An Investigation of the Post-Exercise Hypotensive Response Following an Acute Bout of Aquatic and Overground Treadmill Walking in People Post-Stroke

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DEDICATION

To my parents Simon and Laurie
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ABSTRACT

An Investigation of the Post-Exercise Hypotensive Response Following an Acute Bout of Aquatic and Overground Treadmill Walking in People Post-Stroke

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BACKGROUND: While exercise is a universal recommendation for long term prevention and/or maintenance of hypertension, less is understood about the immediate effects of blood pressure (BP) following a single bout of exercise, otherwise known as post-exercise hypotension. The purpose of this study is to investigate the effects of a single-bout of ATW and OTW on the magnitude and duration of post-exercise ambulatory BP in people post-stroke.

METHODS: 7 people post-stroke participated in a cross-sectional comparative study. Ambulatory BP was monitored for up to eight hours after a bout of aquatic treadmill walking (ATW) and overground treadmill walking (OTW), performed on separate days. Mean systolic and diastolic BP values were compared between both exercise conditions and a day when no exercise was performed (control).

RESULTS: Mean ambulatory systolic BP following ATW was reduced by 5% compared to the control day ($p < 0.01$) and displayed a systematic trend in reduced BP compared to OTW ($p = 0.051$). Mean ambulatory diastolic BP values following OTW and ATW were
reduced by 6% and 7% respectively, compared to the control day ($p < 0.01$). ATW demonstrated a reduction of 6% in mean systolic BP at the eighth hour of exercise compared to baseline ($p < 0.05$).

CONCLUSION: This study demonstrated that people post-stroke are able to lower their BP, under free living conditions, for up to nine hours following a single bout of ATW. In addition, ATW may promote nighttime dipping of systolic BP in people post-stroke.
Section 1: Introduction

Recurrent strokes are a leading cause of death in individuals post-stroke and responsible for approximately one-fourth of all annual stroke cases in the United States (Go et al., 2013). While hypertension is established as a key indicator of a first stroke occurrence, it has recently been identified as a high risk factor for recurrent stroke (Brown, Lisabeth, Roychoudhury, Ye, & Morgenstern, 2005; Furie et al., 2011). In addition, hypertension is associated with a shorter life expectancy and an elevated risk of cardiovascular disease (Arima & Chalmers, 2011). Current guidelines recommend that BP should be lowered to less than 140/90 mmHg to reduce recurrent stroke risk (Chobanian et al., 2003; Mancia et al., 2007). Arima et al. (Arima & Chalmers, 2011) suggest that all persons post-stroke should receive blood pressure (BP)-reduction treatments irrespective of their baseline level of BP.

Prevention of hypertension after an acute stroke is the most effective approach to reduce recurrent stroke risk (Patarroyo & Anderson, 2012). Rodger et al. (1996) have reported that a reduction of either systolic BP by ten mmHg or diastolic BP by five mmHg can reduce the risk of a recurrent stroke by 38% and 28%, respectively. Exercise is often recommended as a means to manage hypertension. It has been reported that exercise can also reduce BP for an immediate duration following a single bout of exercise, a concept known as post-exercise hypotension (PEH) (Kenney & Seals, 1993). Limited studies have documented PEH in people post-stroke.
Treadmill exercise is commonly used as an effective method to elicit a PEH response in adults with hypertension (Gomes Anunciacao & Doederlein Polito, 2011). Previous studies showed that both systolic and diastolic BP can be reduced after treadmill exercise (Quinn, 2000; Wallace, Bogle, King, Krasnoff, & Jastremski, 1999). These studies have also suggested that these reductions of BP after exercise can be sustained for up to 4-11 hours. The precise duration and intensity of exercise to facilitate a PEH response of significant magnitude and duration remains unclear. Some studies have suggested that the most prominent PEH response follows moderate-to-high intensity exercise (at the level of 40-70% peak oxygen consumption) with durations of 15-30 minutes (Guidry et al., 2006; Quinn, 2000). This intensity of treadmill exercise may be beneficial for people post-stroke who aim to lower their levels of BP. The treadmill is commonly used to promote cardiovascular fitness and gait rehabilitation in people post-stroke. It may be particularly appealing to people post-stroke with hypertension as treadmill walking can help manage hypertension while addressing other goals of rehabilitation.

Aquatic treadmill walking (ATW) may provide clinicians with an alternative mode of exercise to manage hypertension in individuals post-stroke. Compared to overground treadmill walking (OTW), ATW has been reported to reduce post-exercise BP in greater magnitude in healthy adults with normotension (Rodriguez et al., 2011). Unfortunately, no studies have examined post-exercise ambulatory BP in persons with stroke. The purpose of this study is to investigate the effects of a single-bout of ATW and OTW on the magnitude and duration of post-exercise ambulatory BP in people post-stroke. This information may help clinicians and researchers advance their understanding
of BP patterns following aerobic exercise in people post-stroke and eventually develop effective strategies of managing hypertension.
Arterial hypertension, otherwise known as high BP, is a leading cause of death in developed countries and increases an individuals’ risk for cardiovascular events including stroke. Nearly 26% of the adult population in the United States is hypertensive (Association, 2012). Hypertension is characterized by elevated pressure on the walls of the arteries which causes the heart to work harder to pump blood through the body. Hypertension is regarded as a resting BP of greater than 140 mmHg systolic and 90 mmHg diastolic (Huntzinger, 2008). Lowering BP is the primary means of preventing coronary artery disease for people with high blood pressure (Huntzinger, 2008). Hypertension often has no perceivable symptoms or warning signs. Thus it is important to regularly monitor BP.

Ambulatory BP monitoring (ABPM) is the assessment of BP under normal living conditions. ABPM has been established as an important measure for future occurrences of stroke or cardiovascular events (Bastos, Bertoquini, Silva, & Polonia, 2006; Castilla-Guerra, Fernandez-Moreno, Espino-Montoro, & Lopez-Chozas, 2009; Lip et al., 1997). ABPM allows clinicians to measure circadian BP rhythms, declines in BP at later hours of the day. This also allows clinicians to measure BP dipping, the difference in nighttime and the following daytime blood pressure values. Lack of a circadian BP rhythm can be associated with future occurrence of stroke and coronary events in people with hypertension (Bastos et al., 2006). ABPM has also been recognized as a powerful tool for the prediction of cardiovascular incidents in the stroke population (Jain, Namboodri, Kumari, & Prabhakar, 2004b).
Stroke

Definition and Characteristics

Stroke is defined as a cerebrovascular event, caused by abnormalities in cerebral blood flow that can result in death of brain tissue ("National Institute of Neurological Disorders and Stroke. Stroke: Hope Through Research," 2012). Stroke is a leading disability in the United States and can result in acute coma, syncope, chronic physiological and neurological impairments, and even death.

