individuals with and without TBI.

Walking is one of the most important aspects of rehabilitation exercise in people with TBI. Treadmill-based gait training has been shown to be effective for walking skill improvement in people with TBI. Particularly in combination with partial weight bearing (PWB) system, treadmill-based gait training has been reported to be more effective. The effects of PWB can also be obtained by practicing walking in water. Although many researchers have documented the effects of aquatic exercises among people with neuromuscular disabilities, few studied characteristics of underwater walking. The study will analyze walking characteristics during aquatic treadmill walking at three different depths of water: waist, chest and neck level.

In this study, you will be asked to change into swim suit and walk with appropriate footwear (aqua shoes) during the testing procedure. Eight mm adhesive markers will be attached (6 on each side of the leg) on your skin. You will be asked to walk at a comfortable pace on aquatic treadmill at three different depths of water. You will be given a five-minute practice trial before you have total of **three two-minute testing trials**. There will be a two-minute resting time between each trial. During your testing trials your walking will be **videotaped** by underwater DV camcorder positioned on your left and right sides.

Potential risks may include slight skin rashes from markers, physical fatigue, dehydration, and water hazards. Non-toxic markers will be used to minimize skin irritation. Physical fatigue will be monitored by an on-site assistant and minimized by providing frequent resting time between trials. You will be advised to drink water prior to and after the testing procedure.

You will be pre-screened for any other potential health risk factors for this study. You should not participate in this study if you are not able to walk or have acute health conditions. In the unlikely event of injury resulting from participating in this

study, **you will be required to assume financial responsibility for your own medical care.** In case you need first-aid, you will be referred to the Student Health Center at California State University, Northridge.

You will not receive monetary compensation for participation in this study. However, you will make valuable contributions to the field of adapted therapeutic exercise and aquatic rehabilitation by enhancing our understanding of underwater. The study will add to the limited literature on the effects of using aquatic treadmill for gait training in people with neuromuscular disabilities. This information will be valuable for providing evidence-based adapted exercise program or rehabilitation for people with disabilities.

Any information collected in this study specifically related to you will remain confidential and will be disclosed only with your written permission or if required by law. The aggregate results of this study will be published, but the names or identity or participants will be kept confidential. All data/documentation collected as part of this project will be secured by the researcher or the research advisor at the conclusion of the study and will be placed in a locked file cabinet at the Center of Achievement

You should understand that this approval to participate in this study is completely voluntary, and **you may decline to participate or withdraw from the study at any time without jeopardy.**

If you wish to discuss a concern about the research, you may direct your question(s) to Research and Sponsored Projects, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330, or call (818) 677-2901. If you have specific questions about the study, you may contact Mai Narasaki or Dr. Taeyou Jung, research advisor, at Center of Achievement, 18111 Nordhoff Street, Northridge, CA 91330, or call (818) 677 – 2182.

I have read the above and understand the conditions outlined for participation in the described study. I give my informed consent to participate in the study.

Name _____
Last First MI

Address _____

City _____ State _____ Zip _____

Signature _____ Date _____

Witness/P.I. signature _____ Date _____

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE
EXPERIMENTAL SUBJECTS
BILL OF RIGHTS

The rights below are the rights of every person who is asked to be in a research study.
As an experimental subject I have the following rights:

To be told what the study is trying to find out,

To be told what will happen to me and whether any of the procedures, drugs, or devices is different from what would be used in standard practice,

To be told about the frequent and/or important risks, side effects or discomforts of the things that will happen to me for research purposes,

To be told if I can expect any benefit from participating, and, if so, what the benefit might be,

To be told the other choices I have and how they may be better or worse than being in the study,

To be allowed to ask any questions concerning the study both before agreeing to be involved and during the course of the study,

To be told what sort of medical treatment (if needed) is available if any complications arise,

To refuse to participate at all or to change my mind about participation after the study is started. This decision will not affect my right to receive the care I would receive if I were not in the study,

To receive a copy of the signed and dated consent form,

To be free of pressure when considering whether I wish to agree to be in the study.

If I have other questions I should ask the researcher or the research assistant, or contact Research and Sponsored Projects, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8232, or phone (818) 677-2941.

X _____
Signature of Subject

Date

APPENDIX B

Repeated Measure MANOVA Summary Tables

Repeated Measure MANOVA

<Both Groups>

Table B1: Stride Time (Both Groups)
Table B2: Stride Length (Both Groups)
Table B3: Stance/Swing Ratio (Both Groups)
Table B4: Cadence (Both Groups)
Table B5: Peak Hip Flexion (Both Groups)
Table B6: Peak Hip Extension (Both Groups)
Table B7: Hip ROM (Both Groups)
Table B8: Peak Knee Flexion (Both Groups)
Table B9: Peak Knee Extension (Both Groups)
Table B10: Knee ROM (Both Groups)
Table B11: Peak Ankle DF (Both Groups)
Table B12: Peak Ankle PF (Both Groups)
Table B13: Ankle ROM (Both Groups)

Repeated Measure MANOVA

<NonTBI Group>

Table B14: Stride Time (NTBI)
Table B15: Stride Length (NTBI)
Table B16: Stance/Swing Ratio (NTBI)
Table B17: Cadence (NTBI)
Table B18: Peak Hip Flexion (NTBI)
Table B19: Peak Hip Extension (NTBI)
Table B20: Hip ROM (NTBI)
Table B21: Peak Knee Flexion (NTBI)
Table B22: Peak Knee Extension (NTBI)

Table B23: Knee ROM (NTBI)
Table B24: Peak Ankle DF(NTBI)
Table B25: Peak Ankle PF (NTBI)
Table B26: Ankle ROM (NTBI)

Repeated Measure MANOVA

<TBI Group>

Table B27: Stride Time (TBI)
Table B28: Stride Length (TBI)
Table B29: Stance/Swing Ratio (NTBI)
Table B30: Cadence (TBI)
Table B31: Peak Hip Flexion (TBI)
Table B32: Peak Hip Extension (TBI)
Table B33: Hip ROM (TBI)
Table B34: Peak Knee Flexion (TBI)
Table B35: Peak Knee Extension (TBI)
Table B36: Knee ROM (TBI)
Table B37: Peak Ankle DF(TBI)
Table B38: Peak Ankle PF (TBI)
Table B39: Peak Ankle ROM (TBI)

