CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Influence of Water Depth on Energy Expenditure During Aquatic Walking in People Post-Stroke

For the degree of Master of Science in Kinesiology

By

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Abstract

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BACKGROUND: Hemiparetic gait in people post-stroke may limit functional mobility and contribute to excessive energy expenditure (EE) during walking. Previous studies identified a decrease in EE during aquatic walking for people post-stroke when compared to overground walking. However, no studies have examined the influence of water depth during aquatic walking on the metabolic cost in people post-stroke. The study aimed to investigate the metabolic cost during aquatic walking at various depths in people post-stroke.

METHODS: Twelve participants post-stroke (aged 55.50±13.32 years) completed six-min of walking in four different conditions: chest-depth, waist-depth, thigh-depth water, and overground. Data was collected on four separate visits with at least 48 hours in between. On the first visit, all participants were asked to walk in chest-depth water at their fastest speed. The walking speed was used as a reference speed, which was applied to the remaining three walking conditions. The order of remaining walking conditions was randomized. Different water depths were adjusted using a movable floor pool. EE, oxygen consumption (VO_2), and minute ventilation (V_E) were measured with a telemetric metabolic system (K4b2, Cosmed Inc., Rome, Italy, 1998).

RESULTS: Repeated measures ANOVA showed statistically significant differences in EE, VO_2, and V_E among the four different walking conditions (all $p<.05$). The participants demonstrated reduction in all variables as the water depth increased from thigh-depth to chest-depth water (EE 5.03 to 3.38kcal/min; VO_2 12.42 to 8.27ml/kg/min; V_E 29.66 to 20.70l/min, $p<.05$). Only thigh-depth walking revealed significant differences when compared to overground walking in all variables (EE 5.03 to 3.95kcal/min; VO_2 12.42 to 10.15ml/kg/min; V_E 29.66 to 22.75l/min, $p<.05$). In addition, walking at waist-depth water showed similar results compared to overground walking in EE (4.09 to 3.95kcal/min), VO_2 (10.20 to 10.15ml/min/kg), and V_E (24.28 to 22.75l/min).

CONCLUSION: Our findings suggest that people post-stroke may benefit from long duration of gait training in chest-depth water as it reduces the energy cost of walking, mostly due to buoyancy. Thigh-depth water is recommended for time-efficient cardiovascular exercise with added resistance. When walking in waist-depth water, the effects of buoyancy and water resistance appear to countervail one another which results in similar metabolic cost to overground walking in people post-stroke.

Chapter 1

Introduction

Gait impairment is one of the major motor characteristics of people post-stroke. Although 65-85% of individuals post-stroke learns to walk independently by six months through rehabilitation, gait abnormalities persist through the chronic stages of the condition (Wade, Wood, Heller, Maggs, & Langton Hewer, 1987). Gait impairment, such as hemiparetic gait, has been documented to show increased energy expenditure (EE) among people post-stroke when compared with an efficient symmetric gait (Zamparo, 1995). Moreover, the amount of increased energy cost has been reported to be twice that of a normal gait (Platts, Rafferty, & Paul, 2006). The high-energy demand while walking has a profoundly negative impact on functional independence, mobility, and community participation in individuals post-stroke (Eng & Tang, 2007).

People post-stroke often experience increased physical inactivity due to the high energy demand of walking, resulting in poor cardiovascular fitness (Lee & Blair, 2002). Poor cardiovascular fitness is related to a higher risk of recurrent stroke and stroke mortality (Salonen et al., 2003). In addition, up to 75% of people who experienced a stroke have some form of cardiovascular disease (Roth, 1993). Therefore, improving cardiovascular fitness is an essential component in stroke rehabilitation.

Treadmill walking has been widely utilized as a method of stroke rehabilitation. Walking on a treadmill has been shown to produce substantial and progressive reduction on the EE in people post-stroke (Macko et al., 1997). The reduced EE during walking is considered to be an indicator of improved cardiovascular fitness (Macko et al., 2005). Body-weight-supported treadmill

(BWST) walking creates a safer walking environment for people post-stroke in the early stage of rehabilitation by reducing the amount of body mass they need to carry. In addition, the metabolic cost of BWST walking has been reported to be lower when compared to unsupported treadmill walking in individuals post-stroke (Danielsson & Sunnerhagen, 2000). However, BWST tends to be expensive and not readily accessible in a rehabilitation setting or community fitness center since it requires instrumented treadmill.

Buoyancy allows an individual to experience partial weight bearing effect in an aquatic setting. The effect of buoyancy reduces the vertical ground reaction force on the lower extremities, which contributes to less body weight bearing during aquatic walking (Nakazawa et al., 1994). A recent study found lower EE during aquatic treadmill walking when compare to overground treadmill walking in individuals post-stroke (Jung, Ozaki, Lai, & Vrongistinos, 2014). Moreover, the body weight support effect from the buoyancy allows people with gait impairment to exercise in the early stage of rehabilitation, even though they lack postural control and balance (Barbeau, Wainberg, & Finch, 1987). The effectiveness of aquatic exercise in people post-stroke has been well documented (Chu et al., 2004; Yoo, Lim, Lee, & Kwon, 2014).

Previous studies reported that aquatic treadmill walking at various water depths affects the metabolic cost in healthy adults (Alkurdi, Sadowski, Paul, & Dolny, 2010; Benelli et al., 2014; Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). When the water depth was below waist level, metabolic cost increased as the water depth increased (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). However, the water depth at waist level and above revealed an opposite trend. It has been reported that metabolic cost reduced as the water depth increased from the waist level (Alkurdi et al., 2010; Benelli et al., 2014).