The level of physiological and neurological impairment following a stroke varies with the location, severity, and duration of cerebral damage (Bowman & Giddings, 2003). Following a stroke, many symptoms may occur simultaneously that affect locomotor, visual, visuospatial, verbal, or sensory function skills (Durstine, Moore, Painter, & Roberts, 2009). Hemiparesis is a common physical deficit following a stroke, which causes partial or complete paralysis of one side of the body. Hemiparesis occurs from damage to the cerebellum, which can result in a reduced number of motor units to perform movement ("National Institute of Neurological Disorders and Stroke. Stroke: Hope Through Research," 2012). Muscle spasticity, stiffness or rigidity of the muscle, is also a common impairment among people post-stroke and is closely related to hemiparesis. Muscle spasticity is caused by a speed dependent hyper-active muscle stretch reflex, which may restrict locomotion. Muscle spasticity is not directly related to the severity of post-stroke symptoms (Sommerfeld, Eek, Svensson, Holmqvist, & von Arbin, 2004). Hemiparesis hinders the gait pattern of people post stroke, which increases the energy cost of walking (Chen, Patten, Kothari, & Zajac, 2005). Inefficient gait
patterns in the stroke population limit community ambulation. However, even with relatively efficient gait, it is estimated that one-third of people post-stroke are not able to walk independently outside of their home (Lord, McPherson, McNaughton, Rochester, & Weatherall, 2004). If individuals post-stroke do not have the ability to walk independently, only 23% of them are able to recover independence through rehabilitation (Jorgensen et al., 1995). Consequently, gait restoration is a primary focus during stroke rehabilitation.

Classifications

The two main categories of strokes are ischemic and hemorrhagic strokes: a blockage or rupture of blood vessels to the brain ("National Institute of Neurological Disorders and Stroke. Stroke: Hope Through Research," 2012). Approximately 80% of the stroke incidences worldwide are ischemic stroke and 20% are hemorrhagic stroke (Donnan, Fisher, Macleod, & Davis, 2008). Ischemic strokes umbrella three different sub-types of stroke occurrences: thrombosis, embolism, and stenosis (Judd, 2005). A thrombotic stroke occurs when a formed blood clot attached to the walls of an artery grows large enough to block blood flow. When a large blood clot detaches from a wall and travels through circulation, it may become wedged into a cerebral artery, which is called an embolic stroke. Stenosis is an abnormal narrowing of blood vessels which can distort blood flow to the brain. Stenosis generally occurs through the formation of plaque on the walls of the arteries that can hinder blood flow. Moreover, abnormal blood flow to the brain can cause minor stroke like symptoms. A transient ischemic attack is a relatively short episode of neurological malfunction caused by lack of cerebral blood flow that does not result in
tissue death (acute infarction). Ischemia (lack of cerebral blood flow) that lasts less than 24 hours is classified as a transient ischemic attack (Warlow, Sudlow, Dennis, Wardlaw, & Sandercock, 2003). Approximately one-third of Americans who experience a TIA each year will have an acute stroke, which may be more severe and require higher levels of rehabilitation, in the near future ("National Institute of Neurological Disorders and Stroke. Stroke: Hope Through Research," 2012).

Hemorrhagic strokes are classified as ruptured blood vessels that result in bleeds surrounding or within areas of the brain. In a typical brain, blood flow does not come into direct contact with brain tissue. However, when cerebral blood vessels are ruptured, increases in intracranial pressure result from the direct accumulation of blood flow which can damage neurological function (Bowman & Giddings, 2003). Although there are numerous ways hemorrhages (ruptures to blood vessels) can occur, a common cause is a bleeding aneurysm ("National Institute of Neurological Disorders and Stroke. Stroke: Hope Through Research," 2012). An aneurysm is a swelling of a cerebral artery. Overtime, the walls of these aneurysms develop weak spots that may burst under high arterial blood pressure. Hemorrhagic strokes can also occur through broken arterial walls. High plaque content that lines the insides of the walls of the artery decreases elasticity. When arterial walls lose elasticity, the walls are prone to cracks and tears that can result in a rupture. Furthermore, if a hemorrhage occurs in the subarachnoid space that separates the arachnoid membrane from the pia membrane (subarachnoid hemorrhage), bleeding can occur that contaminates the cerebrospinal fluid that can lead to overwhelming brain damage. Although subarachnoid hemorrhages are relatively rare and do not account for a large number of stroke-related deaths, they account for a large portion of young mortality
when compared to ischemic stroke (Johnston, Selvin, & Gress, 1998). Since hemorrhagic strokes can occur from increased cerebral pressure on arterial walls, it may be important to monitor BP during exercise.

**Etiology and Incidence**

The onset of stroke is associated with numerous risk factors including, alcohol consumption, inactivity, obesity, type-two diabetes, cigarette smoking, and hypertension (Ezzati et al., 2002; Ohira et al., 2006). A study by Ohira and colleagues (Ohira et al., 2006) found that hypertension had the greatest power to predict the incidence of ischemic strokes. Not surprisingly, hypertension is also the most important risk factor for onset of all types of stroke in able-bodied adults (Ohira et al., 2006). Furthermore, it appears that the cardiovascular fitness level, denoted by maximal oxygen consumption (VO$_2$max), is inversely associated with decreased risk of stroke in healthy adult males. A study by Kurl and colleagues (Kurl et al., 2003), demonstrated that men with higher maximal oxygen consumption were at a decreased risk of stroke compared to men with lower levels of maximal oxygen consumption. Increasing cardiovascular fitness and maintaining healthy levels of blood pressure are important to decrease risk of stroke in healthy able-bodied adults.

Stroke will continue to be a prevalent disability in the future. As of 2008, there are greater than 7,000,000 people in the United States who have had a stroke (Association, 2012). It is estimated that by the year 2030, prevalence of stroke will increase 24.9% from 2010, which results in an additional four million people who will have had a stroke (Heidenreich et al., 2011). Second strokes, recurrent strokes, are responsible for about
23% of the overall stroke occurrence rate in people post-stroke (Association, 2012). Research on the prevention of stroke and recurrent stroke will continue to be important due to the steady prevalence rate of stroke.

**Hypertension in recurrent-stroke**

Although hypertension is regarded as the primary risk factor for occurrence of a stroke in able-bodied adults, there is less knowledge correlating hypertension with increased risk of a person having a recurrent stroke. About 25% of individuals who have recovered from a first stroke may have a recurrent stroke within 5 years (Stroke, 2004). Each recurrent stroke may increase an individual’s risk of severe disability or even death.

Normal BP is characterized by higher values in the daytime as compared to nocturnal values. This decline in blood pressure during later hours of the day is termed nighttime dipping. People with ischemic stroke have been found to lack night time dipping of BP (Jain et al., 2004b), which may result in a high-load of stress on the organs. BP reduced at later hours of the day in people post-stroke may result in a protective effect on cerebral circulation.

