5-2011

Effect of Aquatic and Body Weight Supported Treadmill Exercise on Physiological and Kinematic Measures

Jessica Ensign Wing
Utah State University

Recommended Citation

Wing, Jessica Ensign, "Effect of Aquatic and Body Weight Supported Treadmill Exercise on Physiological and Kinematic Measures" (2011). *All Graduate Plan B and other Reports.* Paper 8.

EFFECT OF AQUATIC AND BODY WEIGHT SUPPORTED TREADMILL EXERCISE ON PHYSIOLOGICAL AND KINEMATIC MEASURES

by

Jessica E. Wing

A paper submitted in partial fulfillment
of the requirement for the degree

of

MASTER OF SCIENCE

in

Health and Human Movement

Approved:

Eadric Bressel, Ed.D. Major Professor	Edward M. Heath, Ph.D. Committee Member

Rolayne Wilson, Ed.D.
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah

2011

ABSTRACT

Effect of Aquatic and Body Weight Supported Treadmill Exercise on Physiological and Kinematic Measures

by

Jessica E. Wing, Master of Science

Utah State University, 2011

Major Professor: Dr. Eadric Bressel
Department: Health, Physical Education, and Recreation

The purpose of this study was to examine the acute effects of underwater treadmill (UTM), body weight supported (BWS), and land treadmill (LTM) exercise on oxygen consumption (VO_2), ratings of perceived exertion (RPE), and two-dimensional kinematics of the lower extremities during. Seventeen healthy and physically active male participants between the ages of 21 and 40 years performed an exercise bout for each mode of exercise. Each exercise bout lasted 7 min, consisting of 5 min of walking and 2 min of running and using the same self-selected treadmill walking and running speeds throughout all three conditions. The VO_2, RPE, and kinematic data were collected during each exercise bout. The participants were submerged to the xiphoid process during the UTM exercise session and 20% of their body weight was unloaded using a Pneumax body weight support unloader for the BWS session. An ANOVA with follow-up multiple comparisons were used to determine significance differences (alpha = 0.05) among modes of exercise. Results revealed that VO_2 values for LTM and BWS were

10% and 6% less (*p* < .02), respectively than UTM walking exercise. During running, there were no significant differences between the LTM and UTM. The VO_2 values were 9% less (*p* < .01) during BWS than LTM exercise. There were no differences between RPE levels for any of the conditions. Plantar flexion joint angular displacement values were greater accompanied by decreased velocities for UTM exercise in comparison to LTM and BWS for both walking and running. Knee extension values were greater for walking and running during LTM and BWS than UTM exercise at 5% and 4% respectively (*p* < 0.001). These findings suggest that VO_2 values are greater during UTM than LTM exercise during self-selected walking speeds and comparable during self-selected running speeds. However, kinematically there are differences in the ankle and knee joints during UTM exercise in comparison to the other two exercise modes, whereas similar lower extremity joint angular displacements and velocities occur during BWS and LTM exercise for both walking and running.

These findings would indicate that based on what a clinician's goal for their patient is, a BWS unloader may be best for a patient doing gait retraining to obtain similar gait techniques as they would find on a LTM and an UTM may be best for a patient wanting to keep their VO_2 responses at the same level as seen on land, but with a decreased concern of providing similar gait techniques as those obtained by a LTM.

(49 pages)

ACKNOWLEDGMENTS

This study was supported by a fellowship grant from the National Swimming Pool Foundation. In addition, I would like to thank my husband, Matthew, my parents, and the rest of my family for their unwavering support and encouragement throughout this process. Also, I would like to thank all of my professors for their assistance, but especially Dr. Eadric Bressel, who, with his help and support, opened my eyes to just how much I could accomplish.

Jessica E. Wing

Introduction

It is well known that exercise is important for maintaining good health, increasing muscle strength, and postural stability. However, various conditions and diseases can inhibit the ability to exercise, which in turn may cause the condition or disease to worsen. For example, obesity is now considered to be a leading cause of death in the United States (Danaei et al., 2009). Due to the individual's excess body weight, there are greater joint stresses that may increase the cause of joint injury or pain (Griffin & Guilak, 2005), which stops exercise and leads to weight gain. Orthopedic injuries due to overuse and high ground reaction forces from land exercise can end athletes' seasons, which stops training and leads to loss in strength and cardiorespiratory fitness. These injuries and conditions, along with many others such as osteoarthritis and neurological conditions, are deterrents to adhering to an exercise regimen (Pollock et al., 1991). This is disconcerting because it creates a cycle with negative effects — debilitating conditions inhibit the ability to exercise, which may increase or complicate the original problem. To address this negative cycle, physicians and professionals in the rehabilitation and conditioning fields have often prescribed two different modes of exercise other than the traditional land treadmill (LTM) based exercises: underwater treadmill (UTM) exercise and body weight supported treadmill (BWS) exercise.

Recently, the popularity of UTMs has been on the rise as water walking is a common rehabilitative exercise that requires no special skill, and can be attempted by individuals of all ages with most medical conditions (Masumoto, Takasugi, Hotta, Fujishima, & Iwamoto, 2005). An UTM is a treadmill submerged in a small pool, with or without water jets running that flow by an individual at a rate comparable to the pace selected and add resistance to the exercise load (Alkurdi, Paul, Sadowski, & Dolny, 2010). These UTMs were designed to allow individuals to walk in an aquatic environment, and research indicates there are potential benefits of aquatic physical exercise in comparison to land-based exercise. It was noted by Hinman, Heywood, and Day (2007) that aquatic exercise may assist in pain relief and ease of movement due to the pressure and warmth of water. Some have also contended that the effects of water resistance allow a greater expenditure of energy (Gleim & Nicholas, 1989; Hall, Macdonald, Maddison, & O'Hare, 1998) while still decreasing the stress and impact forces on the joints of the lower extremities (Barela & Duarte, 2008; Barela, Stolf, & Duarte, 2006). Due to buoyancy's effect on the reduction of the vertical component of ground reaction forces (Nakazawa, Yano, & Miyashita, 1994), UTMs have some benefits over exercising on land for those individuals suffering from injuries or other debilitating conditions.

The magnitude of vertical ground reaction force is related to water depth. Some UTMs allow clinicians the advantage of being able to adjust the water depth and treadmill speed, which are the main determinants of exercise intensity (Figure 1; HydroWorx 2000^{TM} underwater treadmill). Previous research has shown that the xiphoid process is a good medium for obtaining similar cardiorespiratory responses to those observed on land (Hall, Macdonald, Maddison, & O'Hare, 1998; Masumoto, Shono, Hotta, & Fujishima, 2008), while still maintaining a lessened ground reaction force (Barela et al, 2006).

The BWS unloaders are becoming more popular among clinicians for a variety of patient populations such as stroke victims (Barbeau & Visintin, 2003), total hip arthroplasty patients (Hesse et al., 2003), and athletes with tissue or bone damage (Kelsey & Tyson, 1994). These unloaders essentially use the same concept as UTM, except without the use of water (Figure 2; Pneumax body weight support unloader). Instead, a harness and cable system are used to "unweight" the subject to decrease the body weight, and thus decrease the vertical ground reaction force component (Chang, Huang, Hamerski, & Kram, 2000; Grabowski & Kram, 2008; Teunissen, Grabowski, & Kram, 2007). A treadmill is then situated under the harness and cable system to allow BWS exercise. These BWS unloaders provide a safe and controlled environment for those individuals unable to balance or cope with bearing full weight on the lower extremities and also provide a gait training strategy to increase the functional level of ambulation for those that are wheelchair bound, injured, or otherwise restricted (Visintin, Barbeau, Korner-Bitensky, & Mayo, 1998).