Table B1**Repeated Measures MANOVA Table: Stride Time (Both Groups)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	0.04	0.04	0.31	0.58
	Level 2 vs. Level 3	1	0.55	0.55	2.75	0.11
Mode*Subject	Level 1 vs. Level 2	1	0.00	0.00	0.00	1.00
	Level 2 vs. Level 3	1	0.01	0.01	0.05	0.83
Error(Mode)	Level 1 vs. Level 2	26	3.81	0.15		
	Level 2 vs. Level 3	26	5.17	0.20		

Table B2**Repeated Measures MANOVA Table: Stride Length (Both Groups)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	0.01	0.01	1.88	0.18
	Level 2 vs. Level 3	1	0.06	0.06	19.54	0.00
Mode*Subject	Level 1 vs. Level 2	1	0.00	0.00	0.12	0.73
	Level 2 vs. Level 3	1	0.01	0.01	4.50	0.04
Error(Mode)	Level 1 vs. Level 2	26	0.16	0.01		
	Level 2 vs. Level 3	26	0.08	0.00		

Table B3**Repeated Measures MANOVA Table: Stance/Swing Ratio (Both Groups)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	1.37	1.37	11.85	0.00
	Level 2 vs. Level 3	1	0.80	0.80	6.15	0.02
Mode*Subject	Level 1 vs. Level 2	1	0.48	0.48	4.16	0.05
	Level 2 vs. Level 3	1	0.71	0.71	5.41	0.03
Error(Mode)	Level 1 vs. Level 2	26	3.00	0.12		
	Level 2 vs. Level 3	26	3.39	0.13		

Table B4**Repeated Measures MANOVA Table: Cadence (Both Groups)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	131.23	131.23	1.43	0.24
	Level 2 vs. Level 3	1	550.25	550.25	12.34	0.00
Mode*Subject	Level 1 vs. Level 2	1	16.94	16.94	0.18	0.67
	Level 2 vs. Level 3	1	58.57	58.57	1.31	0.26
Error(Mode)	Level 1 vs. Level 2	26	2387.31	91.82		
	Level 2 vs. Level 3	26	1159.74	44.61		

Table B5**Repeated Measures MANOVA Table: Peak Hip Flexion (Both Groups)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	388.50	388.50	7.60	0.01
Level 2 vs. Level 3	1	272.51	272.51	5.87	0.02
Mode*Subject Level 1 vs. Level 2	1	449.02	449.02	8.78	0.01
Level 2 vs. Level 3	1	5.84	5.84	0.13	0.73
Error(Mode) Level 1 vs. Level 2	26	1329.22	51.12		
Level 2 vs. Level 3	26	1207.28	46.43		

Table B6**Repeated Measures MANOVA Table: Peak Hip Extension (Both Groups)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	76.00	76.00	1.83	0.19
Level 2 vs. Level 3	1	79.79	79.79	1.90	0.18
Mode*Subject Level 1 vs. Level 2	1	162.67	162.67	3.91	0.06
Level 2 vs. Level 3	1	40.90	40.90	0.98	0.33
Error(Mode) Level 1 vs. Level 2	26	1082.69	41.64		
Level 2 vs. Level 3	26	1089.46	41.90		

Table B7**Repeated Measures MANOVA Table: Hip ROM (Both Groups)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	120.84	120.84	4.79	0.04
Level 2 vs. Level 3	1	647.22	647.22	18.19	0.00
Mode*Subject Level 1 vs. Level 2	1	71.16	71.16	2.82	0.10
Level 2 vs. Level 3	1	15.83	15.83	0.44	0.51
Error(Mode) Level 1 vs. Level 2	26	655.60	25.22		
Level 2 vs. Level 3	26	924.97	35.58		

Table B8**Repeated Measures MANOVA Table: Peak Knee Flexion (Both Groups)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	176.54	176.54	3.74	0.06
Level 2 vs. Level 3	1	218.84	218.84	2.18	0.15
Mode*Subject Level 1 vs. Level 2	1	37.93	37.93	0.80	0.38
Level 2 vs. Level 3	1	0.02	0.02	0.00	0.99
Error(Mode) Level 1 vs. Level 2	26	1225.79	47.15		
Level 2 vs. Level 3	26	2609.84	100.38		

Table B9

Repeated Measures MANOVA Table: Peak Knee Extension (Both Groups)

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	5.47	5.47	0.19	0.67
	Level 2 vs. Level 3	1	9.01	9.01	0.62	0.44
Mode*Subject	Level 1 vs. Level 2	1	0.58	0.58	0.02	0.89
	Level 2 vs. Level 3	1	4.72	4.72	0.33	0.57
Error(Mode)	Level 1 vs. Level 2	26	744.01	28.62		
	Level 2 vs. Level 3	26	375.46	14.44		

Table B10

Repeated Measures MANOVA Table: Knee ROM (Both Groups)

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	170.79	170.79	4.71	0.04
	Level 2 vs. Level 3	1	316.65	316.65	3.11	0.09
Mode*Subject	Level 1 vs. Level 2	1	56.45	56.45	1.56	0.22
	Level 2 vs. Level 3	1	4.16	4.16	0.04	0.84
Error(Mode)	Level 1 vs. Level 2	26	941.90	36.23		
	Level 2 vs. Level 3	26	2643.96	101.69		

Table B11

Repeated Measures MANOVA Table: Peak Ankle DF (Both Groups)

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	47.28	47.28	3.36	0.08
	Level 2 vs. Level 3	1	213.38	213.38	16.37	0.00
Mode*Subject	Level 1 vs. Level 2	1	35.11	35.11	2.49	0.13
	Level 2 vs. Level 3	1	288.44	288.44	22.12	0.00
Error(Mode)	Level 1 vs. Level 2	26	366.09	14.08		
	Level 2 vs. Level 3	26	338.97	13.04		

Table B12

Repeated Measures MANOVA Table: Peak Ankle PF (Both Groups)

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	17.91	17.91	0.33	0.57
	Level 2 vs. Level 3	1	1205.56	1205.56	15.31	0.00
Mode*Subject	Level 1 vs. Level 2	1	118.01	118.01	2.20	0.15
	Level 2 vs. Level 3	1	119.64	119.64	1.52	0.23
Error(Mode)	Level 1 vs. Level 2	26	1395.31	53.67		
	Level 2 vs. Level 3	26	2047.66	78.76		

Table B13

Repeated Measures MANOVA Table: Ankle ROM (Both Groups)