**Blood Pressure Range for Reduced Risk of Recurrent Stroke**

Recent literature suggests there is a range of systolic BP that may reduce the risk of recurrent stroke in people who have already experienced a first stroke. A post-hoc analysis of a multi-center clinical trial by Ovbiagele and colleagues (Ovbiagele et al., 2011), examined the relationship between high BP and recurrent stroke among 20,330 participants from 35 different countries. Their data found that systolic BP lower than 120
mmHg and greater than 140 mmHg is associated with an increased risk of recurrent stroke. Similar results have been presented in a previous study (Irie, Yamaguchi, Minematsu, & Omae, 1993). Contrary to stroke guidelines that recommend a systolic BP lower than 140 mmHg (Stroke, 2004), these results suggest that the ideal range for systolic BP in people post-stroke may lie between 120 mmHg and 140 mmHg. A year later Ovbiagele and colleagues (Ovbiagele, 2012) supported these findings with further analysis of a trial among 3680 participants. Their results were similar: people with resting systolic BP lower than 120 mmHg or greater than 140 mmHg were associated with an approximate 9-10% increased risk of recurrent stroke (Ovbiagele, 2012). This recommended range of BP is known as the J-curve. Although clinical trials exhibit the importance of the systolic blood pressure J-curve in people post-stroke, there appears to be no guidelines that recommend elevating systolic blood pressure when below 120 mmHg. This is due to conflicting results from other literatures that have found no association between low systolic BP and recurrent stroke (Arima et al., 2006; Dorresteijn et al., 2012; Turnbull & Collaboration, 2003). Current ongoing clinical trials are being performed to investigate the systolic blood pressure range of 120-140 mmHg, known as the J-curve, with reduced risk of recurrent stroke. While many trials have provided sufficient data surrounding systolic BP post-stroke, it appears there is no direct association between diastolic blood pressure and increased risk of recurrent stroke.

Reducing Blood Pressure in People Post-Stroke

Reducing high BP in people post-stroke may decrease risk of recurrent stroke and other cardiovascular incidents. In an analysis of a four-year clinical trial, Arima and
colleagues (Arima et al., 2006) found that drug-induced therapy to reduce blood pressure, among 6105 people with various types of stroke, reduced the risk of recurrent stroke. These results were seen at even lower levels of systolic BP (<120mmHg). These results conflict with the J-curve theory. Their results also exhibited reduced secondary outcomes including coronary heart disease, congestive heart failure, and major vascular events. Turnbull and the Blood Pressure Lowering Treatment Trialists’ Collaboration found similar results (Turnbull & Collaboration, 2003) from analysis of 29 randomized trials. Among 162,341 participants, their results suggest that any common form of drug-induced blood pressure therapy may lower the risk of cardiovascular events. Consequently, reducing BP among people post-stroke with hypertension may reduce the risk of recurrent stroke and other cardiovascular events. In addition, these trials suggest treating BP at lower systolic levels (<120mmHg) may be safe for people post-stroke, which contradicts the J-curve theory. Whether exercise alone can reduce the risk of recurrent stroke, as compared to drug-induced therapy, has yet to be investigated.

Data from various clinical trials, has found systolic BP of greater than 140 mmHg associated with increased risk of a recurrent stroke and cardiovascular events in people post-stroke. Although some studies have shown poor outcomes associated with systolic blood pressure levels less than 120 mmHg, there is still no consensus or guidelines that recommend elevating BP when below 120 mmHg.
Aerobic Exercise and PEH in Healthy Adults

Exercise is a non-pharmacological method of long term BP reduction in people with hypertension. However, the immediate effects of exercise on BP are less established. Following exercise, BP can decrease beyond pre-exercise resting levels, otherwise known as post-exercise hypotension (PEH). By lowering BP throughout the day, there may be a reduced strain on organs and reduced risk of cardiovascular events. Consequently, longer durations of PEH are more clinically significant towards individuals with hypertension.

Aerobic exercise has been documented to reduce ambulatory BP post-exercise, which includes systolic and diastolic BP, up to 11 hours after exercise compared to a day with no-exercise in people with hypertension (Quinn, 2000; Wallace, Bogle, King, Krasnoff, & Jastremski, 1997; Wallace et al., 1999). Other studies (Kaufman, Hughson, & Schaman, 1987; MacDonald, Hogben, Tarnopolsky, & MacDougall, 2001; Moraes et al., 2007b; Pontes et al., 2008) suggest shorter durations (30-120 minutes) of PEH in people with hypertension. However, there is some discrepancy as to whether aerobic exercise is able to reduce post-exercise BP compared to BP levels pre-exercise. Few studies exhibit reductions in systolic BP after exercise compared to pre-exercise (Pescatello, Fargo, Leach, & Scherzer, 1991; Pescatello et al., 1999). While many studies have found no significance in systolic BP compared to pre-exercise levels (Brandao Rondon et al., 2002; Ciolac et al., 2009; Quinn, 2000; Wallace et al., 1999), but did find significance compared to a day without exercise. There are also some studies (Guidry et al., 2006; Pescatello et al., 2004; Syme et al., 2006) that have found an increase in systolic BP compared to pre-exercise resting values, although these results were still lower than a day without exercise.
Moreover, diastolic BP has been found to be lower post-exercise when compared to a day without exercise (Brandao Rondon et al., 2002; Quinn, 2000; Wallace et al., 1999).

There appears to be no literature that has found significant reductions or increases in diastolic blood pressure when compared to pre-exercise levels in people with hypertension (Gomes Anunciacao & Doederlein Polito, 2011). There is solid evidence that aerobic exercise can reduce blood pressure compared to a day without exercise in people with hypertension. However, there is not enough evidence that aerobic exercise can reduce blood pressure compared to pre-exercise resting blood pressure. These conflicting results may be due to differences in methodology which include: mode, intensity, and duration of exercise, as well as the pre-existing level of hypertension among participants.

**Intensity of Exercise and PEH**

Aerobic exercise, alone or combined with resistance exercise, is more effective at reducing BP after exercise in higher magnitude and duration compared to resistance exercise (Keese, Farinatti, Pescatello, & Monteiro, 2011), but the intensity of exercise does not appear to affect the significance of PEH. A study by Pescatello et al. (Pescatello et al., 1991) examined ambulatory BP for 13 hours following an acute bout of aerobic exercise at different intensities in 6 people with hypertension. Their results suggest that ambulatory BP following aerobic exercise was lower than a day without exercise and that the intensity of exercise (40% versus 70% maximum VO2) did not affect the extent to which BP was reduced. The sample size of this study was relatively small. Although there are few studies that have suggested the intensity of exercise affects the magnitude of the
PEH response (Forjaz et al., 2000; Wallace et al., 1997), the majority of the literature finds no such relationship (Brandao Rondon et al., 2002; Ciolac et al., 2009; Guidry et al., 2006; Pescatello et al., 1999; Quinn, 2000). Consequently, aerobic exercise of at least a light-to-moderate intensity may lower BP for a clinically significant amount of hours following exercise, as opposed to a day where no exercise was performed in people with hypertension.