The metabolic cost during aquatic treadmill walking has been reported to show difference among various levels of water immersion in healthy adults. However, to our knowledge, no study examined the influence of water depth on disability population, which includes people who have experienced a stroke. In addition, few studies have attempted to use pool floor walking as a form of aquatic walking; most have used the aquatic treadmill walking. Therefore, the purpose of this study was to investigate the influence of different water depths on metabolic cost during pool floor walking in people post-stroke. It was hypothesized that participants post-stroke would demonstrate lower metabolic cost as the water depth increase during pool floor walking. The secondary purpose was to examine differences in metabolic cost between overground walking and pool floor walking in three water depths in individuals post-stroke. It was hypothesized that participants post-stroke would show higher metabolic cost during overground walking when compared to pool floor walking in three water depths.

Chapter 2

Literature Review

2.1 Definition and Incidence of Stroke

Stroke is a neurological deficit due to lack of oxygen in the brain, caused by either rupture of a blood vessel or blood supply interruption (O’Sullivan & Schmitz, 2007). Stroke is one of the leading causes of adult disability in the U.S. It is reported that there have been an estimated 6.6 million people who have experienced a stroke during a period of 2009 to 2012 (Mozaffarian et al., 2015). The most prevalent symptoms shown in people post-stroke are motor weakness, speech, and gait disturbances (Kimura, Kazui, Minematsu, & Yamaguchi, 2004). The functional limitations in people post-stroke lead to a high risk of secondary complications such as cardiovascular disease, type-II diabetes, metabolic syndrome, and obesity (Hamilton, M., Hamilton, D., & Zderic, 2007).

2.2 Stroke and Gait Impairment

2.2.1 Energy Cost of Gait

Energy Cost of Normal Gait

Several studies have been conducted to observe the energy cost of walking in the normal population. One study examined VO_2 during self-selected speed for different age groups which ranged from 20 to 59 years for young adults and 60 to 80 years for senior participants. The result showed no significant difference between the age groups (Waters, Lunsford, Perry, & Byrd, 1988). Other studies reported the percentage of the VO_2 max as a result of a walking test at the participant’s comfortable walking speed. The rate of VO_2 requires 28% of the VO_2 max of an untrained normal participant from 6 to 12 years of age, 32% of an adult from 20 to 30 years of age, and approximately 48% of a senior subject who was 75 years of age (Waters, Hislop, Thomas, & Campbell, 1983; Waters, Hislop, Perry, Thomas, & Campbell, 1983).

Energy Cost of Impaired Gait

Previous study has reported that 50 to 80% of individuals who survived from stroke will eventually recover their walking ability. However, approximately 20% of individuals unsuccessfully obtained independent mobility (Huitema et al., 2004). Even though the individuals recovered their walking ability, they still suffered from significant gait deviations which includes hemiparetic gait (Von Schroeder, Coutts, Lyden, Billings, & Nickel, 1995).

Due to the high prevalence of gait impairment in people post-stroke, numerous studies have been documented to examine the energy cost of hemiparetic gait. One study compared the metabolic cost to 13 stroke participants and 13 age- and sex- matched healthy participants during self-selected paced walking. The result showed that stroke participants required almost three times more VO_2 per unit of distance than healthy participants (Platts et al., 2006). Detrembleur, Dierick, Stoquart, Chantraine, and Lejeune (2003) also observed the energy cost of walking in nine chronic hemiparetic individuals by measuring the total mechanical work. Total mechanical work value in stroke participants showed twice that of the normal value which was significantly related to increased energy cost of walking.

Many researchers made efforts to identify the mechanism of increased energy cost in impaired gait. Awad and his colleagues (2015) observed 42 individuals with chronic hemiparesis who participated in 12 weeks of walking rehabilitation. The result showed that faster and more symmetric walking was found after the intervention which was significantly associated with high energy efficiency. The researchers concluded that intervention-induced improvements in walking speed and step length asymmetry contributed to energy efficient walking after stroke. Another study conducted by Ijmker et al. (2013) recruited 12 stroke participants measuring the energy cost of walking both with and without handrail support. Handrail support showed significant decrease in energy cost of 16% which can be concluded that balance improvement can contribute to reduced metabolic effort for balance control and eventually leads to reduced cost of walking in people post-stroke.

2.2.2 Exercise Training in Gait Impairment

Numerous literatures have been emphasizing the importance of exercise training on stroke rehabilitation because the higher energy cost of impaired gait leads to a sedentary lifestyle and eventually results in deteriorated cardiorespiratory fitness in people post-stroke. Globas et al. (2012) have examined 38 participants with hemiparetic gait after stroke to compare high-intensity aerobic treadmill exercise (TAEX) and conventional care physiotherapy. TAEX group showed significant improvement in peak exercise capacity (VO_2 peak) and distance walked in 6-minute walk test compared to conventional care group after 3 months of intervention. It was concluded that gait-oriented cardiovascular fitness training improved not only gait but also cardiovascular fitness in people post-stroke. In a similar study, Macko et al. (2005) conducted the aerobic exercise training for a longer period of time with more participants. The researchers investigated the effect of 6 months treadmill aerobic training on ambulatory function and cardiovascular fitness in 61 participants with hemiparetic gait after stroke. Only aerobic training group showed 17% increase in VO_2 peak and nearly triple the achievement in 6-minute walk test compared to the conventional rehabilitation group. The results demonstrated the physiological and functional benefits of aerobic training in people with chronic stroke which is similar to the previous literature.