The effect of BWS exercise on oxygen consumption (VO_2) is influenced by various factors (eg, percent of body weight unloaded, speed, etc), but tends to be lower when compared to LTM exercise, yet lower extremity kinematics tend to be similar. Farley and McMahon (1992) as well as Teunissen et al (2007) noted that the rate of energy consumption decreases during BWS in comparison to LTM, but in less than direct proportion to the weight being supported. So while studies have reported that running with BWS have decreased VO_2 in comparison to LTM running (Teunissen et al, 2007; Farley & McMahon, 1992), some contend that walking at lower percentages of body weight support produce similar VO_2 responses that are seen in regular LTM walking

(Murray, Hunter, Paper, Kelsey, & Murray, 1993). However, these observations may be influenced by the percentage of unloading, the type of harness used, familiarization, and the population tested.

Regarding VO_2 and kinematic comparisons between BWS and UTM exercise, no studies have been conducted that the author is aware of. While many studies have been conducted on UTMs and BWS unloaders separately in comparison to LTM exercise, none have compared LTM to UTM and BWS exercise. An all inclusive comparison among the three modes of exercise allows for a more controlled research design whereby threats to internal validity are minimized. These comparisons will assist clinicians in deciding which mode of treadmill exercise would be most efficacious for their patient or athlete. For example, by determining similarities and/or differences among the three modes of exercise (UTM, BWS, and LTM), this study will potentially allow clinicians to better apply the principles of specificity and overload, which should facilitate and improve the effectiveness of their exercise prescription and rehabilitation.

Accordingly, the purpose of this study was to compare the acute effects of UTM, BWS, and LTM exercise while walking and running on VO_2, ratings of perceived exertion (RPE), and lower extremity kinematics. The researcher was interested in determining if UTM and BWS treadmill exercise could provide the same VO_2 responses with similar kinematics as LTM walking and running. The hypothesis was that VO_2 values during UTM would be similar to LTM for walking and running, whereas BWS would be less for both. This hypothesis is based on the findings from previous research that VO_2 values are similar between UTM and LTM during walking and running (Alkurdi et al, 2010; Rutledge, Silvers, Browder, & Dolny, 2007), but differ between

BWS and LTM exercise (Colby, Kirkendall, & Bruzga, 1999; Grabowski & Kram, 2008). Kinematically, it was hypothesized that UTM joint angular displacements and velocities would be significantly different from LTM and BWS due to the water resistance. This hypothesis is based on the findings from previous studies reporting significant kinematic changes between UTM and LTM (Barela et al, 2006).

Methods

Participants

Seventeen healthy and physically active males between the ages of 21 and 40 volunteered to participate in this study. Participants were a sample of convenience from a university student population and all had previous treadmill experience, no injuries, and were exercising on a consistent basis for the previous 12 months. All participants gave informed consent and the study was approved by the university Institutional Review Board. Physical characteristics for the participants are reported in Table 1.

Procedures

In this quasi-experimental study each participant was asked to perform an exercise bout on each of the three modes of exercise: an UTM (Figure 1; HydroWorx 2000^{TM}, Middletown, PA), a commercial pneumatic BWS unloader (Figure 2; Pneumax Inc., Sandpoint, ID) positioned over the LTM, and on a LTM (Nordic Track 9600, ICON Fitness, Logan UT). Treadmill incline was set at 0º for each mode of exercise. All three exercise bouts were performed during one test session and randomly assigned. A familiarization trial was performed within the 24 hours prior to testing to determine the walking and running speeds to be used for each mode of exercise, as well as to assist the participant in getting accustomed to the equipment and procedures. The participant was allowed as much time as needed, typically 5 to 10 min, during this familiarization session. The self-selected walking and running speeds were determined in the UTM and then matched for the other 2 modes. This was done because it provided typical rehabilitative speeds used clinically for special populations and previous studies have shown that VO_2 values are similar between UTM and LTM walking and running speeds (Alkurdi et al, 2010; Byrne et al, 1996; Rutledge et al, 2007).

During the familiarization session, the treadmill speed was increased incrementally until the participant reached both their walking and running speeds. The walking speed required participants to walk at a self-selected pace they considered "comfortable" and the running speed required participants to run at a self-selected pace they would normally run at while exercising. Self-selected speeds were chosen to obtain typical rehabilitative speeds, and additionally it has been shown that energy cost is at its minimum at stride lengths, stride frequencies, and walking speeds that are self-selected in comparison to constrained walking speeds and tempos (Ralston, 1958; Cavanagh & Kram, 1985; Minetti, Capelli, Zamparo, di Prampero, & Saibene, 1995). The average walking speed selected by the subjects in this study was 1.0 m/s. Farley and McMahon (1992) reported that the net cost of transport for walking at normal weight was lower at the intermediate speeds of 1.0 m/s to 1.5 m/s than at the highest and lowest speeds of 2.0 m/s and 0.5 m/s. Therefore, our subjects' average walking speed fell into the appropriate range of acceptable speeds to minimize energy cost.

During the testing session, the amount of time walking for each exercise mode was 5 min, followed immediately by 2 min of running. Through pilot testing of healthy, exercising subjects, it was found that it took less than 5 s to transition from the walk to run, and that subjects reached steady state after 1 min of running due to their physical fitness and relatively low running intensity. The self-selected walking and running speeds were matched for each mode of exercise for each participant to provide a standard baseline to start from for collecting data, since a change in speed can affect all of the variables being tested. Participants performed the UTM exercise with no shoes at a water depth equal to the xiphoid process. The temperature of the water was 30^{o} C with the air temperature set at 24^{o} C.

The BWS unloader exercise was performed in the same room and in the same manner as the UTM exercise and required participants to wear their normal walking shoes along with typical exercise clothing. Each participant was weighed using a digital lithium scale (Health o meter Sunbeam Products, Inc, Boca Raton, FL), which had been previously calibrated, and 20% of their total body weight was calculated to determine the weight (N) to be unloaded. Unloading 20% of the participants' body weight during BWS exercise was chosen because it has been shown that it is the most comfortable setting for patients, it is used for special populations, and it provides closer metabolic costs and kinematics to LTM (Miyai et al, 2000; Hunter, Smith, Murray, & Murray, 1995; Murray et al, 1993; Threlkeld, Cooper, Monger, Craven, & Haupt, 2003). The definition of percent body weight supported was the percentage of the subject's body weight that was being supported by the BWS unloader. The accuracy of the lifting force of the BWS unloader was assessed prior to beginning the experiment by comparing the number of pounds being lifted to the tensile force indicated on a cable tensiometer (Pacific Scientific Company, 1943, Los Angeles, CA), which was attached to a cable system of the BWS unloader.

The LTM was also performed in the same room and in the same manner as the other two modes of exercise. For the purpose of validity testing, treadmill speed settings of 0.89 m/s were compared between the underwater and land treadmills using a video analysis. An interclass correlation coefficient (ICC = 0.99) performed on the analyzed data indicated nominal speed settings were similar between treadmills.

Measurements

Cardiorespiratory. The VO_2 was recorded during the entire 7 min exercise session of each mode of exercise using a computerized metabolic measurement system (Figure 1; Parvomedics True One 2400, Sandy UT). Calculations of VO_2 ($ml \cdot min^{-1}$ STPD) were made from expired air samples taken from participants breathing through a two-way valve mouthpiece (Hans Rudolph 700 series, Kansas City MO). Measurements of VO_2 were calculated every 15 s and were averaged over the last 2 min of the walking sequence and the last minute of the running sequence. Before each testing session, O_2 and CO_2 analyzers from the metabolic system were calibrated with known gas mixtures and the pneumotach was calibrated with a 3 liter syringe using manufacturer guidelines. As a supplement to the VO_2 data, RPE was recorded during the last minute of the walking and running sessions using the 10 point Borg scale (Borg, 1982).