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	123.36	123.36	2.98	0.10
	Level 2 vs. Level 3	1	404.53	404.53	6.73	0.02
Mode*Subject	Level 1 vs. Level 2	1	281.88	281.88	6.82	0.01
	Level 2 vs. Level 3	1	36.53	36.53	0.61	0.44
Error(Mode)	Level 1 vs. Level 2	26	1075.08	41.35		
	Level 2 vs. Level 3	26	1562.62	60.10		

Table B14**Repeated Measures MANOVA Table: Stride Time (NonTBI Group)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	0.02	0.02	2.53	0.13
Level 2 vs. Level 3	1	0.38	0.38	29.98	0.00
Error(Mode) Level 1 vs. Level 2	14	0.14	0.01		
Level 2 vs. Level 3	14	0.18	0.01		

Table B15**Repeated Measures MANOVA Table: Stride Length (NonTBI Group)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	0.00	0.00	1.89	0.19
Level 2 vs. Level 3	1	0.07	0.07	29.08	0.00
Error(Mode) Level 1 vs. Level 2	14	0.02	0.00		
Level 2 vs. Level 3	14	0.03	0.00		

Table B16**Repeated Measures MANOVA Table: Stance/Swing Ratio (NonTBI Group)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	0.12	0.12	11.14	0.00
Level 2 vs. Level 3	1	1.62	1.62	37.64	0.00
Error(Mode) Level 1 vs. Level 2	14	0.15	0.01		
Level 2 vs. Level 3	14	0.60	0.04		

Table B17**Repeated Measures MANOVA Table: Cadence (NonTBI Group)**

Source	df	SS	MS	F	p
Mode Level 1 vs. Level 2	1	29.01	29.01	1.78	0.20
Level 2 vs. Level 3	1	521.16	521.16	24.26	0.00
Error(Mode) Level 1 vs. Level 2	14	227.77	16.27		
Level 2 vs. Level 3	14	300.70	21.48		

Table B18**Repeated Measures MANOVA Table: Peak Hip Flexion (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	1.18	1.18	0.06	0.80
	Level 2 vs. Level 3	1	106.92	106.92	3.82	0.07
Error(Mode)	Level 1 vs. Level 2	14	255.62	18.26		
	Level 2 vs. Level 3	14	391.85	27.99		

Table B19**Repeated Measures MANOVA Table: Peak Hip Extension (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	8.77	8.77	0.42	0.53
	Level 2 vs. Level 3	1	126.51	126.51	3.80	0.07
Error(Mode)	Level 1 vs. Level 2	14	293.45	20.96		
	Level 2 vs. Level 3	14	465.96	33.28		

Table B20**Repeated Measures MANOVA Table: Hip ROM (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	3.52	3.52	0.26	0.62
	Level 2 vs. Level 3	1	466.03	466.03	28.61	0.00
Error(Mode)	Level 1 vs. Level 2	14	191.31	13.67		
	Level 2 vs. Level 3	14	228.04	16.29		

Table B21**Repeated Measures MANOVA Table: Peak Knee Flexion (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	27.36	27.36	1.08	0.32
	Level 2 vs. Level 3	1	119.96	119.96	1.55	0.23
Error(Mode)	Level 1 vs. Level 2	14	353.68	25.26		
	Level 2 vs. Level 3	14	1082.09	77.29		

Table B22**Repeated Measures MANOVA Table: Peak Knee Extension (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	1.34	1.34	0.23	0.64
	Level 2 vs. Level 3	1	0.37	0.37	0.09	0.77
Error(Mode)	Level 1 vs. Level 2	14	82.22	5.87		
	Level 2 vs. Level 3	14	57.36	4.10		

Table B23**Repeated Measures MANOVA Table: Knee ROM (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	16.62	16.62	0.61	0.45
	Level 2 vs. Level 3	1	133.64	133.64	1.94	0.19
Error(Mode)	Level 1 vs. Level 2	14	380.70	27.19		
	Level 2 vs. Level 3	14	964.90	68.92		

Table B24**Repeated Measures MANOVA Table: Peak Ankle DF (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	0.49	0.49	0.06	0.81
	Level 2 vs. Level 3	1	3.04	3.04	0.66	0.43
Error(Mode)	Level 1 vs. Level 2	14	107.83	7.70		
	Level 2 vs. Level 3	14	64.03	4.57		

Table B25**Repeated Measures MANOVA Table: Peak Ankle PF (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	23.68	23.68	2.53	0.13
	Level 2 vs. Level 3	1	304.57	304.57	9.38	0.01
Error(Mode)	Level 1 vs. Level 2	14	131.20	9.37		
	Level 2 vs. Level 3	14	454.75	32.48		

Table B26**Repeated Measures MANOVA Table: Ankle ROM (NonTBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	17.39	17.39	0.92	0.35
	Level 2 vs. Level 3	1	368.42	368.42	12.23	0.00
Error(Mode)	Level 1 vs. Level 2	14	265.78	18.98		
	Level 2 vs. Level 3	14	421.75	30.13		

Table B27**Repeated Measures MANOVA Table: Stride Time (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	0.02	0.02	0.07	0.80
	Level 2 vs. Level 3	1	0.19	0.19	0.46	0.51
Error (mode)	Level 1 vs. Level 2	12	3.68	0.31		
	Level 2 vs. Level 3	12	4.99	0.42		

Table B28**Repeated Measures MANOVA Table: Stride Length (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	0.01	0.01	0.76	0.40
	Level 2 vs. Level 3	1	0.01	0.01	1.99	0.18
Error (mode)	Level 1 vs. Level 2	12	0.13	0.01		
	Level 2 vs. Level 3	12	0.05	0.00		

Table B29**Repeated Measures MANOVA Table: Stance/Swing Ratio (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	1.62	1.62	6.82	0.02
	Level 2 vs. Level 3	1	0.00	0.00	0.01	0.94
Error (mode)	Level 1 vs. Level 2	12	2.84	0.24		
	Level 2 vs. Level 3	12	2.79	0.23		

Table B30**Repeated Measures MANOVA Table: Cadence (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	113.15	113.15	0.63	0.44
	Level 2 vs. Level 3	1	116.56	116.56	1.63	0.23
Error (mode)	Level 1 vs. Level 2	12	2159.54	179.96		
	Level 2 vs. Level 3	12	859.04	71.59		