Recent studies stated that body weight supported treadmill training (BWSTT) is highly related to improved fitness and ambulation in people post-stroke. MacKay-Lyons, McDonald, Matheson, Eskes, and Klus (2013) compared the effectiveness of BWSTT to usual care (overground gait training) in improving cardiovascular fitness and walking ability in people post-stroke. 50 participants were randomly assigned to BWSTT + usual care group and usual care group. The intervention was conducted for 12-week. The results demonstrated that BWSTT + usual care group showed 30% improvement in VO_2 peak compared to 8% improvement in usual care group. In addition, significant improvement in the endurance walking test was observed in BWSTT + usual care group. These gains were sustained for one year which was not the case for the treadmill exercise training without the body weight support (BWS) system (Globas et al., 2012). Peurala, Tarkka, Pitkänen, and Sivenius (2005) conducted a similar study comparing the BWS gait training to overground walking. 45 participants with chronic stroke have been randomly assigned to BWS gait training group and overground walking group. However, the result showed that both BWS training and overground walking training resulted in increased motor performance and no significant difference was found between the groups. Motor performance in both groups also remained improved at 6 months follow-up.

2.3 Aquatic Walking

2.3.1 Water Properties and Exercise

The water environment can provide BWS effect on walking due to the unique characteristics. Body weight can be partially supported due to the buoyant force which decreases the joint force. The drag force exerted by water also increases the resistance of the body movement which makes the movement slower. These water characteristics allow individuals with physical disabilities to perform exercise, especially walking, by making it easier to control the movement in water than on land (Orselli & Duarte, 2011; Barela, Stolf, & Duarte, 2006).

Based on the water characteristics, many studies have found that exercise training in water is an effective method to elicit the physiological responses which may contribute to health promotion. During water exercise at the same oxygen uptake, elevated HR in water has been reported to be lower than on land (Onodera et al., 2006). The systolic blood pressure (BP) in water was also observed to be lower than on land. Moreover, the diastolic BP after the exercise was lower in water (Matsui et al., 1999). Another study examined the effect of water viscosity on VO_2 value. The result demonstrated that VO_2 was greater in water compared to land due to the water viscosity (Onodera, Miyachi, Yano, & Miyakawa, 1998).

2.3.2 Aquatic vs. Land Walking

Previous studies observed physiological responses to changes in the physical characteristics of water, which is different from the responses coming from land exercise. Jung, Ozaki, Lai, and Vrongistinos (2014) have compared the cardiorespiratory responses between aquatic treadmill walking (ATW) and overground treadmill walking (OTW) in people post-stroke. Eight post-stroke participants conducted both ATW and OTW to observe the difference between two different walking environments. ATW was reported to have decreased VO_2 value by 39%, decreased EE value by 40% compared to OTW. This study demonstrated that the reduced metabolic cost of walking in the water will allow people post-stroke to perform gait training for longer duration.

Another study has been conducted to investigate the difference of metabolic cost during walking in water and on land by Masumoto, Nishizaki, and Hamada (2013). 11 healthy participants participated in this study walking on a treadmill in water and on land. The result showed that not only VO_2 but also rating of perceived exertion (RPE) and preferred stride frequency (SF) were significantly lower in water than on land. This study also reported that changes in SF affected VO_2 and RPE during walking in water.

Previous study has been conducted by Dolbow, Farley, Kim, and Caputo (2008) to examine the physiological responses comparing ATW and OTW depending on the walking speed. 20 healthy participants age from 55 to 64 years were recruited. The water depth was matched to the participant’s waist level for ATW. This was different from the two studies introduced earlier which adjusted the water depth to chest level. This study reported that both ATW and OTW showed significant increase in VO_2, HR, and RPE value as the speed increased. However, no significant difference was found on systolic blood pressure (SBP) value when increasing the speed during OTW. Furthermore, significantly higher VO_2, HR, RPE values were observed during ATW compared to OTW at the speeds of 2.5 mph and 3.0 mph. Compare to the two studies introduced earlier, this study adjusted the water depth to waist level instead of chest level during ATW. This indicates that ATW have shown greater demand on the cardiovascular system in both water depths compared to OTW (Jung et al., 2014; Masumoto et al., 2013; Dolbow et al., 2008).

2.4 Water Depth

Aquatic walking has been proven to be an effective rehabilitation method to improve cardiovascular fitness in people post-stroke (Macko et al., 2005; Chu et al., 2004; Yoo et al., 2014). Several studies have addressed which water level would be effective to elicit the physiological responses that benefits cardiovascular fitness (Alkurdi et al., 2010; Gleim et al., 1989; Pohl & McNaughton, 2003; Benelli et al., 2014). Research by Gleim et al. (1989) recruited 11 healthy participants with the mean age of 27.5 ± 1.8 years. Underwater treadmill tests were conducted in different water depths using ankle, knee, mid-thigh, and waist level. The result demonstrated that VO_2 and HR value increased as the water depth increased. Increase in body surface covered by water might have supplied greater resistive force to the walking movement. However, walking test in waist level showed lower VO_2 compared to mid-thigh and knee level. The researchers interpreted that when enough of the body is submerged, the buoyant force affects the body more than the resistive force which decreases the metabolic cost of walking movement. Pohl et al. (2003) also examined the physiological responses on two different water depths which were thigh- and waist-deep water during walking. Six young healthy participants completed the five-minute walk test on an underwater treadmill. VO_2 and HR values were measured to be significantly higher in thigh-deep water compared to waist-deep water and land. Waist-deep water was significantly higher in VO_2, HR, and VO_2 per stride values compared to land. According to both studies, when the water depth was below waist level, metabolic cost increased as the water depth increased (Gleim et al., 1989; Pohl et al., 2003).