**Duration of Exercise on PEH**

The duration of exercise does appear to affect the magnitude of PEH. However, there is currently not enough literature to support that shorter (10-20 minutes) or longer durations (40-50 minutes) of exercise are optimal for reductions in BP post-exercise. A report by MacDonald and colleagues (MacDonald, MacDougall, & Hogben, 2000) demonstrated that there is no difference in PEH when comparing shorter (10 minutes) and longer (30 minutes) durations of exercise. Their results suggest that 10 minutes of exercise is sufficient to elicit a PEH response in eight borderline hypertensive participants. However, results from a study by Mach and colleagues (Mach, Foster, Brice, Mikat, & Porcari, 2005) demonstrate greater durations of exercise promote higher reductions in BP post-exercise. Guidry and colleagues (Guidry et al., 2006) also found longer durations (30 minutes) of exercise had greater reductions in diastolic BP post-exercise compared to shorter durations (10 minutes). Although there appears to be a relationship between the duration of exercise and reduction in BP post-exercise, more research needs to be conducted on larger populations of people with hypertension.
Pre-existing Levels of Blood Pressure on PEH

Pre-existing levels of blood pressure may affect the magnitude of the PEH response. A study by Wallace and colleagues (Wallace et al., 1997) demonstrated that hypertensive adults had greater reductions in blood pressure after exercise compared to people whom are normotensive. After 50 minutes of treadmill walking, people with hypertension were able to sustain a reduction in systolic blood pressure for up to 11 hours compared to a day without exercise (control day). Diastolic blood pressure was also reduced for approximately 6 hours following exercise compared to the control day. Normotensive participants had no significant reduction in blood pressure post-exercise compared to the control day. These results have been confirmed with other literature (Forjaz et al., 2000; Pescatello et al., 1991). Consequently, both the magnitude and duration of PEH was more significant among people with hypertension. Since there is sufficient evidence that PEH can occur in people who are normotensive (Liu et al., 2012; Syme et al., 2006), the exercise stimulus administered by Wallace and colleagues (Wallace et al., 1997) may not have been sufficient to elicit a PEH response in normotensive adults. People with hypertension may require a lower exercise intensity to elicit a PEH response. It is important to consider the pre-existing levels of resting blood pressure in research participants when analyzing the literature.

Mode of Exercise and PEH

Aerobic treadmill exercise (Brandao Rondon et al., 2002; Forjaz et al., 2000; Moraes et al., 2007a; Pescatello et al., 1991; Pescatello et al., 1999) and stationary cycling (Kaufman et al., 1987; Quinn, 2000; Wallace et al., 1997, 1999) are the most common modes of exercise used in studies to elicit a PEH response in people with hypertension.
To the best of my knowledge there is no literature that compares the PEH response of treadmill exercise to stationary cycling. Both treadmill exercise (Quinn, 2000; Wallace et al., 1999) and stationary cycling (Pescatello et al., 1991; Pescatello et al., 1999) have been shown to elicit a significant PEH response in people with hypertension. The mode of exercise performed may not be significant as long as the duration and intensity of exercise are sufficient to elicit a PEH response.

**Treadmill Exercise in Stroke**

Treadmill exercise has been recently gaining popularity among the stroke population and is a safe and effective form of cardiovascular exercise at even high intensities (Brouwer, Parvataneni, & Olney, 2009; Globas et al., 2011; Macko, DeSouza, et al., 1997; Macko, Katzel, et al., 1997; Tang A, 2010). Treadmill exercise is also commonly used for gait rehabilitation. Benefits from gait-induced treadmill therapy include, improved walking symmetry (Harris-Love, Forrester, Macko, Silver, & Smith, 2001; McCain, Smith, Polo, Coleman, & Baker, 2011), increased walking speed (Globas et al., 2011), reduced energy cost of walking (Macko, DeSouza, et al., 1997), and improved functional mobility (Macko et al., 2005), in people post-stroke. However, overground treadmills possess physical limitations for people post-stroke, particularly in the early recovery phase of rehabilitation. The Copenhagen stroke study (Jorgensen et al., 1995) found that out of 1196 participants post-stroke, 28 percent had a moderate to severe level of disability and 20% of participants were not able to recover walking function within 11 weeks. It may be hard for people post-stroke with moderate to severe disability to perform overground treadmill walking. People post-stroke have been shown to expend
approximately twice the energy cost during walking compared to healthy-efficient gait (Danielsson, Willén, & Sunnerhagen, 2007; Platts, Rafferty, & Paul, 2006). Furthermore, overground treadmill walking requires a high energy cost and has been shown to require more energy expenditure than floor walking at a matched speed in people post-stroke (Brouwer et al., 2009). If a primary goal during rehabilitation is to elicit a PEH response in people post-stroke with hypertension, a rehabilitator may require a mode of aerobic exercise people post-stroke can perform for 10-20 minutes that is easier to achieve than an overground treadmill.

Aquatic Exercise

Aquatic treadmill exercise can elicit a similar cardiovascular response to an overground treadmill in various populations (Brubaker, Ozemek, Gonzalez, Wiley, & Collins, 2011; Greene et al., 2009). Furthermore, Park and colleagues (Park et al., 2010) examined the effects of aquatic and overground treadmill exercise on gait and physical function of people post-stroke. Their data found that both the aquatic and the overground treadmill were able to improve gait and physical function of people post-stroke. However, the aquatic treadmill had a higher positive impact on improved weight bearing of the affected leg, improved time of stance phase, and a greater emotional aspect, than overground treadmill exercise.

The aquatic treadmill may also be a safer environment for people post-stroke due to the physiological properties of water. Water buoyancy during aquatic exercise alleviates body weight, which decreases impact force on joints, muscles, and bones (Bartels et al., 2007). At slow treadmill speeds, water buoyancy has also been suggested to reduce the
energy cost of aquatic treadmill walking compared to overground treadmill walking in people with arthritis (Hall, Grant, Blake, Taylor, & Garbutt, 2004). Water buoyancy can alleviate different percentages of body weight at various water depths. Approximately 50% of body weight is supported with the water depth located at the anterior superior iliac spine, 75 to 80% at the xiphoid process, and 90% at the seventh cervical vertebrae (Bates & Hanson, 1996). Hydrostatic pressure, the perpendicular pressure exerted to the surface of an object under water, and water density, may also improve balance and stabilize joints during water immersion (Bates & Hanson, 1996). A study by Matsumoto and colleagues (Matsumoto, Kawahira, Etoh, Ikeda, & Tanaka, 2006) found that warm-water therapy around 41 degrees is effective at reducing spasticity in people post-stroke. The aquatic environment is a safe alternative method of cardiovascular exercise and gait therapy. For these reasons aquatic exercise is a common mode of exercise during rehabilitation.