Gait Kinematics. Two-dimensional kinematics of the lower extremity joints were collected from all subjects during the three modes of treadmill exercise. For the UTM, a

Panasonic WV-CS574 video camera was positioned in a non-image distorting window that allowed a sagittal plane view of the left lower extremity. For LTM and BWS exercises, a Panasonic PV-GS 150 video camera captured sagittal plane motion of the left lower extremity. The UTM camera was positioned approximately 1 m from the participant at a height of 0.5 m from the ground. The land camera was positioned approximately 2.5 m away at a height of 0.5 m. The UTM and LTM cameras sampled at 60 Hz with a shutter speed of 0.02 s and were scaled using a 1 m scaling rod placed in the field of view prior to data collection. Gait kinematics were calculated from coordinate data taken from the digitization of colored markers using a motion analysis system (Peak Performance Technologies, Inc., Englewood, CO). The colored markers were positioned on the skin over the following 4 bony landmarks: Superolateral femur, lateral femoral condyle, lateral malleolus, and the distal phalange of the fifth toe.

Regarding data analysis, a 4th order, zero lag Butterworth low-pass filter was used to smooth the raw coordinate data, and cut-off frequencies were chosen using the Jackson Knee Method (Jackson, 1979). Angular displacements and angular velocities were calculated using finite difference equations (Winter, 1990). Gait data from three consecutive strides (three stance phases, two swing phases) were analyzed from the last minute of each walking and running session. This was to allow the subjects to establish a consistent gait pattern. Stance phase was defined as the time between heel strike and toe-off, and the swing phase was determined as the time between toe-off to heel strike. Maximum and minimum joint angular displacements and velocities of the hip, knee, and ankle were determined for the stance and swing phases. Maximum angles at the ankle, knee, and hip joints reflected plantar flexion, knee extension, and hip extension values, whereas minimum angles reflected dorsiflexion, knee flexion, and hip flexion values. Angle conventions used for kinematics are shown in Figure 3.

Statistical Analyses

The independent variable in this study was mode of exercise (UTM, BWS unloader treadmill, or LTM) and the dependent variables were VO_2, RPE, and gait kinematics (minimum and maximum joint angular displacement and velocity for each joint). A one-way repeated measures analysis of variance (ANOVA) with three levels was used to examine the effect of exercise mode on each dependent variable. When appropriate, follow-up multiple comparisons were used to examine differences between each mode using an alpha set at 0.05 to determine significance. A Holm's correction to the 0.05 level was made for kinematic comparisons because of the large number of comparisons (i.e., 70) (Lundbrook, 1998) and the risk this poses on misinterpreting a true Type I error (Knudson, 2009). To help appreciate clinical differences, effect sizes (ES) were quantified to appreciate the meaningfulness of any statistical differences and Cohen's (1988) convention for effect size interpretation was used (< 0.41 = small, 0.41 – 0.7 = medium, and > 0.7 = large).

Results

Data from all participants were used in the statistical analyses of the results. There were no outliers. As stated previously, the average walking speed of the participants was about 1.0 m/s (SD = ± 0.22). The average running speed of the participants was approximately 2.5 m/s (SD = ± 0.25).

Oxygen Consumption

The VO_2 measurements were significantly different between all 3 modes of exercise for the walking sequence (Table 2). The VO_2 values were greatest during UTM walking with the values during LTM walking being 10% less ($p = 0.001$; ES = 0.74) and 6% less during BWS ($p = 0.05$; ES = 0.43). The BWS walking mode elicited VO_2 values that were 4% greater ($p < 0.02$) than LTM walking. During the running sequence, there was no VO_2 difference between the modes of LTM and UTM ($p > 0.05$), however, there was a significant difference between LTM and BWS with VO_2 values during BWS being 9% less ($p = 0.001$; ES = 1.08). There were no significant differences in any of the RPE scores between any of the conditions for walking as well as running (Table 2).

Kinematics

Joint angular displacement and angular velocity measurements that were significantly different at the $p = 0.05$ level are shown in Tables 3-5. The reported minimum joint angle measurements for the ankle in dorsiflexion while in the stance phase during LTM and BWS were significantly more dorsiflexed than during UTM exercise for walking and running by approximately 9% and 7% ($p < 0.02$; Table 6; ES =

1.62). During the stance phase, plantar flexion joint angles for the ankle during LTM were significantly lower than during UTM exercise for walking and running by 5% and 6% respectively ($p < 0.05$; Table 6; ES = 0.97) as well as 5% lower during the swing phase ($p < 0.008$; Table 7; ES = 0.81).

During stance and swing, knee extension joint angle values in UTM were approximately 5% less for walking and running sequences, respectively ($p < 0.001$; Table 6 & 7; ES = 1.19) than LTM and BWS. The knee flexion joint angle values in UTM were about 5% less than LTM and BWS during walking and running ($p < 0.002$; Table 6; ES = 0.83) at stance, but 25% greater while running during swing phase ($p < 0.001$; Table 7; ES=2.88). During stance, hip flexion joint angle values in UTM were 3% greater than LTM and BWS while walking ($p < 0.007$; Table 6; ES = 1.14) and 7% greater while running during swing ($p < 0.002$; Table 7; ES = 1.86).

Angular velocities for the ankle, knee, and hip joints in the UTM were significantly lower than LTM and BWS exercise. During stance, angular velocities during UTM exercise were 46% and 35% less in walking and running compared to LTM and BWS ($p < 0.009$; Table 8; ES = 0.82) in dorsiflexion. In addition, angular velocities were 22% and 43% less in walking and running during UTM exercise in comparison to LTM and BWS ($p < 0.001$; Table 8; ES = 1.44) in knee flexion, and 38% and 89% less respectively ($p < 0.005$; Table 8; ES = 0.81) in hip flexion. Angular velocities during UTM in knee extension were significantly less than LTM in walking and running by 49% and 32% respectively ($p < 0.001$; Table 9; ES = 2.60) as well as hip extension while walking by 57% ($p < 0.001$; Table 9; ES = 1.72) during the swing phase. Other values that were not significantly different for the conditions are displayed in Tables 6-9.

Minimal differences were seen between LTM and BWS treadmill exercise for the lower extremity kinematics. During swing, there was 6% greater knee flexion ($p < 0.001$; Table 7; ES = 0.77) and 2% greater hip flexion ($p < 0.009$; Table 7; ES = 0.53) while running during LTM versus BWS. Additionally, angular velocities during knee extension in LTM running were 11% greater ($p < 0.001$; Table 9; ES = 0.86) and 22% greater in hip extension ($p < 0.004$; Table 9; ES = 0.62) than BWS exercise.

Discussion

The unique aspect of this study was comparing three modes of treadmill exercise that unloaded body weight to different amounts in different environments (water versus land) while recording physiological and kinematic measures. Results of this comparison will potentially allow clinicians to better identify which mode is best for specific populations and patients. Results of this study indicated that healthy young participants may walk on an UTM and obtain higher energy expenditures than LTM, but similar values at running speeds. Unexpectedly, there were greater VO_2 values during BWS treadmill exercise than LTM when walking (albeit only 4%), but while running provided lower VO_2 values. While the RPE values were not significantly different between the three modes, they did follow the same trend as the walking VO_2 results. The RPE during UTM walking was the greatest and the RPE during LTM walking was the lowest. From the present study, results also indicated a significant difference in kinematics during UTM exercise, especially the ankle and knee joints, from the LTM and BWS exercise. So while UTM exercise may provide greater or similar VO_2 values to the LTM, there are substantial differences in the kinematics between the two modes, particularly when considering ES were moderate to high.