On the other hand, previous studies revealed that the water depth on waist level and above showed an opposite trend when compared to the water depth below waist level. Benelli et al. (2014) observed the difference of waist and chest level water depths on physiological responses using a non-motorized underwater treadmill. 15 middle-aged healthy women performed underwater walking tests on chest and waist level. Significant differences were found in VO_2 and HR responses between chest and waist level water depths. VO_2 and HR were 13.5% and 8.1% higher on waist level, respectively. The result reflected that the participants showed energy cost effective walking on the chest level water depth compared to waist level. Another study conducted by Alkurdi et al. (2010) compared three water depths around the chest level. 18 female participants aged 21-60 years walked on an underwater treadmill using chest, 10 cm below, and 10 cm above chest level on three separate days. EE and HR were highest on 10 cm below chest level followed by chest and 10 cm above chest. Even though this study examined the small changes in water depth compared to other studies, it still resulted in significant difference on metabolic cost during aquatic walking.

2.5 *Summary*

Gait impairment which is one of the prevalent symptoms after stroke has been reported to increase the energy cost of walking (Platts et al., 2006; Detrembleur et al., 2003). Several studies have been conducted to seek for an effective rehabilitation method such as aerobic treadmill training or BWSTT to reduce the energy cost of walking for this population (Globas et al., 2012; Macko et al., 2005; MacKay-Lyons et al., 2013; Peurala et al., 2005). Several researchers recommended exercise training in the water to decrease the metabolic cost of walking by utilizing the water characteristics which are not provided on land (Orselli et al., 2011; Barela et al., 2006). Physiological responses during aquatic and overground walking were compared to identify a better walking environment for people post-stroke (Jung et al., 2014). Additionally, the influence of different water depths on physiological responses was observed by several studies (Gleim et al., 1989; Pohl et al., 2003; Benelli et al., 2014; Alkurdi et al., 2010). However, no research was found which examined the influence of water depth on disability population. Moreover, alternative mode of exercise, such as pool floor walking, has not been investigated. Therefore, the purpose of this study is to examine the influence of different water depths on physiological responses during pool floor walking in people post-stroke.

Chapter 3

Methods

3.1 Participants

A total of 12 individuals post-stroke (25-60 years, 6 males/6 females, mean age 55.50±13.32 years) participated in this study. Participant's mean height and weight were as follows: height (165.67±9.61cm), weight (79.25±15.18kg). All participants were minimum of six-month post-stroke after their diagnosis (Table 1). Participants were able to walk independently without a walking aid for a minimum of ten minutes, cooperate with the testing procedures, and had no surgery within the last six months. Participants were excluded if they had an acute injury, cardiovascular complication, or fear of water. The study was approved by an Institutional Review Board. The study received written informed consent from each participant prior to data collection. A Fugl-Meyer Lower Extremity Assessment was completed to assess the motor ability on the participants' lower extremity.

3.2 Experimental Design

The study was conducted in the movable floor pool (CmbH & Company, Wilhelmshaven, Germany) and open carpeted room at the university-based therapy center. Participants were required to complete four walking sessions in different conditions: chest-depth, waist-depth, and thigh-depth water, and overground. Chest-depth was defined as the level of xiphoid process, waist-depth was defined as the level of umbilicus, and thigh-depth was defined as the level of greater trochanter. The water depths were adjusted using the movable floor pool. Dependent variables such as EE, VO_2, and minute ventilation (V_E) were measured during the six-minute walk test using the telemetric metabolic system (K4b^2, Cosmed Inc., Rome, Italy, 1998) at each water depth. The telemetric metabolic system was kept in a waterproof container during aquatic walk tests. The water temperature was maintained constant at 34-35°C.

3.3 Experimental Procedure

All participants completed four walking sessions on a separate day with at least 48 hours between. Each walking session consisted of ten-minute seated rest and six-minute walking on a 20-meter oval shaped walkway. Participants were asked not to consume any caffeine or alcohol at least three hours prior to each session.

During the first session, participants were instructed to walk at their fastest speed for six minutes at chest-depth water. Lap time was recorded to identify participants' walking speed. A metronome was also used to measure the participants' cadence. The same procedure was repeated for the remaining three walking conditions such as waist-depth, thigh-depth water, and land on a separate day. The order of the three remaining walking conditions was randomized. The averaged lap time from chest-depth walk test was used for all other walking conditions to match the walking speed. In addition, auditory feedback was provided during the walk tests using a metronome to match the cadence. Dependent variables were monitored throughout the protocol.

3.4 Data Analysis

The mean EE, VO_2, and V_E values based on the six-minute walk tests in four walking conditions were calculated. Separate repeated measures ANOVA was used to observe the difference among four walking conditions. P-values were adjusted by using Bonferroni method. Data analyses were performed using SPSS software, version 22.0 (IBM SPSS Statistics 22, Armonk, NY, USA).

Chapter 4

Results

A total of 12 participants post-stroke completed this study. Participants' information is shown in Table 1. Statistical analysis revealed significant differences among four walking conditions in EE, VO_2, and V_E (all $p<0.05$). The means and standard deviations of physiological responses for different walking conditions are displayed in Table 2.

Post hoc analysis showed a significant decrease in EE, VO_2, and V_E as the water depth increased. The participants significantly decreased EE by approximately 33% from thigh level to chest level (5.03 to 3.38kcal/min; p=.009) and 17% from waist level to chest level (4.09 to 3.38kcal/min; p=.009). They significantly decreased VO_2 by 33% from thigh level to chest level (12.42 to 8.27ml/kg/min; p=.008) and 19% from waist level to chest level (10.20 to 8.27ml/kg/min; p=.020). Significant decrease by 30% in V_E was noted from thigh level to chest level (29.66 to 20.70l/min; p=.036). However, no significant difference in V_E was identified between waist level and chest level (Figure 1).

When comparing aquatic and overground walking, statistical significance was only found on thigh-depth water in all variables. EE, VO_2, and V_E in thigh-depth walking showed 22%, 18%, and 23% increase, respectively, when compared to overground walking (3.95 to 5.03kcal/min, p=.018; 10.15 to 12.42ml/kg/min, p=.015; 22.75 to 29.66l/min, p=.009). Although no significant differences were found between waist-depth walking and overground walking, similar values were noted in all variables which require further explanation in the discussion section (Figure 1).