Aquatic Exercise and PEH

There are few studies that have compared the effectiveness of aquatic and land-based aerobic exercise on the PEH response in healthy adults. A study by Pontes and colleagues (Pontes et al., 2008) examined the effectiveness of pool floor running to overground running on the PEH response of 16 people with hypertension. Their results suggest that pool floor running promoted a similar PEH response to overground running. 4 years later, a study by Rodriguez et al. (Rodriguez et al., 2011) compared the effects of a single-bout of acute overground treadmill walking versus aquatic treadmill walking in 12 healthy adults and 11 healthy-trained adults. Their results suggest that aquatic treadmill walking elicited a greater reduction in BP for an hour following exercise in a controlled laboratory
setting. In addition, their findings imply that people who are un-trained (lower fitness level indicated by maximum oxygen consumption, VO\textsubscript{2max}) have greater reductions in BP following exercise compared to people who are trained. These results suggest that people post-stroke, whom have lower aerobic capacities compared to healthy adults, may show greater reductions in BP compared to healthy adults and may also exhibit greater reductions in BP following exercise on an aquatic treadmill as opposed to an overground treadmill. A year later, Terblanche and colleagues (Terblanche & Millen, 2012) examined the magnitude and duration of PEH following aquatic and overground treadmill exercise in 21 males and females with various levels of hypertension. They found that both the aquatic and overground treadmill exhibited a PEH response of similar magnitude. Both daytime and nighttime BP values were significantly lower than a day without exercise (control day). However, the duration of PEH following aquatic treadmill exercise lasted only 9 hours compared to 24 hours following overground treadmill exercise. Their results also suggest that aquatic treadmill exercise is safe mode of exercise for men and women with hypertension. Although these studies (Rodriguez et al., 2011; Terblanche & Millen, 2012) have documented significance in PEH while comparing aquatic and overground treadmill exercise, both of these studies have errors with how the exercise intensity was matched between both treadmills. Terblanche and colleagues used heart rate and rate of perceived exertion (RPE) to correlate a specific percentage of oxygen consumption (VO\textsubscript{2}) to monitor the intensity of exercise between both treadmills. Rodriguez and colleagues are vague about how exercise intensity was monitored, but it appears they also used heart rate to monitor the intensity of exercise. Since heart rate correlated to oxygen consumption (VO\textsubscript{2}) has been found to differ by approximately 9 beats per minute between an aquatic
and overground treadmill (Hall et al., 2004), heart rate alone will not provide an accurate matched intensity between an aquatic and overground treadmill. It may be best to match the intensity of exercise by assessing gas-by-gas analysis of VO$_2$ along with heart rate between both treadmills.

Recent studies have indicated that aquatic treadmill exercise may reduce blood pressure post-exercise in healthy adults (Rodriguez et al., 2011; Terblanche & Millen, 2012). However, no studies have compared the effects of aquatic and overground treadmill exercise on ambulatory blood pressure in people post-stroke. This knowledge may help rehabilitation professionals advance their understanding of PEH to provide non-pharmaceutical interventions for the management of BP in people post-stroke. Thus the purpose of this study is to investigate the magnitude and duration of the PEH response to a single-bout of aquatic treadmill exercise and overground treadmill exercise in people post-stroke. We hypothesize that aquatic treadmill exercise may elicit a greater PEH response compared to overground treadmill exercise in people post-stroke.
Section 2: Methods

Participants

A total of 7 participants post-stroke were recruited for this study from a university-based aquatic therapy program. The mean age of participants in this study was 56.57 ± SD years (range: 36-67 years) and the average time post-stroke 4.85 ± SD years. All participants in this study were classified with normotensive levels of resting BP, and no participants were using anti-hypertensive medication throughout the study. Participant characteristics are summarized in Table 1.

In order for participants to be included they had to meet inclusion criteria: a medical diagnosis of stroke, a minimum of six months post-stroke, and a minimum age of 35. Participants were excluded from the study if they had a resting systolic BP greater than 140 mmHg or less than 90 mmHg, a resting diastolic BP above 89 mmHg or below 60 mmHg, cardiovascular complication, and acute injury or surgery within the last six months. All participants were asked to refrain from smoking or drinking caffeinated drinks on days of data collection. The study protocol was approved by the institutional review board of the university. Participants’ informed consent and medical clearance were collected prior to data collection.
Instrumentation

To compare BP responses between two exercise modes, an aquatic treadmill (AquaGaiter, FERNO, Ohio, 2003) and an overground treadmill (Gait Trainer Treadmill II, BIODEX, USA, X) were utilized. The water depth of aquatic treadmill walking was adjusted to the height of the xiphoid process of each participant using a movable floor pool. (KBE Baulemate, GmbH & Co., Wilhelmshaven, Germany, 2003). The pool temperature was held consistently at 33 degrees Celsius.

An ambulatory BP monitor (ABPM-05, Meditech Inc, USA) was used to record all BP measurements. Validity and reliability of the instrument have been established according to the British Hypertension Society protocol (Barna, Keszei, & Dunai, 1998). The ambulatory BP monitor was secured to the waist of each participant and programmed to record data every 15 minutes for up to nine hours after exercise. BP data were stored in the instrument and later transferred to processing software (Meditech Software REF) for analysis. Participants were allowed to assume their activities of daily living while wearing the BP monitor.

A telemetric metabolic system (K4b², COSMED Inc., Rome, Italy, 1998) was used to match the intensity of exercise between the two exercise modes. The validity and reliability of the portable system have been previously established (Art et al., 2006; Duffield, Dawson, Pinnington, & Wong, 2004). Participants wore a harness to fasten the portable unit to their chest while they were performing OTW. The unit was secured inside of a waterproof case and placed on a nearby dry deck for the ATW condition.
Procedure

All participants completed 25 minutes of walking on an aquatic and overground treadmill on two separate sessions. Each exercise session consisted of five minutes of warm-up, 15 minutes of walking at 70% of peak oxygen consumption (VO$_2$peak), and five minutes of cool-down. Participants came to the laboratory for a total of five visits: the initial visit, two days of familiarization, and two exercise sessions.

The initial visit consisted of anthropometric data collection, a Fugl-Meyer Lower Extremity Assessment, and a modified sub-maximal exercise test performed on a stationary cycle (Eng, Dawson, & Chu, 2004). Participants were then given an ambulatory BP monitor and instructed to record their BP on a separate day without exercise (control day).

During the control day, participants were instructed to rest for the initial hour of BP measurement, which was designated as their pre-exercise baseline. Following the initial hour of rest, participants were informed to resume their activities of daily living while BP was measured every 15 minutes for the next twelve hours. Exercise journals were completed by participants to document hourly activity during BP readings. Following the control day, participants came to the laboratory for two familiarization visits and two exercise data collection sessions.

A familiarization session was provided on a separate day at least 48 hours prior to each exercise data collection session. During familiarization sessions seated and standing BP was measured in water and on land, in order to check the possible influence of water submersion or change of body position on BP. Participants rested in a seated position for
ten minutes while their BP was recorded. In addition, resting BP was measured in a standing position for ten minutes. Following a total of twenty minutes of rest, participants then performed a graded walking test on either an aquatic or overground treadmill in random order, to ensure that each participant could safely walk at 70% of their VO$_2$peak.