The VO_2 values while running were lower during BWS than LTM exercise which is consistent with previous studies (Grabowski & Kram, 2008; Teunissen et al, 2007). However, greater VO_2 values were observed while walking for BWS than LTM, which is not completely consistent with previous literature. For example, Thomas, De Vito, and Macaluso (2007) reported that healthy subjects were able to walk at a faster speed during 40% of unloaded BWS exercise with similar energy and cardiac cost as a slower, comfortable speed at 0% BWS. Another study reported that while walking at 1.34 m/s VO_2 values decreased 6% at 20% BWS in comparison to 0% BWS (Colby et al, 1999). However more in line with our research finding, Farley and McMahon (1992) observed that under simulated reduced gravity (using a modified BWS unloader concept) the rate of energy consumption decreases in proportion to body weight during running but not walking. They reported that when gravity was reduced by 75%, VO_2 decreased by 72% and 33% during running and walking, respectively; however, Grabowski, Farley, and Kram (2005) found VO_2 only decreased by 21% while walking. They also reported that when subjects walked with a 25% reduction in body weight, the decrease in net metabolic rate was not significant (Grabowski et al , 2005); however, their participants walked at slightly higher speeds than participants of the present study. In view of the results of the present study and those previously published, it may be contended that VO_2 values while running during BWS decreases approximately in proportion to the body weight being supported, but walking does not and can elicit similar VO_2 responses to LTM at lower BWS settings, such as the 20% BWS used in the present study.

Further research reported that while walking at 1.0 m/s the amount of mechanical energy exchange or percent recovery was not significantly different from LTM at 0.75 G (25% BWS) and 0.50 G (50% BWS) (Griffin, Tolani, & Kram, 1999). This supports the idea that the recovery of mechanical energy is high in walking and practically nil in running (Cavagna, Thys, & Zamboni, 1976). This also supports and helps explain the findings of Farley and McMahon (1992). While running cannot elicit a high recovery of mechanical energy, the slower speed of walking can, which helps outweigh the BWS in decreasing the VO_2 significantly and instead produce similar VO_2 values seen with LTM exercise. Another study by Murray et al (1993) looked at the effect of speed on VO_2 during BWS. They selected 0.89 m/s and 1.79 m/s as gait speeds in their study because they wanted to represent normal clinical walking speeds commonly prescribed for ambulatory rehabilitation programs. They reported that when walking at 0.89 m/s VO_2 values were not significantly different between LTM, 20% BWS, and 40% BWS. But when walking at 1.79 m/s it was found that both 20% and 40% BWS reported significantly less VO_2 values than LTM (Murray et al, 1993). In the present study the average walking speed chosen by the subjects was 1.0 m/s, which falls into the range of applicable speeds for clinical purposes, and is similar to the speeds in BWS versus LTM studies reporting VO_2 values are not significantly different between LTM and BWS exercise. So it appears that VO_2 differences between BWS and LTM exercise may depend on the speed of walking.

In the present study the harness used during BWS may have allowed participants to walk and run without any restriction of the lower limbs. However, about two-thirds of the subjects complained of feeling quite restricted in the upper body. The harness was strapped tightly around the lower chest, midsection, and waist with a strap going underneath the buttocks with an additional two large, thick straps coming up over the shoulders to connect to the cable system. This placed most of the pressure on the lower chest and abdomen area, while at the same time blocking shoulder joint movement. This immobilization of the upper body may have increased the energy expenditures during walking. Umberger (2008) found that energy expenditure increased by about 8% when the arm swing was suppressed in comparison to normal walking, and that lower extremity joint angles and angular velocities were nearly identical for walking normally and with a suppressed arm swing. This helps support the present study's findings as participants complained of restriction from the harness during BWS exercise and had greater VO_2 values than LTM, but similar kinematics in the lower extremities were recorded between the two modes. In addition it has been found that when a healthy body is restricted, for example with a limb immobilized in a brace, it increases their energy expenditure than if they were to walk normal (Elsworth, et al, 2006). For a healthy individual to wear a brace it is inefficient use of the body's muscles and thereby increases energy expenditure. Millslagle, Levy, and Matack (2006) reported that the Z-line harness, which is similar to the one used in the present study, decreased torso rotation significantly while running at 40% BWS. Grabowski and Kram (2008) even discussed the issue that harness systems may not be applicable for use over extended time periods because they can cause discomfort and impede circulation. While the present study recorded complaints from participants concerning the BWS harness restriction as well as a 4% increase in VO_2 values than LTM, which is abnormal, more research is needed on various harness styles during BWS and their effects on physiological variables.

Additionally, another factor that may influence VO_2 during BWS exercise is that walking and running in an unloader for the first time for healthy subjects may be considered a novel task since there is not an everyday practical need for it for that population. Previous studies have shown that healthy subjects performing a novel gross motor task (such as walking backwards or walking on hands and feet) had significantly higher VO_2 values during the first recording session, but after a few practice sessions the VO_2 decreased significantly as the body adjusted and became more familiar with the task (Heath, Blackwell, Baker, Smith, & Kornatz, 2001; Sparrow & Irizarry-Lopez, 1987). However, previous BWS studies provided a familiarization trial before collecting data very similar to the present study's procedures and showed subjects demonstrated habituation to BWS exercise within 1 min of treadmill walking (Donelan & Kram, 1997; Threlkeld et al, 2003). The procedures were set up with only one familiarization trial with the intent to give insight into situations where no familiarization would be used, such as stroke and paralysis patients. This makes it more plausible that it may have to do with upper body restriction and speed which led to the 4% increase in VO_2 values while walking during BWS exercise than LTM in the present study. Taking all of these things into account may help to explain the higher VO_2 in BWS than LTM when walking, but more research is needed.

Unlike the VO_2 discrepancies observed during walking BWS and LTM exercise, VO_2 results during UTM exercise while walking and running in the present study are consistent with previous studies. Alkurdi et al (2010) determined that walking at the xiphoid level had significantly higher energy expenditure values than LTM. Byrne et al (1996) observed that walking in UTM elicited greater VO_2 than LTM at similar speeds done in the present study as well. Rutledge et al (2007) reported that metabolic costs were similar between LTM and UTM at running speeds while exercising at the xiphoid process. While the buoyancy of the water decreases ground reaction forces, the increased speed of exercising in the water magnifies the drag force and may cancel the lowering metabolic cost associated with buoyancy and make the body work harder which leads to higher VO_2 values.

In comparing the differences and similarities between BWS and UTM exercise, the VO_2 values during UTM walking were 6% greater than BWS walking, but both of those modes elicited greater VO_2 measurements in comparison to LTM. The reported RPE values while walking, though not statistically significant, follow that same trend shown in the walking VO_2 values. The RPE during UTM walking was greater than BWS walking, however, the RPE values for both UTM and BWS walking were greater than LTM. During the running sequence, the VO_2 measurements during UTM exercise were not significantly different from BWS exercise, even though VO_2 values during LTM was not different from UTM, but significantly greater than BWS exercise. The running RPE values, which were not statistically significant, were the same between the UTM and BWS exercise, and were greater than the LTM. So while VO_2 values are greater during UTM walking than BWS, they are not different while running. These findings for oxygen consumption are vital for rehabilitative purposes in addressing specific populations. For example, in order for an injured athlete to continue to keep their VO_2 responses at the same level as before the injury, but keep ground reaction forces down, they can get on an UTM and obtain the same VO_2 measurements as seen on a LTM. An obese individual can obtain the same results as well. For neurological disorders such as stroke victims, BWS treadmill exercise may be most efficacious due to the safe and controlled environment with the harness.