Table 1. Characteristics of the 12 participants post-stroke

Characteristics	Stroke (n=12)
Gender (M/F)	6/6
Age (years)	55.50±13.32
Height (cm)	165.67±9.61
Weight (kg)	79.25±15.18
Years post-stroke	4.42±2.43
Affected side (R/L)	5/7

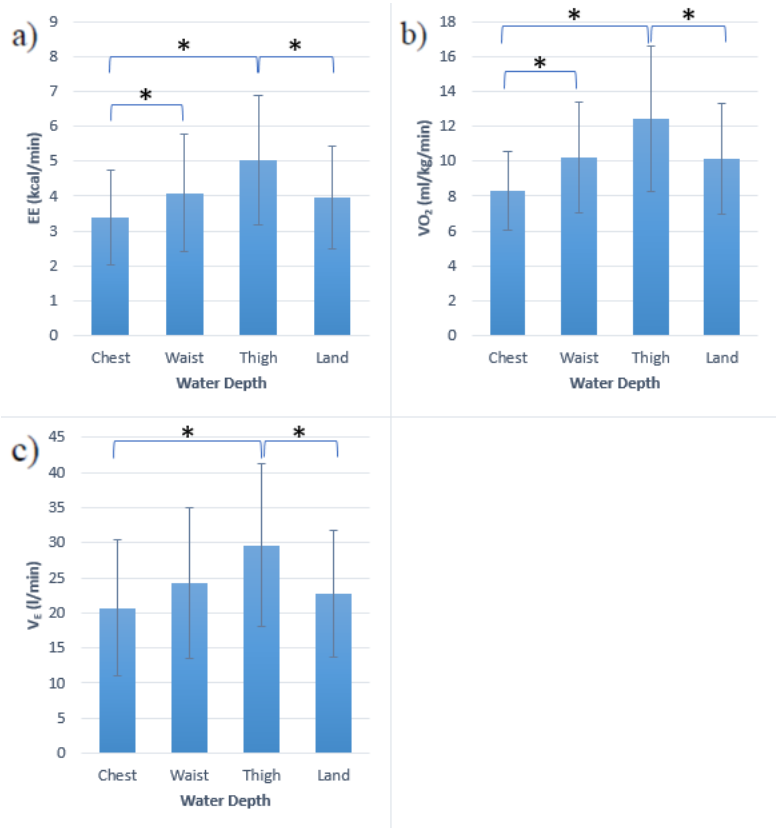
M = male; F = female; R = right; L = left.
Mean ± standard deviation.

Table 2. Physiological responses in different walking conditions

	Water Depth				
Measures	**Chest**	**Waist**	**Thigh**	**Land**	***p*-value**
EE (kcal/min)	3.38±1.36[b,c]	4.09±1.68[d]	5.03±1.87[a,d]	3.95±1.48[b]	0.01
VO_2 (ml/kg/min)	8.27±2.26[b,c]	10.20±3.15[d]	12.42±4.18[a,d]	10.15±3.17[b]	0.01
V_E (l/min)	20.70±9.64[b]	24.28±10.79	29.66±11.51[a,d]	22.75±9.02[b]	0.03

EE = energy expenditure; VO_2 = oxygen consumption; V_E = minute ventilation.
Mean ± standard deviation.
[a] *Significantly different than land (p < .05).*
[b] *Significantly different than thigh (p < .05).*
[c] *Significantly different than waist (p < .05).*
[d] *Significantly different than chest (p < .05).*

Figure 1. Physiological responses in different walking conditions



a) Energy expenditure, b) oxygen consumption, and c) minute ventilation.

*represents significant difference between different walking conditions

Chapter 5

Discussion

The study aimed to investigate physiological responses to pool floor walking at different water depths in individuals post-stroke. Our findings showed decreased physiological responses during chest-depth walking as compare to waist-depth and thigh-depth respectively. Thigh-depth walking demonstrated the highest physiological responses among the three water depths. The secondary purpose was to identify differences in physiological responses between overground walking versus walking in three water depths in individuals post-stroke. Significantly higher physiological responses during thigh-depth walking were observed when compare to overground walking. In addition, waist-depth walking expended similar energy to overground walking at a matched walking speed.

5.1 Water Depth

Chest depth: Our results demonstrated that significantly less energy was spent as the water depth increased from thigh to chest and waist to chest levels. When the water depth increased to chest-depth water, it enhanced the effect of body weight support during pool floor walking thanks to increased buoyancy. Approximately 50% of body weight is supported at the waist-depth, 70-75% at the chest-depth, and 90% at the neck-depth (Koury, 1996). The increased effect of buoyancy at the chest-depth water appears to reduce the workload and result in reduced metabolic cost in people post-stroke.

Our findings are consistent with what have been reported in the previous study. Benelli and his colleagues (2014) reported significantly lower VO_2 and heart rate (HR) in chest-depth walking as compare to waist-depth walking, regardless of the step frequency. A non-motorized treadmill was used in the previous study. Greater friction and increased muscle activation are reported in a non-motorized treadmill when compared to the conventional motorized treadmill (Snyder, Myatt, Weiland, & Bednarek, 2011). A non-motorized treadmill somehow shares similar characteristics to pool floor walking. Similar characteristics in these two modes of walking may have contributed to consistent outcome. Comparison between chest-depth walking and thigh-depth walking in physiological responses has never been investigated in the previous studies. Majority of the previous studies was limited to assessing the water depths in either above or below the waist level.