Participants returned to the laboratory on two separate sessions for exercise data collection: one walking session on an aquatic treadmill and the other on an overground treadmill. Since BP varies throughout different periods of the day, all participants were instructed to arrive in the laboratory between nine-11am. Prior to exercise, participants remained seated for ten minutes while their BP was recorded three times at the fifth and tenth minute of rest. The average of these measurements was designated as the pre-exercise baseline. Participants then walked on a treadmill for 25 minutes, which consisted of a five-minute graded warm-up and cool-down, and 15 minutes of exercise at approximately 70% of each participant’s VO$_2$peak. In order to maintain this intensity of exercise, speed adjustments were made based on the real-time collection of breath-by-breath oxygen consumption (VO$_2$) data. In addition, heart rate (HR) and Borg’s rating of perceived exertion (RPE) (Borg, 1982) were monitored.

After completion of each walking trial, participants were asked to wear an ABPM, and BP values were recorded for a total of nine hours after exercise. The first hour was recorded in a seated resting position under laboratory conditions. For the next eight hours participants were allowed to resume their daily activities while wearing an ABPM, which automatically recorded BP every 15 minutes. Participants were instructed to record their hourly activity in exercise journals, which were later used to monitor their hourly activities. Upon completion of the first exercise session, participants then revisited the
laboratory a week later to perform the same experimental procedures under the second walking condition that was randomly selected.

Systolic and diastolic BP measurements were recorded from the non-affected arm of people post-stroke. BP was recorded before (pre-exercise baseline), during, and up to nine hours post-exercise. BP during exercise was measured immediately after the 15-minute exercise period before the five-minute cool-down based on a modified protocol by Dolbow et al. (2008). During aquatic treadmill walking, a floatation device was used to support the arm to ensure that the arm was positioned at the level of the heart above the water.

Analysis

The primary dependent variables included systolic and diastolic BP measured at three different time phases: pre-exercise baseline, during exercise, and post-exercise. Post-exercise BP data were analyzed at five different time points. First, they were compared to pre-exercise baseline BP across the three conditions (control, ATW, and OTW). Second, post-exercise data were also compared to pre-exercise baseline BP within each condition. The main effects across the three conditions were tested with mixed model MANOVAs. The between-factors were the three test conditions (control, ATW, and OTW) and the within-factors the repeated measures over time. The within factors were analyzed using repeated measures ANOVA. All statistical analyses were performed using SPSS Statistics 22 (IBM Corp., Armonk, NY, USA, 2013).
Section 3: Results

All seven participants completed the experimental procedures of this study. The test conditions did not show differences in pre-exercise resting BP. The mean systolic BP values of both seated and standing rest in the pool (116.5 ± 11.56 and 120.1 ± 5.59, respectively) showed no significant differences compared to those on land (114.3 ± 11.63 and 120.07 ± 5.59, respectively). Also, mean diastolic BP values in both seated and standing rest in the pool (71.78 ± 12.0 and 76.18 ± 8.75, respectively) were not different from those on land (69.96 ± 10.93 and 79.81 ± 6.80, respectively).

The means and standard deviations of VO\(_2\) during OTW and ATW are shown in Table 2. The matched intensity of exercise between the two exercise conditions was determined based upon the average of breath-by-breath gas analysis of VO\(_2\). Mean VO\(_2\) values during the warm-up, exercise and cool-down were not significantly different between ATW and OTW. In addition, mean energy expenditure during exercise was not statistically significant between OTW (3.76 ± 1.33) and ATW (3.81 ± 0.96).

Mean BP responses were compared between the pre-exercise baseline and the first, third, fifth, seventh, and ninth hour post-exercise. Systolic BP responses at each time phase can be seen for each of the three test conditions in Figure 1. When compared to the aquatic pre-exercise baseline (115.0 ± 12.69), the ninth hour post-exercise demonstrated a reduction of 6% in mean systolic BP \((F_{(1,5)} = 12.78, p < 0.05)\). No other significant differences were found in mean systolic BP and diastolic BP among the six time phases within each test condition.
Mean BP values at each time phase were compared among the three test conditions, shown in Table 3. At the pre-exercise baseline, mean systolic and diastolic BP values showed no significant difference among the three test conditions. Additionally, during exercise and at the first hour post-exercise, mean systolic BP values displayed no significant difference among each test condition.

When comparing systolic BP at each time phase post-exercise between test conditions, significant differences were only found at the ninth hour. Mean systolic BP at the ninth hour following ATW was reduced by 11% ($F_{(1,5)} = 14.08$, $p < 0.01$) compared to that of the control day ($122.5 \pm 14.18$), shown in Figure 1. In addition, OTW displayed a trend of a 3% reduction of systolic BP at the same hour ($118.35 \pm 7.07$) compared to that of the control day ($F_{(1,5)} = 5.82$, $p = 0.052$).

Similar to the post-exercise response of systolic BP, a significant reduction of diastolic BP was seen at the ninth hour. At the ninth-hour after ATW, mean diastolic BP ($70.86 \pm 13.2$) was reduced by 8% ($F_{(1,5)} = 12.73$, $p < 0.01$) compared to mean diastolic BP of the control day ($77.2 \pm 11.1$). Also, OTW showed a 7% reduction of mean diastolic BP at the ninth hour post-exercise ($71.40 \pm 9.21$) compared to the control day ($F_{(1,5)} = 7.71$, $p < 0.01$).

In order to compare the mean BP response of the entire post-exercise period among conditions, BP values from each hour were averaged into a single overall value. This mean value was then compared between each condition, shown in Figure 3. Overall post-exercise systolic BP following ATW was 3% lower than that of OTW ($t = 4.06$, $p < 0.05$) and 5% to that of the control day ($t = 5.11$, $p < 0.01$). OTW did not show a
significant difference in overall systolic BP compared to the control day. On the other hand, mean overall post-exercise diastolic BP following both OTW and ATW were lower than that of the control day by 6% ($t = 4.01, p < 0.01$) and 7% ($t = 4.33, p < 0.01$), respectively.
Table 1. Participant Characteristics

<table>
<thead>
<tr>
<th>Measure</th>
<th>n = 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>56.57 ± 10.24</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.44 ± 10.23</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.60 ± 16.18</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>27.36 ± 4.67</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>3:4</td>
</tr>
<tr>
<td>Fugl-Meyer Score LA (0-28)</td>
<td>23.71 ± 3.15</td>
</tr>
<tr>
<td>Time Post Stroke (years)</td>
<td>4.85 ± 5.07</td>
</tr>
<tr>
<td>Sub Max VO$_2$ (ml/kg$^1$minute$^-1$)</td>
<td>16.37 ± 3.12</td>
</tr>
<tr>
<td>Affected Side (right : left)</td>
<td>4:3</td>
</tr>
</tbody>
</table>

M = male; F = female; R = right; L = left; LA = lower extremity assessment; VO$_2$ = oxygen consumption; N/A = not applicable. Mean ± SD.
Table 2. Oxygen Consumption During Exercise