There were minimal differences between joint angular displacements and velocities between BWS and LTM which is consistent with previous literature. Threlkeld et al (2003) reported that BWS levels at 10% and 30% produced similar gait kinematics to normal treadmill walking, but at 50% and 70% unloading significant joint kinematic changes were recorded. van Hedel, Tomatis, and Müller (2006) also observed that BWS levels at 25% produced minimal kinematic changes compared to regular land treadmill walking. They concluded from their study that to compare similar joint angles between BWS and LTM that the training should be done with velocities higher than 0.69 m/s and less than 50% body weight unloading which may be supported by the results of the present study of exercising at 1.0 m/s and greater with 20% BWS. During UTM the joint velocities were less than BWS and LTM due to the water resistance. The biggest joint angle difference was in the ankle. The ankle was always more plantar flexed in UTM than the other two modes. This is consistent with previous studies as Barela et al (2006) observed that the ankle was more plantar flexed in water during the support phase and at the end of the swing phase. The knee was also significantly different during UTM from LTM and BWS. During the swing phase the knee was always more flexed during UTM, which may be an adjustment made by the subjects to accommodate for the drag forces experienced in the water. The hip was more flexed during UTM as well to compensate for the water resistance hitting the body. The buoyancy factor makes the apparent body weight reduced, but the drag force created as the limbs move forward through the water makes it necessary for the body to make changes to overcome it and maintain a constant speed when walking and running. This thereby changes the gait technique from LTM, which clinicians may take into account while deciding which mode is best for their patient and their goals of rehabilitation and training.

The results of this study should be interpreted in light of the limitations of the study. Only acute changes were collected from the one data collection session; whereas if a longer training program were used it may result in physiological and biomechanical adaptations that may change this study's outcomes.

From subjective comments made by the participants of the study it was noted that most preferred the UTM to the other two modes of exercise. Most participants commented that they enjoyed the feel of the water, from the water temperature to the water resistance, which helped break the mundane norm of the LTM that they were accustomed to. The LTMs are much more easily accessible and affordable than UTMs and BWS unloaders; however, as UTMs and BWS unloaders are becoming more popular, more facilities, hospitals, and living-assistance homes may consider incorporating them into their rehabilitation programs based on their patients' needs.

It may be concluded that healthy young participants will display greater VO_2 values during short-term exercise on an UTM than BWS and LTM while walking, and similar VO_2 while running on an UTM versus LTM. Decreased VO_2 will be attained on a BWS unloader compared to LTM while running, but it will allow similar lower extremity kinematics of the joint angular displacements and velocities as LTM exercise. Decreased velocities due to the added water resistance occurred during UTM exercise, which also affected the joint angular displacements, especially the ankle. These findings would indicate that based on what a clinician's goal for their patient is, there are a couple options on how to best achieve that goal. A BWS unloader may be best for a patient doing gait retraining to obtain similar gait techniques as they would find on a LTM. With the assistance of the BWS unloader, a safe and controlled environment is created and provides a mode of exercise to decrease weight with similar kinematics as a LTM. A UTM may be best for a patient wanting to keep their VO_2 responses at the same level as seen on land, but with a decreased concern of providing similar gait techniques as those obtained by a LTM. More research is needed on the comparison of all three of these exercise modes to help develop an exercise program for specific populations for each mode.

Table 1

Physical Characteristics of Participants (n = 17, males)

Characteristic	Mean	SD	Min	Max
Age (yr)	25.6	4.5	21	40
Height (cm)	184.0	6.4	176.5	198.1
Body mass (kg)	84.2	16.2	64.6	131.1

Table 2

Ratings of Perceived Exertion (RPE) and Volume of Oxygen Consumed (VO_2; mean (±SD)) During Land Treadmill (LTM), Body Weight Supported (BWS), and Underwater Treadmill (UTM) Exercise.

	RPE		VO_2 (mL/kg/min)	
Condition	Walk	Run	Walk	Run
LTM	0.76 (0.70)	3.32 (0.76)	9.91 (0.94)	26.67^{b} (2.13)
BWS	0.88 (0.76)	3.58 (0.93)	10.37^{a} (1.06)	24.37 (2.51)
UTM	1.05 (0.88)	3.58 (0.98)	$11.03^{a,b}$ (1.52)	25.61 (2.64)

Note: a—significantly different from LTM
b—significantly different from BWS

Table 3
Ankle Kinematic Variables Significant at the 0.05 Level and the Effect Size.

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs UTM stance min angular position for walking	0.001	0.05/22 = 0.002	1.94*
LTM vs UTM stance min angular position for running	0.001	0.05/21 = 0.002	2.27*
LTM vs UTM stance max angular position for running	0.001	0.05/20 = 0.003	1.50*
BWS vs UTM stance max angular position for running	0.001	0.05/19 = 0.003	1.08*
LTM vs UTM swing max angular position for running	0.001	0.05/18 = 0.003	1.10*
LTM vs UTM stance min angular velocity for walking	0.001	0.05/17 = 0.003	3.93*
BWS vs UTM stance min angular velocity for walking	0.001	0.05/16 = 0.003	2.76*
LTM vs UTM stance max angular velocity for walking	0.001	0.05/15 = 0.003	2.03*
BWS vs UTM stance max angular velocity for walking	0.001	0.05/14 = 0.004	1.53*
BWS vs UTM stance min angular position for walking	0.002	0.05/13 = 0.004	1.67*
BWS vs UTM stance min angular position for running	0.002	0.05/12 = 0.004	1.62*

Table 3 (continued).

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs BWS stance min angular position for running	0.005	0.05/11 = 0.005	0.51*
LTM vs UTM stance max angular position for walking	0.005	0.05/10 = 0.005	0.97*
BWS vs UTM swing max angular position for running	0.005	0.05/9 = 0.006	0.77*
LTM vs UTM stance min angular velocity for running	0.006	0.05/8 = 0.006	1.08*
LTM vs UTM swing min angular velocity for running	0.006	0.05/7 = 0.007	0.94*
LTM vs UTM swing max angular position for walking	0.008	0.05/6 = 0.008	0.81*
BWS vs UTM stance min angular velocity for running	0.009	0.05/5 = 0.01	0.82*
BWS vs UTM stance max angular position for walking	0.016	0.05/4 = 0.01	0.91
LTM vs BWS swing max angular position for walking	0.029	0.05/3 = 0.02	0.26
LTM vs BWS stance max angular position for running	0.032	0.05/2 = 0.03	0.69
LTM vs BWS swing max angular position for running	0.05	0.05/1 = 0.05	0.34

*significant at the adjusted level

Table 4
Knee Kinematic Variables Significant at the 0.05 Level and the Effect Size.