Waist depth: There was no statistical significance found between waist-depth and thigh-depth walking in the current study. However, our results showed a trend of decreased physiological responses on waist-depth walking when compared to thigh-depth walking. Waist-depth water may have allowed the participants to benefit from the effect of buoyancy, whereas thigh-depth water did not provide sufficient body weight support to observe the significant reduction in physiological responses. In the thigh-depth water, drag force from the water resistance seems to affect the propelling motion of the legs during pool floor walking, whereas decreased buoyancy provides less weight support. The previous studies reported significantly lower physiological responses to waist-depth walking when compared to thigh-depth walking in healthy adults (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). Differences in walking speed may have contributed to the discrepancy. Drag force is greatly affected by movement velocity in water, in addition to surface area, water density, and drag coefficient, $F_d = ½ C_D \rho A v^2$ (Alexander, 1977). People post-stroke demonstrates slower walking speed than healthy adults (Jung, Ozaki, Lai, & Vrongistinos, 2014). The slower walking speed in participants post-stroke can substantially reduce drag force while walking in water. This reduced drag force associated with slower walking speed of participants post-stroke must have contributed to the inconsistent results. In addition, different methodology may be associated with our inconsistent findings. The definition of thigh-depth water was different in the previous studies. We defined the thigh-depth water at the level of the greater trochanter while previous studies used the mid-point between the anterior superior iliac spine and the central patella (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). Although the difference in the water depth was relatively small (upper thigh vs. mid-thigh), it might have contributed to finding different results in physiological responses during pool floor walking.

5.2 Aquatic vs. Overground Walking

Thigh-depth vs. overground walking: Participant post-stroke showed significantly higher physiological values in thigh-depth walking compared to overground walking at a matched speed. This result is consistent with the previous studies that found higher physiological responses during thigh-depth treadmill walking compare to overground treadmill walking in healthy adults (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). The effect of water resistance applied on the lower extremities seems to create drag force in thigh-depth walking, as water is approximately 800 times denser than air (Dowzer & Reilly, 1998). It is interesting to find consistent outcomes even though two previous studies used different methods including the sample of participants (healthy vs. people post-stroke) and the mode of ambulation (treadmill vs. pool floor walking). As discussed earlier, the slower walking speed in people post-stroke is associated with decreased drag force, thus less physiological responses are expected than healthy adults. However, in our present study, participants are asked to walk on the pool floor which is considered forward locomotion. Forward locomotion in water may require additional energy to travel through the water when compared to stationary walking on an aquatic treadmill. Also, higher push-off forces are required during forward locomotion, whereas stationary walking on a treadmill does not require as much (Brouwer, Parvataneni, & Olney, 2009). Therefore, despite the methodological differences, our findings were consistent with the two previous studies.

Waist-depth vs. overground walking: Our results demonstrated similar values between waist-depth walking and overground walking in participant post-stroke. Waist-depth water in which 50% body weight support is expected may have counterbalanced the added resistance to the movement imposed by water (Conti, Minganti, Magini, & Felici, 2015). In contrast, other studies reported that waist-depth jogging or running showed a higher metabolic cost to overground (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). Different modes of ambulation on these studies can be related to the discrepancy. Faster leg movement propelling through the water during jogging or running may have produced greater drag force compared to walking in the present study, particularly slower walking among people post-stroke. Greater drag force applied on the leg requires the involved muscles to perform more mechanical work, which results in increased oxygen uptake.

Chest-depth vs. overground walking: Our findings demonstrated no significant differences between chest-depth and overground walking at a matched speed. However, our results revealed a trend of decreased physiological responses to chest-depth walking compared to overground walking. This finding indicates that energy consumption in chest-depth walking was similar to that of overground walking in individuals post-stroke. Even with 70-75% body weight support in chest-depth water, participants had to carry their bodies through the water with increased surface area. The influence of buoyancy appeared to countervail the effects of water resistance. As a result of countervailing effects, we may have not found significant differences in physiological responses. Our results are inconsistent with previous research findings which reported higher physiological responses during chest-depth treadmill walking compared to overground treadmill walking (Alkurdi, Sadowski, Paul, & Dolny, 2010; Hall, Macdonald, Maddison, & O'Hare, 1998). The fast movement speed in healthy adults appears to generate greater drag force which made them use greater energy. Again, differences in walking speed is considered to be one of the affecting factors for these inconsistent results.

5.3 Limitations and Future Studies

There are several limitations in this study to be considered. First, the sample size in this study (N=12) was relatively small, which limits our ability to generalize the outcomes in this population. Future studies with a larger sample size are warranted. Additionally, our study recruited individuals post-stroke with high functional mobility. It is recommended to investigate individuals post-stroke with lower functional mobility. Similar methodology may be applied to examining other disability population with gait impairment. Lastly, we were limited to using one speed throughout the different water depths during pool floor walking. Further research is suggested to observe the influence of various speeds, in different water depths, on physiological responses during pool floor walking.

5.4 Conclusion

The purpose of this study was to examine the influence of different water depths on EE during pool floor walking in people post-stroke. Our results indicate that the EE of individuals post-stroke, during pool floor walking, appears to be significantly influenced by water depth. These findings suggest that people post-stroke may sustain a longer duration of exercise, such as gait training, in chest-depth water. Thigh-depth water may be recommended as an ideal environment for time-efficient cardiovascular exercise. Our results also demonstrated that walking in waist-depth water does not change the physiological responses as compared to overground walking. Thus, this finding suggests that energy conservation may not be expected during walking in the waist-depth water. However, people post-stroke can still benefit from the various characteristics of water for their training, such as pain reduction, decreased fear of fall, freedom of movement, and so forth.