Table B31**Repeated Measures MANOVA Table: Peak Hip Flexion (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	780.66	780.66	8.73	0.01
	Level 2 vs. Level 3	1	167.13	167.13	2.46	0.14
Error (mode)	Level 1 vs. Level 2	12	1073.60	89.47		
	Level 2 vs. Level 3	12	815.44	67.95		

Table B32**Repeated Measures MANOVA Table: Peak Hip Extension (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	215.16	215.16	3.27	0.10
	Level 2 vs. Level 3	1	3.00	3.00	0.06	0.81
Error (mode)	Level 1 vs. Level 2	12	789.23	65.77		
	Level 2 vs. Level 3	12	623.51	51.96		

Table B33**Repeated Measures MANOVA Table: Hip ROM (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	176.15	176.15	4.55	0.05
	Level 2 vs. Level 3	1	214.95	214.95	3.70	0.08
Error (mode)	Level 1 vs. Level 2	12	464.29	38.69		
	Level 2 vs. Level 3	12	696.93	58.08		

Table B34**Repeated Measures MANOVA Table: Peak Knee Flexion (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	176.46	176.46	2.43	0.15
	Level 2 vs. Level 3	1	100.30	100.30	0.79	0.39
Error (mode)	Level 1 vs. Level 2	12	872.11	72.68		
	Level 2 vs. Level 3	12	1527.75	127.31		

Table B35**Repeated Measures MANOVA Table: Peak Knee Extension (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	4.49	4.49	0.08	0.78
	Level 2 vs. Level 3	1	12.50	12.50	0.47	0.51
Error (mode)	Level 1 vs. Level 2	12	661.80	55.15		
	Level 2 vs. Level 3	12	318.10	26.51		

Table B36**Repeated Measures MANOVA Table: Knee ROM (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	197.69	197.69	4.23	0.06
	Level 2 vs. Level 3	1	183.61	183.61	1.31	0.27
Error (mode)	Level 1 vs. Level 2	12	561.21	46.77		
	Level 2 vs. Level 3	12	1679.05	139.92		

Table B37**Repeated Measures MANOVA Table: Peak Ankle DF (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	76.47	76.47	3.55	0.08
	Level 2 vs. Level 3	1	465.72	465.72	20.33	0.00
Error (mode)	Level 1 vs. Level 2	12	258.27	21.52		
	Level 2 vs. Level 3	12	274.94	22.91		

Table B38**Repeated Measures MANOVA Table: Peak Ankle PF (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	106.33	106.33	1.01	0.33
	Level 2 vs. Level 3	1	972.90	972.90	7.33	0.02
Error (mode)	Level 1 vs. Level 2	12	1264.11	105.34		
	Level 2 vs. Level 3	12	1592.91	132.74		

Table B39**Repeated Measures MANOVA Table: Ankle ROM (TBI Group)**

Source		df	SS	MS	F	p
Mode	Level 1 vs. Level 2	1	363.15	363.15	5.38	0.04
	Level 2 vs. Level 3	1	92.37	92.37	0.97	0.34
Error (mode)	Level 1 vs. Level 2	12	809.30	67.44		
	Level 2 vs. Level 3	12	1140.87	95.07		

Appendix C

Raw Data in SPSS Coding Format

Table C 1

Abbreviations used for coding for spatiotemporal variables

R_STR_W	Right stride time waist level
R_SS_W	Right stance/swing ratio waist level
R_SL_W	Right stride length waist level
R_CD_W	Right cadence waist level
L_STR_W	Left stride time waist level
L_SS_W	Left stance/swing ratio waist level
L_SL_W	Left stride length waist level
L_CD_W	Left cadence waist level
R_STR_C	Right stride time chest level
R_SS_C	Right stance/swing ratio chest level
R_SL_C	Right stride length chest level
R_CD_C	Right cadence chest level
L_STR_C	Left stride time chest level
L_SS_C	Left stance/swing ratio chest level
L_SL_C	Left stride length chest level
L_CD_C	Left cadence chest level
R_STR_N	Right stride time neck level
R_SS_N	Right stance/swing ratio neck level
R_SL_N	Right stride length neck level
R_CD_N	Right cadence neck level
L_STR_N	Left stride time neck level
L_SS_N	Left stance/swing ratio neck level
L_SL_N	Left stride length neck level
L_CD_N	Left cadence neck level

Table C 2

Abbreviations used for coding for kinematic variables

RH_MAX_W	Right hip peak flexion waist level
RH_MIN_W	Right hip peak extension waist level
RH_EX_W	Right hip excursion waist level
RK_MAX_W	Right knee peak flexion waist level
RK_MIN_W	Right knee peak extension waist level
RK_EX_W	Right knee excursion waist level
RA_MAX_W	Right ankle peak flexion waist level
RA_MIN_W	Right ankle peak extension waist level
RA_EX_W	Right ankle excursion waist level
LH_MAX_W	Left hip peak flexion waist level
LH_MIN_W	Left hip peak extension waist level
LH_EX_W	Left hip excursion waist level
LK_MAX_W	Left knee peak flexion waist level
LK_MIN_W	Left knee peak extension waist level
LK_EX_W	Left knee excursion waist level
LA_MAX_W	Left ankle peak flexion waist level
LA_MIN_W	Left ankle peak extension waist level
LA_EX_W	Left ankle excursion waist level
RH_MAX_C	Right hip peak flexion chest level
RH_MIN_C	Right hip peak extension chest level
RH_EX_C	Right hip excursion chest level
RK_MAX_C	Right knee peak flexion chest level
RK_MIN_C	Right knee peak extension chest level
RK_EX_C	Right knee excursion chest level
RA_MAX_C	Right ankle peak flexion chest level
RA_MIN_C	Right ankle peak extension chest level
RA_EX_C	Right ankle excursion chest level