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs UTM stance min angular position for running	0.001	0.05/29 = 0.002	1.21*
LTM vs UTM stance max angular position for walking	0.001	0.05/28 = 0.002	2.97*
BWS vs UTM stance max angular position for walking	0.001	0.05/27 = 0.002	2.09*
BWS vs UTM stance max angular position for running	0.001	0.05/26 = 0.002	1.81*
LTM vs BWS swing min angular position for running	0.001	0.05/25 = 0.002	0.77*
LTM vs UTM swing min angular position for running	0.001	0.05/24 = 0.002	2.88*
BWS vs UTM swing min angular position for running	0.001	0.05/23 = 0.002	3.64*
LTM vs UTM swing max angular position for walking	0.001	0.05/22 = 0.002	1.87*
BWS vs UTM swing max angular position for walking	0.001	0.05/21 = 0.002	2.60*
LTM vs UTM swing max angular position for running	0.001	0.05/20 = 0.003	1.19*
BWS vs UTM swing max angular position for running	0.001	0.05/19 = 0.003	1.44*

Table 4 (continued).

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs UTM stance min angular velocity for walking	0.001	0.05/18 = 0.003	1.64*
BWS vs UTM stance min angular velocity for walking	0.001	0.05/17 = 0.003	1.44*
LTM vs UTM stance min angular velocity for running	0.001	0.05/16 = 0.003	3.36*
BWS vs UTM stance min angular velocity for running	0.001	0.05/15 = 0.003	2.62*
LTM vs UTM stance max angular velocity for running	0.001	0.05/14 = 0.004	2.63*
BWS vs UTM stance max angular velocity for running	0.001	0.05/13 = 0.004	2.03*
LTM vs UTM swing min angular velocity for running	0.001	0.05/12 = 0.004	1.90*
BWS vs UTM swing min angular velocity for running	0.001	0.05/11 = 0.005	1.36*
LTM vs UTM swing max angular velocity for walking	0.001	0.05/10 = 0.005	4.25*
BWS vs UTM swing max angular velocity for walking	0.001	0.05/9 = 0.006	3.21*
LTM vs BWS swing max angular velocity for running	0.001	0.05/8 = 0.006	0.86*

Table 4 (continued).

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs UTM swing max angular velocity for running	0.001	0.05/7 = 0.007	2.60*
BWS vs UTM swing max angular velocity for running	0.001	0.05/6 = 0.008	1.63*
LTM vs UTM stance min angular position for walking	0.002	0.05/5 = 0.01	0.99*
BWS vs UTM stance min angular position for walking	0.004	0.05/4 = 0.01	0.83*
LTM vs UTM stance max angular position for running	0.004	0.05/3 = 0.02	1.43*
LTM vs BWS stance min angular velocity for running	0.019	0.05/2 = 0.03	0.61*
LTM vs BWS swing min angular velocity for running	0.029	0.05/1 = 0.05	0.73*

*significant at the adjusted level

Table 5
Hip Kinematic Variables Significant at the 0.05 Level and the Effect Size.

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
BWS vs UTM stance min angular position for walking	0.001	0.05/19 = 0.003	1.87*
BWS vs UTM swing min angular position for running	0.001	0.05/18 = 0.003	2.23*
LTM vs UTM swing max angular position for walking	0.001	0.05/17 = 0.003	1.48*
BWS vs UTM swing max angular position for walking	0.001	0.05/16 = 0.003	1.32*
LTM vs UTM stance min angular velocity for running	0.001	0.05/15 = 0.003	2.06*
LTM vs BWS stance max angular velocity for walking	0.001	0.05/14 = 0.004	1.00*
LTM vs UTM swing min angular velocity for running	0.001	0.05/13 = 0.004	1.43*
LTM vs UTM swing max angular velocity for walking	0.001	0.05/12 = 0.004	1.72*
BWS vs UTM swing max angular velocity for walking	0.001	0.05/11 = 0.005	1.79*
LTM vs UTM swing min angular position for running	0.002	0.05/10 = 0.005	1.86*
BWS vs UTM stance min angular velocity for running	0.002	0.05/9 = 0.006	1.89*

Table 5 (continued).

Comparisons	*p* value	Holm's Adjusted Value	Effect Size
LTM vs BWS swing max angular velocity for running	0.004	0.05/8 = 0.006	0.62*
LTM vs UTM stance min angular velocity for walking	0.005	0.05/7 = 0.007	0.95*
LTM vs UTM stance min angular position for walking	0.007	0.05/6 = 0.008	1.14*
BWS vs UTM stance min angular velocity for walking	0.007	0.05/5 = 0.01	0.81*
LTM vs UTM swing min angular velocity for walking	0.009	0.05/4 = 0.01	0.97*
LTM vs BWS swing min angular position for running	0.009	0.05/3 = 0.02	0.53*
BWS vs UTM stance max angular position for running	0.01	0.05/2 = 0.03	1.06*
BWS vs UTM swing min angular velocity for walking	0.03	0.05/1 = 0.05	0.75*

*significant at the adjusted level

Table 6
Joint Angles (mean (±SD)) for the Stance Phase of Gait during LTM, BWS, and UTM exercise. The minimum and maximum angle values are displayed for the ankle, knee and hip joints.

	LTM		BWS		UTM	
Ankle	Walk	Run	Walk	Run	Walk	Run
Dorsiflexion	94.1 (4.6)	88.6 (5.3)	95.4 (5.2)	90.9[a] (4.8)	103.1[a, b] (4.7)	96.9[a, b] (3.7)
Plantar Flexion	120.7 (5.0)	122.4 (5.2)	121.1 (5.7)	124.6 (3.2)	127.7[a] (7.2)	130.3[a, b] (5.3)
Knee						
Flexion	127.9 (3.7)	137.7 (5.1)	129.0 (5.0)	141.6 (2.2)	134.4[a, b] (6.5)	143.7[a] (4.9)
Extension	179.0[c] (3.1)	165.1[c] (4.3)	178.4[c] (4.1)	166.4[c] (4.2)	169.9 (2.7)	158.9 (5.8)
Hip						
Flexion	161.0[c] (2.9)	158.8 (3.9)	163.3[c] (2.9)	161.1 (2.6)	157.8 (4.1)	159.4 (3.8)
Extension	189.8 (4.0)	193.8 (4.3)	190.2 (4.2)	194.0[c] (3.8)	192.5 (3.1)	189.9 (5.2)

Note: a—significantly different from LTM
b—significantly different from BWS
c—significantly different from UTM

Table 7
Joint Angles (mean (±SD)) for the Swing Phase of Gait during LTM, BWS, and UTM exercise. The minimum and maximum angle values are displayed for the ankle, knee and hip

	LTM		BWS		UTM	
Ankle	Walk	Run	Walk	Run	Walk	Run
Dorsiflexion	106.6 (5.2)	97.9 (5.7)	106.5 (5.3)	98.5 (6.1)	104.7 (3.5)	100.5 (3.9)
Plantar Flexion	122.1 (5.0)	130.2 (6.8)	123.8 (6.4)	132.3 (6.2)	127.9[a] (7.2)	137.4[a, b] (6.5)
Knee						
Flexion	113.6 (4.9)	95.3[c] (8.4)	115.3 (6.0)	101.8[a, c] (8.4)	113.0 (8.1)	71.1 (16.7)
Extension	178.2[c] (5.8)	167.4[c] (6.6)	179.4[c] (4.6)	169.2[c] (6.7)	167.3 (5.3)	159.5 (6.8)
Hip						
Flexion	153.8 (4.7)	148.9[c] (4.5)	155.2 (4.5)	151.6[a, c] (4.9)	153.5 (5.5)	140.6 (9.5)
Extension	170.5 (4.4)	192.3 (4.9)	171.3 (4.9)	191.7 (5.5)	179.1[a, b] (5.8)	189.7 (4.9)

Note: a—significantly different from LTM
b—significantly different from BWS
c—significantly different from UTM

Table 8
Joint Angular Velocity (mean (±SD)) for the Stance Phase of Gait during LTM, BWS, and UTM exercise. The minimum and maximum velocity values are displayed for the ankle, knee and hip joints.