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APPENDIX A

California State University, Northridge
CONSENT TO ACT AS A HUMAN RESEARCH PARTICIPANT

Influence of Water Depth on Energy Expenditure during Aquatic Walking in People Post-Stroke

You are being asked to participate in a research study titled "Influence of water depth on energy expenditure during aquatic walking in people post-stroke". This study is conducted by Hyosok Lim as part of the requirements for the M.S. degree in Kinesiology, Adapted Physical Activity. Participation in this study is completely voluntary. Please read the information below and ask questions about anything that you do not understand before deciding if you want to participate. A researcher listed below will be available to answer your questions.

PURPOSE OF STUDY

The purpose of this research study is to examine the influence of different water depths on energy expenditure during pool floor walking in people post-stroke.

PARTICIPATION CRITERIA

Inclusion Criteria

- You are eligible to participate in this study if you have a medical diagnosis of stroke, minimum of six months post-stroke, age of 18 years or above, physician's medical clearance, ability to walk in water and on land for ten minutes, ability to understand and follow verbal instructions and no severe cognitive and emotional impairments that would interfere with research protocol.

Exclusion Criteria

- You are not eligible to participate in this study if you have an acute injury, surgery within the last six months, cardiovascular complication, uncontrolled hypertension or fear of water.

Time Commitment

This study will involve approximately one hour per visit. You will be asked to visit on four separate days.

PROCEDURES

We will collect your energy expenditure data while you are walking in water at the chest, waist, and neck level as well as on land. The energy expenditure data will be obtained from the air mask that you inhale and exhale. We will use a device called a portable metabolic system which will collect and analyze your oxygen consumption during walking. After you perform the walk test with chest level water depth on your first visit, the order of the remaining walking conditions will be randomized.

The following procedures will occur:

First visit
You will be asked to bring comfortable exercise-clothing, shoes, swimming suits and/or trunks, and towels. You will be asked to sign this consent form as well as the "Bill of Rights". You will also need to submit your medical history and clearance form from a licensed primary physician.
Baseline heart rate, blood pressure and biometric data (height, weight, BMI and age) will be recorded. Your functional ability will be assessed using a Fugl-Meyer lower extremity motor assessment.
You will be instructed to change into your swimming suit and/or trunk and complete a six-minute walk test at the chest level water. Before you perform the walk test, you will rest in a seated position for ten minutes. You will be asked to walk for six minutes at your comfortable speed while wearing a mask connected to the portable metabolic system. A sanitized mask will be attached to your face, and you will be asked to breathe into the mask during the test. If you need to use an assistive device you will be allowed to use it in all conditions. The depth of the water will be adjusted to the chest level using movable pool floor. Water and additional rest will be given if needed. If you feel any abnormal discomfort, the walk test will be terminated upon your request.
Your next walking condition will be randomly selected and scheduled at the end of the first visit. You will be instructed to not consume any caffeine or alcohol at least three hours prior to the second visit. This visit will approximately last for 60 minutes.

Second visit
You will be asked to rest in a seated position for ten minutes and walk under previously selected condition (neck level, waist level, or land) for six minutes while wearing a mask connected to the portable metabolic system. A sanitized mask will be attached to your face, and you will breathe into the mask. If the randomized walking condition for this visit is on the land, you will be asked prior to this visit to bring comfortable exercise-clothing and shoes. If you were randomized to perform the walk test in water (either neck or waist level water depth) during this visit, you will be asked prior to this visit to bring swimming suits and/or trunks, and towel.
The neck level water depth will be adjusted to the height where your collar bone and breastbone meets, and the waist level water depth will be adjusted to the height of the belly button as the pool floor will move accordingly. The walk test on land will be performed in the Expansion Room of the Center of Achievement and the walk way will be exactly the same as the pool walk way.
The rate at which you will walk during this test will be determined from the walking speed determined from the chest level walk test from the first visit. The matched speed will be paced by a metronome. Distance walked, lap times and step rate will be recorded. If you need to use an assistive device, you will be allowed to use it in all conditions. If you feel any abnormal discomfort, the walk test will be terminated upon your request. At the end of the visit, we will schedule the date of the third visit, and you will be asked to bring the items necessary for the walk test during the third visit under the condition you have yet to complete. You will be instructed to not consume any caffeine or alcohol at least three hours prior to the third visit. The second visit will take about 60 minutes to complete.

Third visit
You will be asked to perform ten minutes of seated rest and another six minutes of walking under the condition you have yet to walk while wearing the mask connected to the portable metabolic system. You will follow the same protocol as you did during the second visit. This visit will be completed in about 60 minutes.

Fourth visit
You will be asked to perform ten minutes of seated rest and another six minutes of walking under the condition you have yet to walk while wearing the mask connected to the portable metabolic system. You will follow the same protocol as you did during the second and third visit. This visit will be completed in about 60 minutes.

RISKS AND DISCOMFORTS
The possible risks and/or discomforts associated with the procedures described in this study include: falling, drowning, cardiovascular complications such as collapse and, in rare instances, death, dehydration, physical fatigue, pain, soreness, muscle cramps, muscle spasms, and other water safety issues. Medical clearance from your physician will be required in order to participate in this study. You will be allowed to rest and drink water when necessary to prevent physical fatigue and dehydration during the walking session. You will be closely followed by CPR/AED and First Aid certified research assistants during the entire procedures to prevent potential risks such as fall. Also, a certified lifeguard will be present during pool floor walking sessions to ensure your safety. CPR/AED and first aid certified research assistants will aid in procedures. If you show abnormal signs or symptoms listed above, data collection procedure will cease immediately and first aid procedure will follow. Emergency services (911) will be contacted. This study involves no more than minimal risk. There are no known harms or discomforts associated with this study beyond those encountered in normal daily life.

BENEFITS
Participation Benefits
You may not directly benefit from participation in this study.