LH_MAX_C	Left hip peak flexion chest level
LH_MIN_C	Left hip peak extension chest level
LH_EX_C	Left hip excursion chest level
LK_MAX_C	Left knee peak flexion chest level
LK_MIN_C	Left knee peak extension chest level
LK_EX_C	Left knee excursion chest level
LA_MAX_C	Left ankle peak flexion chest level
LA_MIN_C	Left ankle peak extension chest level
LA_EX_C	Left ankle excursion chest level
RH_MAX_N	Right hip peak flexion neck level
RH_MIN_N	Right hip peak extension neck level
RH_EX_N	Right hip excursion neck level
RK_MAX_N	Right knee peak flexion neck level
RK_MIN_N	Right knee peak extension neck level
RK_EX_N	Right knee excursion neck level
RA_MAX_N	Right ankle peak flexion neck level
RA_MIN_N	Right ankle peak extension neck level
RA_EX_N	Right ankle excursion neck level
LH_MAX_N	Left hip peak flexion neck level
LH_MIN_N	Left hip peak extension neck level
LH_EX_N	Left hip excursion neck level
LK_MAX_N	Left knee peak flexion neck level
LK_MIN_N	Left knee peak extension neck level
LK_EX_N	Left knee excursion neck level
LA_MAX_N	Left ankle peak flexion neck level
LA_MIN_N	Left ankle peak extension neck level
LA_EX_N	Left ankle excursion neck level

Table C 3-1

Repeated Measure MANOVA (Both Groups)

injury	R_STR_W	R_SS_W	R_SL_W	R_CD_W	L_STR_W	L_SS_W	L_SL_W	L_CD_W	RH_MAX_W	RH_MIN_W	RH_EX_W	RK_MAX_W	RK_MIN_W
1	1.94	1.62	0.67	62	1.97	1.56	0.68	61	22.09	-21.10	43.19	67.25	4.79
1	1.61	1.52	0.70	75	1.60	1.39	0.69	75	43.51	10.34	33.17	73.75	7.04
1	1.91	1.85	0.66	63	1.81	1.59	0.63	66	31.86	-9.25	41.11	66.56	1.49
1	1.77	1.53	0.80	68	1.77	1.64	0.80	68	40.03	7.67	32.36	82.86	19.87
1	1.41	1.31	0.83	85	1.37	1.45	0.81	88	34.74	-4.16	38.89	65.24	7.23
1	1.64	1.22	0.83	73	1.64	1.34	0.83	73	49.32	7.19	42.14	66.54	14.61
1	1.54	1.30	0.83	78	1.51	1.25	0.81	79	23.84	-0.95	24.79	73.57	17.07
1	1.37	1.91	0.59	88	1.37	1.74	0.59	88	41.18	21.93	19.25	66.73	12.28
1	1.47	1.45	0.74	82	1.50	1.50	0.76	80	29.59	-0.23	29.82	71.40	11.91
1	1.47	1.58	0.71	82	1.47	1.45	0.71	82	46.52	6.85	39.67	74.36	16.10
1	2.04	1.43	0.99	59	2.04	1.55	0.99	59	46.24	2.07	44.17	72.35	8.01
1	1.51	1.36	0.73	79	1.50	1.14	0.73	80	31.64	6.69	24.95	62.70	8.65
1	1.51	1.48	0.52	79	1.47	1.72	0.51	82	41.76	16.99	24.77	69.52	12.94
1	1.64	1.45	0.91	73	1.37	1.45	0.76	88	40.59	-1.03	41.62	66.55	8.05
1	1.74	1.49	0.69	69	1.67	1.49	0.67	72	40.90	12.33	28.57	76.19	16.41
2	3.71	2.71	0.32	32	3.70	2.49	0.32	32	28.13	-9.08	37.21	54.53	-5.36
2	3.44	0.94	0.30	35	3.40	1.91	0.30	35	61.09	-4.95	66.04	70.39	36.78
2	1.67	1.39	0.87	72	1.70	0.95	0.89	71	38.09	0.58	37.51	79.81	12.80
2	1.30	2.94	0.18	92	1.27	2.85	0.18	94	43.64	13.51	30.14	63.00	12.89
2	2.07	2.29	0.18	58	2.13	2.38	0.18	56	64.44	31.64	32.80	61.00	26.85
2	2.07	2.29	0.37	58	2.13	1.92	0.38	56	56.70	10.51	46.19	73.17	12.10
2	3.07	1.98	0.43	39	3.10	1.26	0.43	39	77.22	24.97	52.25	98.97	12.43
2	2.40	2.48	0.32	50	2.24	1.80	0.33	54	58.92	31.92	26.99	56.08	25.92
2	3.47	3.03	0.33	35	3.47	2.47	0.32	35	43.13	-4.08	47.21	59.53	10.36
2	3.37	2.62	0.35	36	3.37	2.15	0.35	36	73.22	29.40	43.82	54.27	19.98
2	3.17	2.30	0.33	38	3.24	2.03	0.34	37	71.56	27.76	43.80	54.23	2.53
2	2.51	2.59	0.26	48	2.47	2.21	0.26	49	62.99	24.21	38.77	58.12	16.94
2	3.31	2.80	0.40	36	3.37	2.15	0.41	36	47.72	12.17	35.54	62.26	12.88

Table C 3-2

Repeated Measure MANOVA (Both Groups)