	LTM		BWS		UTM	
Ankle	Walk	Run	Walk	Run	Walk	Run
Dorsiflexion	-106.9[c] (28.8)	-154.7[c] (33.5)	-92.2[c] (16.6)	-141.9[c] (53.0)	-57.4 (12.6)	-100.1 (50.8)
Plantar Flexion	224.4[c] (43.9)	322.7 (57.8)	214.1[c] (51.6)	321.7 (46.2)	135.0 (21.6)	290.3 (30.6)
Knee						
Flexion	-274.2[c] (31.5)	-294.3[b, c] (39.2)	-266.7[c] (21.8)	-266.4[c] (45.5)	-213.7 (36.9)	-167.3 (37.8)
Extension	62.9 (18.9)	184.9[c] (36.9)	50.3 (19.8)	161.3[c] (36.3)	54.8 (23.4)	87.8 (43.3)
Hip						
Flexion	-146.3[c] (23.1)	-45.4[c] (38.5)	-138.4[c] (17.6)	-41.4[c] (44.2)	-91.4 (58.0)	4.8 (24.4)
Extension	90.8[b] (13.5)	207.3 (38.9)	77.3 (13.0)	204.8 (26.9)	84.9 (19.5)	187.4 (30.5)

Note: a—significantly different from LTM
b—significantly different from BWS
c—significantly different from UTM

Table 9
Joint Angular Velocity (mean (±SD)) for the Swing Phase of Gait during LTM, BWS, and UTM exercise. The minimum and maximum velocity values are displayed for the ankle, knee and hip joints.

	LTM		BWS		UTM	

Ankle	Walk	Run	Walk	Run	Walk	Run
Dorsiflexion	-130.3 (52.6)	-205.3[c] (59.1)	-143.9 (59.6)	-183.6 (41.2)	-121.4 (26.3)	-167.5 (40.3)
Plantar Flexion	72.9 (31.8)	118.9 (67.6)	75.1 (27.7)	126.5 (67.7)	66.3 (20.6)	107.9 (50.8)
Knee						
Flexion	-179.5 (38.2)	-397.7[b, c] (62.2)	-174.7 (45.1)	-364.9[c] (44.8)	-185.6 (30.3)	-281.9 (61.0)
Extension	358.5[c] (41.4)	541.9[b, c] (67.4)	345.6[c] (50.8)	484.1[c] (72.3)	182.6 (29.5)	366.3 (74.8)
Hip						
Flexion	-139.0[c] (15.3)	-247.9[c] (31.6)	-134.4[c] (24.3)	-221.5 (32.7)	-118.8 (20.8)	-201.2 (32.6)
Extension	70.4[c] (23.1)	128.7[b] (45.0)	70.6[c] (22.3)	100.9 (38.5)	30.6 (14.7)	106.3 (44.0)

Note: a—significantly different from LTM
b—significantly different from BWS
c—significantly different from UTM

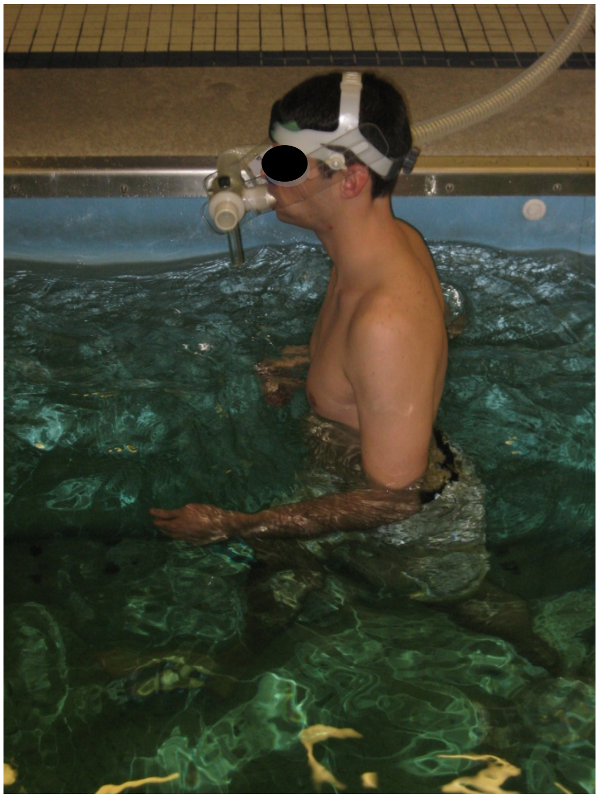

Figure 1. Experimental set-up for the underwater treadmill mode.

Figure 2. The Pneumax body weight support unloader.

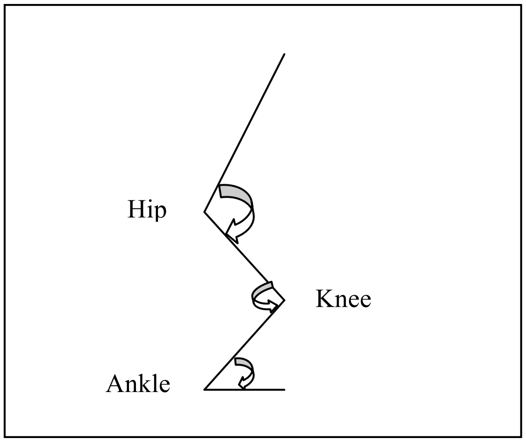

Figure 3: Angle conventions used for the two-dimensional lower extremity kinematics.

References

Alkurdi, W., Paul, D.R., Sadowski, K., & Dolny, D.G. (2010). The effect of water depth on energy expenditure and perception of effort in female subjects while walking. *International Journal of Aquatic Research and Education, 4*, 49-60.

Barbeau, H., & Visintin, M. (2003). Optimal outcomes obtained with body weight support combined with treadmill training in stroke subjects. *Archives of Physical Medicine and Rehabilitation, 84,* 1458-1465.

Barela, A.M., & Duarte, M. (2008). Biomechanical characteristics of elderly individuals walking on land and in water. *Journal of Electromyography and Kinesiology, 18*(3), 446-454.

Barela, A.M., Stolf, S.F., & Duarte, M. (2006). Biomechanical characteristics of adults walking in shallow water and on land. *Journal of Electromyography and Kinesiology, 16*(3), 250-256.

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sport and Exercise, 14*, 377-381.

Byrne, H.K., Craig, J.N., & Wilmore, JH. (1996). A comparison of the effects of underwater treadmill walking to dry land treadmill walking on oxygen consumption, heart rate, and cardiac output. *Journal of Aquatic Physical Therapy, 4*, 4-11.

Cavagna, G. A., Thys, H., & Zamboni, A. (1976). The sources of external work in level walking and running. *Journal of Physiology, 262*, 639-657.

Cavanagh, P.R. & Kram, R. (1985). Mechanical and muscular factors affecting the efficiency of human movement. *Medicine and Science in Sports and Exercise, 17*, 326-331.

Chang, Y-H., Huang, H.W., Hamerski, C.M., & Kram, R. (2000). The independent effects of gravity and inertia on running mechanics. *The Journal of Experimental Biology, 203*, 229-238.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Colby, S.M., Kirkendall, D.T., & Bruzga, R.F. (1999). Electromyographic analysis and energy expenditure of harness supported treadmill walking: Implications for knee rehabilitation. *Gait and Posture, 10*, 200-205.