<table>
<thead>
<tr>
<th>Condition</th>
<th>VO2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(ml/kg·1/min·1)</td>
</tr>
<tr>
<td>Overground Treadmill:</td>
<td></td>
</tr>
<tr>
<td>Warm-up</td>
<td>8.45 ± 1.46</td>
</tr>
<tr>
<td>Exercise</td>
<td>10.98 ± 1.90</td>
</tr>
<tr>
<td>Cool-down</td>
<td>8.45 ± 1.06</td>
</tr>
<tr>
<td>Aquatic Treadmill:</td>
<td></td>
</tr>
<tr>
<td>Warm-up</td>
<td>7.62 ± 0.84</td>
</tr>
<tr>
<td>Exercise</td>
<td>10.59 ± 1.78</td>
</tr>
<tr>
<td>Cool-down</td>
<td>6.95 ± 1.24</td>
</tr>
</tbody>
</table>

VO2 = oxygen consumption. Means ± STD.
## Table 3. Blood Pressure

<table>
<thead>
<tr>
<th>Measures</th>
<th>Systolic BP (mmHg)</th>
<th>Diastolic BP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting Baseline</td>
<td>120.9 ± 10.41</td>
<td>75.47 ± 10.57</td>
</tr>
<tr>
<td>Overall Post-Exercise</td>
<td>120.9 ± 2.30</td>
<td>75.04 ± 2.55</td>
</tr>
<tr>
<td><strong>Overground Treadmill:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting Baseline</td>
<td>117.36 ± 11.77</td>
<td>82.86 ± 14.01</td>
</tr>
<tr>
<td>Exercise</td>
<td>137.71 ± 12.15</td>
<td>-</td>
</tr>
<tr>
<td>1-hr Post-Exercise</td>
<td>117.43 ± 11.72</td>
<td>73.00 ± 11.54</td>
</tr>
<tr>
<td>Overall Post-Exercise</td>
<td>117.67 ± 4.35</td>
<td>* 71.85 ± 1.74</td>
</tr>
<tr>
<td><strong>Aquatic Treadmill:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting Baseline</td>
<td>115.0 ± 9.1</td>
<td>71.60 ± 5.36</td>
</tr>
<tr>
<td>Exercise</td>
<td>136.14 ± 12.69</td>
<td>-</td>
</tr>
<tr>
<td>1-hr Post-Exercise</td>
<td>116.8 ± 10.57</td>
<td>73.60 ± 8.89</td>
</tr>
<tr>
<td>Overall Post-Exercise</td>
<td>*^ 114.56 ± 4.74</td>
<td>* 71.25 ± 2.54</td>
</tr>
</tbody>
</table>

BP = blood pressure; hr = hour; Ambulatory = 2nd to 9th hour post-exercise.
* represents significance at \( p < 0.05 \) compared to control.
^ represents significance at \( p < 0.05 \) compared to overground treadmill.
Means ± SD.
**Figure 1** Hourly Systolic BP Post-Exercise

Abbreviations: OTW = overground treadmill walking, ATW = aquatic treadmill walking, Control = no exercise.

Means.

* represents significance at \( p < 0.01 \) compared to the control day.

^ represents significance within the condition as compared to baseline \( p < 0.05 \).
Figure 2  Hourly Diastolic Blood Pressure Post-Exercise

Abbreviations: OTW = overground treadmill walking, ATW = aquatic treadmill walking, Control = no exercise.
Means.
* represents significance at \( p < 0.01 \) for both the OTW and ATW condition compared to the control day.
Section 4: Discussion

The purpose of this study was to compare the post-exercise hypotensive response between aquatic and overground treadmill walking at an equivalent intensity. BP was measured for nine hours after each bout of treadmill walking. These values were also compared to a day when no exercise was performed. In addition, hourly BP measurements were compared within each of the three test conditions. Our results showed that systolic BP may be reduced for up to nine hours following a single session of aquatic treadmill walking compared to that of overground treadmill walking and a day when no exercise is performed. On the other hand, both treadmills exhibited a lower diastolic BP post-exercise compared to a day without exercise. When comparing hourly BP values within each test condition, aquatic treadmill walking showed a significant decline in systolic BP at the ninth hour of exercise compared to pre-exercise resting values. These findings suggest that cardiovascular exercise can elicit clinically meaningful reductions of BP in people post-stroke.

**Resting Blood Pressure**

Resting BP responses have been found to remain consistent between land and water around a temperature of 30 degrees Celsius, with the water at chest-depth (indicated by the water level at the xiphoid process), in a variety of populations (Cider, Sunnerhagen, Schaufelberger, & Andersson, 2005; Cider, Svealv, Tang, Schaufelberger, & Andersson, 2006; Rodriguez et al., 2011). Our results demonstrated similar findings; resting BP responses showed no significant difference in sitting or standing between the land and water environment. Although some studies have suggested that water immersion
slightly elevates resting BP, these studies were generally performed in higher depths of water located at the shoulder-neck-level (Kokot, Ulman, & Cekański, 1983; Sugiyama et al., 1993). The outcomes from this study confirm that water immersion at chest-depth, between 32 and 34 degrees Celsius, does not alter resting BP responses of people post-stroke.

**Matched Intensity**

To compare post-exercise BP between aquatic- and land-based exercise in normotensive adults, previous studies have utilized HR to match the exercise intensity (Rodriguez et al., 2011; Terblanche & Millen, 2012). However, Hall and colleagues (2004) have reported that walking in water elicits a lower HR compared to walking on land. This suggests that HR alone may not be reliable for matching the intensity of exercise between aquatic and overground treadmill walking. Since oxygen consumption is reported as a valid measure of exercise intensity in people post-stroke (Brouwer et al., 2009; Fisher & Gullickson, 1978), our study monitored the real-time collection of oxygen consumption data to match the intensity of exercise between walking conditions.

**Post-Exercise Hypotension**

*(Overall BP reductions aquatic compared to control day and clinical significance)*

After participants performed a single session of walking on an aquatic treadmill, mean BP over nine hours was lower than that of the control day by 6.3 mmHg systolic and 3.8 mmHg diastolic. Our data are similar to reported reductions in BP post-exercise of approximately two to 12 mmHg systolic and 2 mmHg diastolic in the general adult population with hypertension (Cardoso et al., 2010). Furthermore, our results may be
clinically meaningful for people post-stroke with hypertension who aim to reduce their risk of recurrent stroke. It has been reported that a decrease in resting BP of 10 mmHg systolic or 5 mmHg diastolic BP is associated with a reduced risk of recurrent stroke by 38% and 28%, respectively (Rodgers et al., 1996). Even minimal declines in systolic BP of as little as two mmHg following aerobic training have been associated with a 4% decrease in coronary heart disease and 3% decrease in all-cause mortality (Whelton et al., 2002).