injury	RK_EX_W	RA_MAX_W	RA_MIN_W	RA_EX_W	LH_MAX_W	LH_MIN_W	LH_EX_W	LK_MAX_W	LK_MIN_W	LK_EX_W	LA_MAX_W	LA_MIN_W	LA_EX_W
1	62.46	-0.71	-53.53	52.82	18.10	-18.77	36.87	65.34	2.34	63.00	-5.44	-40.17	34.72
1	66.71	-17.62	-43.41	25.79	55.98	22.86	33.12	71.13	9.23	61.90	-12.93	-47.12	34.19
1	65.07	-11.43	-48.85	37.42	33.13	-17.45	50.58	65.05	2.68	62.37	-12.20	-48.46	36.25
1	62.99	-12.24	-54.90	42.65	46.61	14.53	32.07	71.47	0.10	71.37	-13.83	-50.56	36.73
1	58.00	-9.82	-47.46	37.64	47.17	7.89	39.28	57.12	4.61	52.51	-14.42	-52.27	37.85
1	51.93	-17.03	-47.63	30.60	51.54	18.77	32.77	70.22	17.34	52.88	-21.63	-40.15	18.51
1	56.50	-7.85	-35.93	28.08	25.79	-4.44	30.23	75.74	12.73	63.01	-9.45	-35.59	26.13
1	54.45	-11.91	-35.40	23.48	14.32	-9.02	23.34	50.33	9.36	40.97	-14.92	-43.56	28.65
1	59.49	-19.86	-40.98	21.12	36.15	15.19	20.96	70.87	9.00	61.87	-17.87	-41.87	24.01
1	58.26	-14.80	-47.88	33.08	38.89	-0.15	39.05	67.41	3.09	64.32	-20.12	-43.16	23.04
1	64.33	-16.61	-54.22	37.60	56.70	14.59	42.12	73.07	9.66	63.41	-17.64	-57.76	40.12
1	54.05	-23.83	-42.39	18.56	40.69	11.70	28.99	63.85	5.63	58.22	-20.93	-42.51	21.58
1	56.58	-13.55	-42.2	28.65	33.29	8.76	24.52	61.16	10.31	50.85	-9.91	-42.02	32.11
1	58.50	-14.23	-48.24	34.01	42.33	0.66	41.68	67.64	10.01	57.63	-16.92	-44.30	27.38
1	59.78	-12.90	-48.55	35.65	39.95	7.60	32.35	66.32	5.06	61.26	-11.87	-47.43	35.56
2	59.89	-23.98	-76.39	52.41	55.37	16.90	38.47	58.41	-2.48	81.76	-21.76	-53.39	31.64
2	33.61	-2.74	-36.63	39.37	85.87	23.55	62.32	108.57	26.81	81.76	-12.11	-47.30	35.19
2	67.01	-7.24	-47.01	39.77	43.88	14.70	29.19	74.56	16.95	57.61	-7.94	-47.96	40.02
2	40.10	-12.16	-31.22	19.06	39.65	15.31	24.33	30.98	14.73	16.25	-13.88	-32.54	19.16
2	34.15	-10.56	-31.08	20.52	60.45	29.98	30.47	60.09	26.07	34.02	-11.05	-33.31	22.26
2	61.07	-5.21	-39.12	33.92	66.51	24.68	41.83	64.54	12.10	52.44	-6.54	-33.31	26.77
2	86.54	-21.59	-52.34	30.74	86.89	32.21	54.67	90.71	8.98	81.73	-17.75	-42.03	24.28
2	30.16	-14.15	-28.19	14.05	58.66	32.92	25.74	56.74	26.82	29.92	-13.22	-29.60	16.39
2	49.17	-18.98	-61.39	42.41	63.87	13.55	50.32	63.41	2.52	60.89	-16.76	-39.33	22.57
2	34.30	-9.76	-57.14	47.88	77.52	24.65	52.87	61.18	19.29	41.90	-21.73	-56.49	34.76
2	51.70	-11.19	-51.10	39.91	72.42	26.56	45.85	60.53	24.27	36.26	-21.47	-60.38	38.91
2	41.17	-13.92	-49.42	35.50	98.88	55.70	43.18	56.80	24.27	32.53	-28.56	-62.04	33.48
2	49.38	-12.13	-54.94	42.81	57.56	25.50	32.07	63.30	3.39	59.91	-15.02	-44.33	29.31

Table C 3-3

Repeated Measure MANOVA (Both Groups)

injury	R_STR_C	R_SS_C	R_SL_C	R_CD_C	L_STR_C	L_SS_C	L_SL_C	L_CD_C	RH_MAX_C	RH_MIN_C	RH_EX_C	RK_MAX_C	RK_MIN_C
1	2.04	1.43	0.71	59	2.11	1.51	0.73	57	15.06	-30.49	45.55	65.81	6.15
1	1.54	1.57	0.67	78	1.53	1.32	0.66	78	41.01	12.73	28.29	75.58	5.79
1	2.14	1.55	0.74	56	2.10	1.63	0.73	57	34.95	-12.23	47.18	65.55	0.63
1	1.77	1.42	0.80	68	1.74	1.72	0.79	69	42.81	8.66	34.15	81.17	22.28
1	1.34	1.35	0.79	90	1.30	1.32	0.77	92	36.76	0.18	36.58	62.50	2.45
1	1.77	1.13	0.89	68	1.71	1.14	0.86	70	33.11	-1.51	34.62	77.66	10.30
1	1.44	1.15	0.78	83	1.47	1.33	0.79	82	31.17	1.91	29.26	75.49	16.05
1	1.37	1.91	0.59	88	1.50	1.50	0.65	80	41.36	18.28	23.08	64.04	12.37
1	1.67	1.29	0.84	72	1.67	1.09	0.84	72	28.11	2.63	25.49	55.94	12.50
1	1.51	1.36	0.73	79	1.47	1.58	0.71	82	49.74	9.90	39.85	78.63	15.25
1	2.04	1.27	0.99	59	2.00	1.22	0.97	60	46.07	5.91	40.16	69.93	11.30
1	1.51	1.36	0.73	79	1.50	1.38	0.73	80	34.88	6.47	28.41	65.45	6.55
1	1.47	1.58	0.51	82	1.51	1.36	0.52	79	45.50	19.12	26.38	73.95	10.81
1	1.51	1.36	0.84	79	1.47	1.58	0.82	82	41.01	8.66	32.36	62.50	6.55
1	1.84	1.39	0.73	65	1.80	1.25	0.72	67	45.38	9.28	36.10	70.57	10.90
2	3.71	1.85	0.32	32	3.73	1.66	0.32	32	30.75	-9.75	40.51	64.75	-2.08
2	2.77	1.25	0.24	43	2.84	1.49	0.25	42	35.54	-18.10	53.64	64.56	37.61
2	2.84	0.88	1.48	42	1.74	1.18	0.91	69	31.48	3.46	28.02	81.40	18.20
2	2.24	2.73	0.31	54	2.07	2.14	0.29	58	53.91	0.31	53.61	61.70	7.55
2	3.84	1.91	0.33	31	2.54	2.06	0.22	47	60.60	32.00	28.60	60.92	27.51
2	2.04	3.08	0.36	59	2.13	3.02	0.38	56	47.41	11.38	36.03	77.01	12.78
2	3.21	1.82	0.45	37	3.07	1.19	0.43	39	77.01	24.96	52.03	97.61	19.71
2	2.24	1.80	0.36	54	2.14	1.78	0.34	56	49.61	15.86	33.75	46.79	16.93
2	3.54	1.79	0.31	34	3.54	1.70	0.26	34	37.05	-2.15	39.21	71.05	2.30
2	2.47	2.25	0.26	49	2.63	1.83	0.27	46	64.18	31.85	32.33	45.92	6.43
2	2.81	1.99	0.29	43	2.76	1.30	0.29	43	66.64	39.11	27.53	45.87	10.87
2	2.11	2.01	0.22	57	2.2	1.75	0.23	55	55.29	21.96	33.32	40.87	12.74
2	3.51	1.70	0.43	34	3.47	1.59	0.42	35	50.50	15.52	34.98	61.28	17.98