Danaei, G., Ding, E.L., Mozaffarian, D., Taylor, B., Rehm, J., Murray, C.J.L., et al. (2009). The preventable causes of death in the United States: Comparative risk assessment of dietary, lifestyle, and metabolic risk factors. *PLoS Medicine, 6*(4), e1000058.

Donelan, J.M. & Kram, R. (1997). The effect of reduced gravity on the kinematics of human walking: A test of the dynamic similarity hypothesis for locomotion. *The Journal of Experimental Biology, 200*, 3193-3201.

Elsworth, C., Dawes, H., Collett, J., Howells, K., Ramsbottom, R., Izadi, H., et al. (2006). Oxygen cost during treadmill walking with hip and knee immobilized. *Journal of Sports Science and Medicine, 5*, 640-645.

Farley, C.T., & McMahon, T.A. (1992). Energetics of walking and running: Insights from simulated reduced-gravity experiments. *Journal of Applied Physiology, 73*, 2709-2712.

Gleim, G.W., & Nicholas, J.A. (1989). Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. *American Journal of Sports Medicine, 17*(2), 248-252.

Grabowski, A., Farley, C.T., & Kram, R. (2005). Independent metabolic costs of supporting body weight and accelerating body mass during walking. *Journal of Applied Physiology, 98*, 579-583.

Grabowski, A.M., & Kram, R. (2008). Effects of velocity and weight support on ground reaction forces and metabolic power during running. *Journal of Applied Biomechanics, 24*, 288-297.

Griffin, T.M., & Guilak, F. (2005). The role of mechanical loading in the onset and progression of osteoarthritis. *Exercise and Sport Sciences Reviews, 33*, 195-200.

Griffin, T.M., Tolani, N.A., & Kram, R. (1999). Walking in simulated reduced gravity: Mechanical energy fluctuations and exchange. *Journal of Applied Physiology, 86*, 383-390.

Hall, J., Macdonald, I.A., Maddison, P.J., & O'Hare, J.P. (1998). Cardiorespiratory responses to underwater treadmill walking in healthy females. *European Journal of Applied Physiology and Occupational Physiology, 77*(3), 278-284.

Heath, E.M., Blackwell, J.R., Baker, U.C., Smith, D.R., & Kornatz, K.W. (2001). Backward walking practice decreases oxygen uptake, heart rate and ratings of perceived exertion. *Physical Therapy in Sport, 2*, 171-177.

Hesse, S., Werner, C., Seibel, H., von Frankenberg, S., Kappel, E., Kirker, S., et al. (2003). Treadmill training with partial body-weight support after total hip arthroplasty: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 84*, 1767-1773.

Hinman, R.S., Heywood, S.E., & Day, A.R. (2007). Aquatic physical therapy for hip and knee osteoarthritis: Results of a single-blind randomized controlled trial. *Physical Therapy, 87*(1), 32-43.

Hunter, D., Smith, E., Murray, J.M., Murray, T.D. (1995). Energy expenditure of below-knee amputees during harness-supported treadmill ambulation. *Journal of Orthopaedic and Sports Physical Therapy, 21*(5), 268-276.

Jackson, K.M. (1979). Fitting of mathematical functions to biomechanical data. *IEEE Transactions of Biomedical Engineering*, *26*, 122-124.

Kelsey, D., & Tyson, E. (1994). A new method of training the lower extremity using unloading. *Journal of Orthopaedic and Sports Physical Therapy, 19*, 218-223.

Knudson, D. (2009). Significant and meaningful effects in sports biomechanics research. *Sports Biomech, 8*(1), 96-104.

Lundbrook, J. (1998). Multiple Comparison Procedures Updated. *Clinical Experimental Pharmacology and Physiology, 25*, 1032-1037.

Masumoto, K., Shono, T., Hotta, N., & Fujishima, K. (2008). Muscle activation, cardiorespiratory response, and rating of perceived exertion in older subjects while walking in water and on dry land. *Journal of Electromyography and Kinesiology, 18*, 581-590.

Masumoto, K., Takasugi, S., Hotta, N., Fujishima, K., & Iwamoto, Y. (2005). Muscle activity and heart rate response during backward walking in water and on dry land. *European Journal of Applied Physiology, 94*, 54-61.

Millslagle, D., Levy, M., & Matack, N. (2006). Kinematic assessment of treadmill running using different body-weight support harnesses. *Perceptual and Motor Skills, 103*, 607-618.

Minetti, A.E., Capelli, C., Zamparo, P., di Prampero, P., & Saibene, F. (1995). Effects of stride frequency on mechanical power and energy expenditure of walking. *Medicine and Science in Sports and Exercise, 27*, 1194-1202.

Miyai, I., Fujimoto, Y., Ueda, Y., Yamamoto, H., Nozaki, S., Saito, T., & Kang, J. (2000). Treadmill training with body weight support: Its effect on Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation, 81*, 849-852.

Murray, J.M., Hunter, D.L., Paper, M.W., Kelsey, D.D., & Murray, T.D. (1993). Determination of the physiological effects of unloaded treadmill exercise. *Cardiopulmonary Physical Therapy Journal, 4*(2), 13-16.

Nakazawa, K., Yano, H., & Miyashita, M. (1994). Ground reaction forces during walking in water. In M. Miyashita, Y. Mutoh, & A.B. Richardson (Eds.), *Medicine and Science in Aquatic Sports* (pp.28-34). Basel: Karger.

Pollock, M.L., Carroll, J.F., Graves, J.E., Leggett, S.H., Braith, R.W., Limacher, M., & Hagberg, J.M. (1991). Injuries and adherence to walk/jog and resistance training programs in the elderly. *Medicine and Science in Sports and Exercise, 23*, 1194-1200.

Ralston, H.J. (1958). Energy-speed relation and optimal speed during level walking. *European Journal of Applied Physiology, 17*, 277-283.

Rutledge, E., Silvers, W.M., Browder, K., & Dolny, D. (2007). Metabolic-cost comparison of submaximal land and aquatic treadmill exercise. *International Journal of Aquatic Research and Education, 1*, 118-133.

Sparrow, W.A. & Irizarry-Lopez, V.M. (1987). Mechanical efficiency and metabolic cost as measures of learning a novel gross motor task. *Journal of Motor Behavior, 19*, 240-264.

Teunissen, L.P., Grabowski, A., & Kram, R. (2007). Effects of independently altering body weight and body mass on the metabolic cost of running. *The Journal of Experimental Biology, 210*, 4418-4427.

Thomas, E.E., De Vito, G., & Macaluso, A. (2007). Physiological costs and temporo-spatial parameters of walking on a treadmill vary with body weight unloading and speed in both healthy young and older women. *European Journal of Applied Physiology, 100,* 293-299.

Threlkeld, A.J., Cooper, L.D., Monger, B.P., Craven, A.N., Haupt, H.G. (2003). Temporospatial and kinematic gait alterations during treadmill walking with body weight suspension. *Gait and Posture, 17*, 235-245.

Umberger, B.R. (2008). Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. *Journal of Biomechanics, 41*, 2575-2580.

van Hedel, H.J.A., Tomatis, L., Müller, R. (2006). Modulation of leg muscle activity and gait kinematics by walking speed and bodyweight unloading. *Gait and Posture, 24*, 35-45.

Visintin, M., Barbeau, H., Korner-Bitensky, N., & Mayo, N.E. (1998). A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. *Stroke, 29*, 1122-1128.

Winter, D.A. (1990). *Biomechanics and Motor Control of Human Movement*. New York: John Wiley and Sons Inc.