Benefits to Others or Society
Society may benefit from understanding the significance of this study. The findings of this study may show which aquatic walking condition (chest, waist, and neck water depth) is a feasible and effective method to improve cardiovascular fitness and walking ability in individuals post-stroke with elevated energy cost. With improvements in cardiovascular fitness, people post-stroke may increase functional mobility, which may lead to more independent activities of daily living as well as increase of participation in the community.

ALTERNATIVES TO PARTICIPATION
The only alternative to participation in this study is not to participate.

COMPENSATION, COSTS AND REIMBURSEMENT
Compensation for Participation
You will not be paid for your participation in this research study.

Costs
You will be responsible for the following cost: transportation fees. However, parking passes will be provided by the Center of Achievement.

Reimbursement
You will not be reimbursed for any out of pocket expenses, such as transportation fees.

WITHDRAWAL OR TERMINATION FROM THE STUDY AND CONSEQUENCES
You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately**. The research team may also end your participation in this study if you do not follow instructions, miss scheduled visits, or if your safety and welfare are at risk.

CONFIDENTIALITY
Participation Identifiable Data
All identifiable information that will be collected about you will be removed and replaced with a code. A list linking the code and your identifiable information will be kept separate from the research data. This will be placed in a locked file cabinet located in the office of the faculty advisor named on the first page of this form. Only the primary investigator, Hyosok Lim, and faculty advisor, Taeyou Jung, Ph.D, will have access to these files.

Data Storage
All research data, hard and digital copies, will be stored in a secure computer with password protection and a locked cabinet in two separate offices at the Center of Achievement.

Data Access
The researcher and faculty advisor named on the first page of this form will have access to your study records. No research assistants will have access to your information. Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed without your separate consent, except as specifically required by law. Publications and/or presentations that result from this study will not include identifiable information about you.

Data Retention
The researchers intend to keep the research data for approximately three years and then it will be destroyed. If data will be retained, only the faculty advisor named on the first page of this form will have access to information that will not be identifiable and will be stored in a secure password-protected computer and a locked cabinet.

Mandated Reporting
Under California law, the researcher(s) is/are required to report known or reasonably suspected incidents of abuse or neglect of a child, dependent adult or elder, including, but not limited to, physical, sexual, emotional, and financial abuse or neglect. If any researcher has or is given such information, he or she may be required to report it to the authorities.

IF YOU HAVE QUESTIONS
If you have any comments, concerns, or questions regarding the conduct of this research please contact the research team listed on the first page of this form.
If you have concerns or complaints about the research study, research team, or questions about your rights as a research participant, please contact Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, or phone 818-677-2901.

VOLUNTARY PARTICIPATION STATEMENT
You should not sign this form unless you have read it and been given a copy of it to keep. **Participation in this study is voluntary.** You may refuse to answer any question or discontinue your involvement at any time without penalty or loss of benefits to which you might otherwise be entitled. Your decision will not affect your relationship with California State University, Northridge. Your signature below indicates that you have read the information in this consent form and have had a chance to ask any questions that you have about the study.

I agree to participate in the study.

____________________________________ _______________
Participant Signature Date

____
Printed Name of Participant

____________________________________ _______________
Researcher Signature Date

____
Printed Name of Researcher

APPENDIX B

FUGL-MEYER ASSESSMENT
LOWER EXTREMITY (FMA-LE)
Assessment of sensorimotor function

ID:
Date:
Examiner:

Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S: The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med 1975, 7:13-31.

E. LOWER EXTREMITY					
I. Reflex activity, supine position			none	can be elicited	
Flexors: knee flexors			0	2	
Extensors: patellar, Achilles			0	2	
		Subtotal I (max 4)			
II. Volitional movement within synergies, supine position			none	partial	full
Flexor synergy: Maximal hip flexion (abduction/external rotation), maximal flexion in knee and ankle joint (palpate distal tendons to ensure active knee flexion).	Hip	flexion	0	1	2
	Knee	flexion	0	1	2
	Ankle	dorsiflexion	0	1	2
Extensor synergy: From flexor synergy to the hip extension/adduction, knee extension and ankle plantar flexion. Resistance is applied to ensure active movement, evaluate both movement and strength.	Hip	extension	0	1	2
		adduction	0	1	2
	Knee	extension	0	1	2
	Ankle	plantar flexion	0	1	2
		Subtotal II (max 14)			
III. Volitional movement mixing synergies, sitting position, knee 10cm from the edge of the chair/bed			none	partial	full
Knee flexion from actively or passively extended knee	no active motion		0		
	no flexion beyond 90°, palpate tendons of hamstrings			1	
	knee flexion beyond 90°, palpate tendons of hamstrings				2
Ankle dorsiflexion compare with unaffected side	no active motion		0		
	limited dorsiflexion			1	
	complete dorsiflexion				2
		Subtotal III (max 4)			
IV. Volitional movement with little or no synergy, standing position, hip at 0°			none	partial	full
Knee flexion to 90° hip at 0°, balance support is allowed	no active motion / immediate and simultaneous hip flexion		0		
	less than 90° knee flexion or hip flexion during movement			1	
	at least 90° knee flexion without simultaneous hip flexion				2
Ankle dorsiflexion compare with unaffected side	no active motion		0		
	limited dorsiflexion			1	
	complete dorsiflexion				2
		Subtotal IV (max 4)			
V. Normal reflex activity supine position, evaluated only if full score of 4 points achieved on earlier part IV, compare with unaffected side					
Reflex activity knee flexors, Achilles, patellar	0 points on part IV or 2 of 3 reflexes markedly hyperactive		0		
	1 reflex markedly hyperactive or at least 2 reflexes lively			1	
	maximum of 1 reflex lively, none hyperactive				2
		Subtotal V (max 2)			
		Total E (max 28)			

E. LOWER EXTERMTY	/28
F. COORDINATION / SPEED	/6
TOTAL E-F (motor function)	/34