Table C 3-4

Repeated Measure MANOVA (Both Groups)

injury	RK_EX_C	RA_MAX_C	RA_MIN_C	RA_EX_C	LH_MAX_C	LH_MIN_C	LH_EX_C	LK_MAX_C	LK_MIN_C	LK_EX_C	LA_MAX_C	LA_MIN_C	LA_EX_C
1	59.65	-11.85	-58.40	46.56	23.03	-20.60	43.64	69.30	1.07	68.22	-6.58	-44.84	38.26
1	69.78	-14.72	-40.60	25.88	51.96	26.70	25.26	75.27	12.69	62.57	-16.12	-56.21	40.09
1	64.92	-13.43	-41.94	28.51	15.57	-29.01	44.57	62.39	2.80	59.59	-14.54	-46.37	31.83
1	58.89	-14.71	-57.20	42.49	46.91	15.47	31.44	68.15	8.81	59.34	-10.65	-56.27	45.63
1	60.05	-13.70	-49.04	35.33	39.79	5.83	33.96	52.97	3.23	49.74	-13.54	-56.27	42.73
1	67.36	-14.69	-51.75	37.06	50.72	19.26	31.46	73.26	16.61	56.66	-13.47	-41.33	27.86
1	59.45	-5.64	-39.84	34.20	27.95	-1.72	29.68	67.60	13.43	54.17	-9.56	-30.60	21.05
1	51.67	-14.87	-47.09	32.22	19.55	-5.00	24.55	52.97	7.37	45.60	-16.08	-40.41	24.33
1	43.44	-16.17	-43.16	26.99	38.16	14.34	23.82	65.22	9.24	55.98	-15.16	-49.42	34.26
1	63.38	-16.64	-46.44	29.80	35.19	0.33	34.86	60.55	4.09	56.46	-16.50	-42.64	26.14
1	58.63	-15.71	-56.04	40.33	67.09	17.98	49.11	77.44	13.13	64.31	-18.76	-58.94	40.18
1	58.90	-19.66	-45.52	25.87	37.74	11.02	26.73	65.37	4.77	60.60	-24.81	-45.03	20.22
1	63.13	-7.31	-40.33	33.02	36.74	13.53	23.22	66.81	12.35	54.47	-11.43	-43.48	32.05
1	55.95	-16.17	-41.94	25.77	51.96	15.47	36.48	52.97	4.77	48.20	-15.16	-46.37	31.21
1	59.66	-16.40	-44.19	27.78	43.57	7.90	35.67	56.76	4.43	52.33	-15.83	-44.51	28.68
2	66.83	-23.02	-67.36	44.35	8.13	-18.46	26.58	46.20	-2.36	48.56	-19.63	-41.03	21.41
2	26.95	0.27	-35.19	35.45	77.25	25.58	51.66	106.79	28.92	77.87	-11.43	-38.55	27.11
2	63.20	-7.46	-55.01	47.55	37.30	8.89	28.40	71.28	15.53	55.74	-4.86	-47.71	42.85
2	54.16	-17.55	-40.12	22.57	42.10	23.11	18.99	34.17	10.54	23.63	-16.44	-38.41	21.97
2	33.41	-17.75	-33.98	16.22	64.83	29.62	35.21	63.06	26.99	36.07	-14.45	-38.35	23.90
2	64.23	-4.86	-55.01	50.15	77.25	25.49	51.76	46.36	21.50	24.86	-16.46	-31.21	14.76
2	77.90	-21.75	-50.47	28.72	73.76	21.41	52.36	103.40	19.64	83.75	-10.34	-36.84	26.50
2	29.86	-18.04	-38.00	19.96	49.12	31.07	18.05	43.27	21.53	21.74	-20.25	-31.76	11.51
2	68.75	-16.72	-66.26	49.55	54.05	22.99	31.06	71.05	23.99	47.07	-6.91	24.99	-31.90
2	39.48	-16.86	-55.30	38.44	73.73	25.87	47.86	47.34	5.36	41.98	-26.71	-62.37	25.66
2	35.00	-22.61	-59.84	37.22	65.67	23.27	42.41	43.38	6.08	37.29	-28.73	-59.00	30.27
2	28.14	-26.23	-43.50	17.26	53.38	14.32	39.07	34.15	4.14	30.01	-31.36	-51.63	20.27
2	43.30	-11.04	-44.92	33.88	56.38	19.43	36.95	59.20	15.16	44.04	-17.30	-36.82	19.52

Table C 3-5

Repeated Measure MANOVA (Both Groups)

injury	R_STR_N	R_SS_N	R_SL_N	R_CD_N	L_STR_N	L_SS_N	L_SL_N	L_CD_N	RH_MAX_N	RH_MIN_N	RH_EX_N	RK_MAX_N	RK_MIN_N	RK_EX_N
1	2.24	1.31	0.78	54	2.24	1.38	0.78	54	21.45	-8.89	30.34	54.68	6.04	48.64
1	1.71	1.31	0.74	70	1.67	1.29	0.72	72	39.42	15.57	23.86	76.10	4.79401	71.305
1	2.37	1.30	0.82	51	2.47	1.38	0.86	49	33.58	-9.28	42.86	70.14	1.66	68.48
1	2.01	1.14	0.91	60	2.01	1.23	0.91	60	37.70	4.88	32.82	82.51	17.99	64.51
1	1.20	0.45	0.71	100	1.33	0.48	0.79	90	34.08	10.02	24.06	79.48	6.61	72.87
1	2.04	0.61	1.03	59	1.97	0.59	0.99	61	39.48	11.00	28.48	55.42	8.89	46.53
1	1.64	0.74	0.88	73	1.60	0.93	0.86	75	30.98	7.11	23.87	67.43	11.29	56.14
1	1.74	1.49	0.76	69	1.71	1.31	0.74	70	40.22	19.45	20.77	67.33	9.80	57.53
1	1.84	1.04	0.93	65	1.80	0.94	0.91	67	25.47	2.92	22.54	53.98	11.44	42.54
1	1.47	1.33	0.71	82	1.50	1.38	0.73	80	54.72	15.47	39.25	73.00	19.59	53.40
1	2.04	0.85	0.99	59	2.07	0.95	1.01	58	37.23	12.69	24.54	63.98	14.89	49.09
1	1.54	1.08	0.75	78	1.54	1.08	0.75	78	24.14	7.76	16.38	61.92	9.45	52.47
1	1.71	1.11	0.59	70	1.67	1.09	0.58	72	42.68	22.28	20.41	71.95	13.69	58.25
1	1.64	1.45	0.91	73	1.64	1.34	0.91	73	36.53	0.86	35.67	62.78	5.27	57.51
1	1.94	1.00	0.77	62	2.25	0.60	0.90	53	38.38	16.15	22.23	75.72	10.15	65.56
2	2.94	1.85	0.26	41	2.90	1.42	0.25	41	19.85	-0.93	20.79	44.05	5.85	38.20
2	3.34	1.05	0.29	36	3.17	1.38	0.28	38	58.65	-20.99	79.64	84.61	34.29	50.32
2	2.54	2.79	1.32	47	2.14	0.46	1.11	56	22.69	6.06	16.64	71.32	19.68	51.64
2	2.34	2.34	0.33	51	2.41	2.44	0.33	50	41.05	9.40	31.65	54.24	7.44	46.80
2	2.54	1.92	0.22	47	2.67	1.97	0.23	45	65.75	29.35	36.40	58.86	23.45	35.41
2	2.34	3.42	0.42	51	2.40	3.53	0.43	50	49.84	19.35	30.49	84.61	37.53	47.08
2	3.27	1.04	0.45	37	3.10	0.31	0.43	39	68.39	30.48	37.91	92.88	16.05	76.83
2	2.61	2.90	0.36	46	2.58	2.85	0.36	47	52.75	29.85	22.90	61.22	25.03	36.19
2	2.94	1.60	0.34	41	2.80	1.41	0.34	43	26.15	7.44	18.72	50.42	16.22	34.20
2	3.67	1.82	0.38	33	3.84	1.34	0.40	31	57.75	24.56	33.19	37.86	6.08	31.78
2	3.77	1.22	0.39	32	3.73	2.11	0.39	32	57.43	23.81	33.62	50.36	7.06	43.90
2	2.77	1.89	0.29	43	2.87	1.31	0.30	42	50.58	18.96	31.62	48.13	14.16	33.98
2	2.84	1.76	0.35	42	2.83	1.36	0.34	42	45.42	17.30	28.12	59.03	18.03	41.00

Table C 3-6

Repeated Measure MANOVA (Both Groups)

injury	RA_MAX_N	RA_MIN_N	RA_EX_N	LH_MAX_N	LH_MIN_N	LH_EX_N	LK_MAX_N	LK_MIN_N	LK_EX_N	LA_MAX_N	LA_MIN_N	LA_EX_N
1	-9.97	-55.63	45.67	27.05	-15.17	42.23	55.68	6.29	49.40	-3.19	-52.30	49.10
1	-20.23	-54.71	34.48	51.96	26.70	25.26	75.27	12.69	62.57	-16.12	-56.21	40.09
1	-15.11	-53.99	38.88	23.34	-20.34	43.68	68.48	1.64	66.84	-13.45	-59.32	45.87
1	-15.27	-67.32	52.05	43.65	18.47	25.18	51.28	9.10	42.18	-14.25	-60.41	46.15
1	-10.82	-54.05	43.24	47.23	14.20	33.02	60.82	4.00	56.82	-14.19	-36.26	22.07
1	-18.20	-41.40	23.20	37.00	15.35	21.65	44.19	11.39	32.81	-10.19	-39.93	29.74
1	-4.66	-43.24	38.58	20.59	-4.01	24.60	72.00	11.07	60.93	-4.21	-35.66	31.46
1	-17.34	-56.19	38.85	15.01	-3.17	18.18	55.06	8.54	46.51	-14.70	-58.67	43.97
1	-12.85	-50.15	37.29	40.01	17.13	22.87	60.86	11.63	49.23	-17.72	-50.97	33.25
1	-18.93	-56.34	37.41	38.69	7.17	31.52	55.45	6.37	49.08	-18.42	-48.21	29.78
1	-18.55	-54.09	35.54	55.49	20.84	34.65	78.68	13.82	64.86	-16.51	-65.93	49.42
1	-20.57	-48.30	27.73	30.87	9.99	20.88	54.38	2.52	51.85	-23.35	-47.61	24.25
1	-8.45	-50.32	41.87	34.69	12.23	22.46	61.11	9.50	51.60	-9.29	-51.02	41.73
1	-16.65	-47.69	31.04	30.17	-2.49	32.66	56.34	6.51	49.82	-11.82	-49.63	37.81
1	-9.64	-52.19	42.55	40.96	13.22	27.74	60.96	6.75	54.21	-11.74	-43.64	31.90
2	-36.87	-77.20	40.33	44.91	12.23	32.68	35.16	9.93	25.23	-32.39	-55.78	23.38
2	-5.91	-28.80	22.89	67.69	12.93	54.76	100.98	28.60	72.37	-23.55	-49.48	25.93
2	-14.03	-45.98	31.95	35.00	17.38	17.61	62.97	17.02	45.96	-8.25	-37.19	28.94
2	-22.24	-67.33	45.09	31.29	12.01	19.28	25.75	8.73	17.02	-20.03	-55.78	35.75
2	-21.38	-44.05	22.68	64.62	31.30	33.32	63.18	23.56	39.61	-19.34	-44.72	25.38
2	-7.33	-28.80	21.46	67.69	12.93	54.76	62.97	20.82	42.15	-23.84	-49.48	25.64
2	-32.34	-56.85	24.51	57.07	20.71	36.36	74.43	14.03	60.41	-14.07	-49.08	35.01
2	-19.31	-41.18	21.87	51.61	22.09	29.52	37.66	24.12	13.54	-24.84	-44.99	20.15
2	-30.53	-62.86	32.33	43.69	11.07	32.62	47.51	11.29	36.23	-26.05	-47.44	21.40
2	-20.96	-46.76	25.80	52.54	20.18	32.36	50.95	2.12	48.82	-23.91	-56.83	32.92
2	-23.39	-68.99	45.60	56.11	21.66	34.45	46.86	3.93	42.93	-25.35	-60.33	34.98
2	-37.39	-72.49	35.10	58.58	24.16	34.41	55.80	2.16	53.64	-30.73	-55.11	24.38
2	-17.42	-50.58	33.16	52.57	18.22	34.35	55.35	13.86	41.49	-22.69	-50.52	27.83