(Comparing treadmills overall and significance of systolic BP reductions)

When examining diastolic BP among the three test conditions, both ATW and OTW showed a lower overall diastolic BP than a day without exercise. However, overall systolic BP values post-exercise were significantly lower following aquatic treadmill walking compared to overground treadmill walking and to a control day. This may be clinically significant, because systolic BP values are more closely associated to cardiovascular risk compared to those of diastolic BP (Zanchetti & Waeber, 2006). Clinical trials have demonstrated that systolic BP is harder to manage through anti-hypertensive treatment and most responsible for poor rates of BP control (Lloyd-Jones et al., 2000). The authors reported that 89.7% of people who received anti-hypertensive treatment were able to regulate their diastolic BP, whereas systolic BP was only controlled in 49% of all cases.

(Acknowledging that statistical significance between may not mean clinical significance)
The comparison of overall post-exercise systolic BP between the aquatic and overground treadmill showed statistical significance. However, the mean difference was marginal (input mean values later, raw means) and the clinical significance of this difference appears unclear. Also, these findings are inconsistent with a previous study that examined post-exercise BP in people with hypertension following aquatic- and land-based exercise. Terblanche & Millen (2012) reported that a single-bout of land-based exercise reduced post-exercise BP in greater magnitude and duration to that of aquatic exercise. This difference appeared most prominent after the 11th hour after exercise. However, their exercise sessions incorporated both a resistance and a cardiovascular exercise component, which was not matched for intensity between exercise conditions. The greatest reductions of BP seen in the present study occurred during the eighth and ninth hour post-exercise, the last two hours of BP monitoring. Since treadmill exercise has been shown to reduce BP for up to 24 hours after exercise (Terblanche & Millen, 2012), it is possible that greater declines in BP may be seen after longer periods of monitoring. Thus, future studies should examine longer durations of BP responses to aquatic and overground treadmill walking at an equivalent intensity.

(Introduction of nighttime dipping in normal adults and significance)

Typical daily BP is characterized by high levels of pressure during the working hours of the day with BP drops of approximately ten to twenty percent at nighttime. This concept is known as diurnal variation, or nighttime dipping (Routledge & McFetridge-Durdle, 2007). An absence of dipping during the night can lead to a higher load of BP throughout the day, which may cause an increased amount of strain on the internal organs. It is critical to monitor changes in BP from early hours in the day till late at night
in order to prevent hypertension-related health complications (Mancia et al., 1997; Staessen et al., 1999). In addition, nighttime dipping has been identified as an accurate predictor of stroke, heart failure, and sudden death in elderly individuals with hypertension (Staessen et al., 1999). People post-stroke have been documented to lack nighttime dipping of BP (Castilla-Guerra et al., 2009; Jain, Namboodri, Kumari, & Prabhakar, 2004). Our results were similar in findings: on a day when no exercise was performed, people post-stroke displayed no decline in BP at nighttime when compared to morning BP values. On the other hand, after people post-stroke exercised on an aquatic treadmill between nine to eleven am they were able to reduce their systolic BP by 6% at nighttime. This suggests that exercise on an aquatic treadmill may promote nighttime dipping of BP in people post-stroke. Further investigation is warranted to monitor BP for longer periods of time, possibly through sleep and morning hours of the following day.

(Clinical significance)

Reductions of BP following a bout of treadmill exercise can be viewed favorably for people post-stroke with hypertension, as it may provide them with an effective method of managing their BP. The present study recruited only people post-stroke with normotension. It is possible that we may observe greater declines of BP after exercise in people post-stroke with hypertension. People with hypertension have been documented to display a greater reduction in BP after exercise compared to people with normotension (Wallace et al., 1999). It is necessary to verify whether the findings from the present study are translatable to people post-stroke with hypertension. Our results provide clinicians in rehabilitation with a scientific understanding of post-exercise hypotension in
people post-stroke, which may assist them with designing and implementing effective intervention programs.

**Limitations**

We acknowledge that there are limitations in this study. Since the sample size of this study was relatively small, this may limit the clinical interpretation of the study outcomes. Secondly, this study focused on the main effects of acute exercise on BP, but did not investigate the mechanism of post-exercise hypotension. Previous studies have shown that hypotension can be induced by a reduction in sympathetic drive (Kulics, Collins, & DiCarlo, 1999), vascular resistance, and stroke volume (Brandão Rondon et al., 2002), all of which have been found to be augmented during aquatic exercise (Gabrielsen et al., 2000; Pontes et al., 2008). Lastly, this study investigated the immediate response to a single-bout of exercise on BP. Future studies may examine the effects of long term interventions within this population.

**Conclusion**

This study was the first to our knowledge to analyze the post-exercise hypotensive response of people post-stroke. Our results indicate that people post-stroke are able to sustain a sufficient walking intensity necessary to elicit a significant decline in BP following cardiovascular exercise. Aquatic treadmill walking showed a greater reduction of systolic BP over a nine-hour period as compared to overground treadmill walking. However, further investigation is warranted to validate these findings with a larger sample size or longer monitoring period. Also, our results suggest aquatic treadmill walking can elicit a clinically meaningful nighttime reduction in BP. Thus, it is
recommend for clinicians to consider using aquatic treadmill walking as a non-pharmaceutical means to regulate BP in people post-stroke.

REFERENCES


41


sessions in healthy trained and untrained women Int J Gen Med (Vol. 4, pp. 549-554).


Appendix A

*California State University, Northridge*

**The Effects of Aquatic and Overground Treadmill Exercise on Post Exercise Hypotension in People Post-Stroke.**

**INFORMED CONSENT**

**Introduction**

You are being asked to participate in a research study. 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 the Study**

The purpose of this research study is to evaluate the effects of
Subject Information
You are eligible to participate in this study if you have been diagnosed with hemiplegic stroke, are a minimum of 6 months post-stroke, are above 34 years old, are able to participate in approximately 30 minutes of walking on an underwater treadmill and overground treadmill, are able to read, communicate, and follow directions in English. You are not eligible to participate in this study if you have a resting systolic blood pressure of greater than 140 mmHg or below 100 mmHg, a resting diastolic blood pressure of greater than 95 mmHg or below 61 mmHg, cardiorespiratory complications, or have had surgery within the last 6 months.

This study will last approximately a week and total 10 hours of clinical time and 72 hours of ambulatory blood pressure measurement monitoring which will approximate to a total of 3 days and 10 hours of your time.

Procedures
Upon being recruited for this study, participants will be required to obtain medical clearance from their primary physician prior to any participation in this study. Once medical clearance has been obtained, participants will be instructed to schedule their initial
visit. To participate in the study, participants will be required to bring and wear: a bathing suit, exercise shorts, a shirt, and a towel.

After participant’s have obtained medical clearance they will be directed to come to the Center of Achievement through Adapted Physical Activity (CoA) on the California State University, Northridge campus for a brief one-on-one explanation of the significance behind this study as well as an explanation of the exercise protocol. All data collection and cardiovascular sessions will be held at the CoA, CSUN.

The initial visit will include: 1) participants’ characteristics will be recorded and will then be subject to a lower extremity motor assessment: (FMA-LE, University of Gothenburg, Sweden), 2) participants will perform a maximal exercise test. 3) Participants will be given an ambulatory blood pressure monitor to assess their blood pressure for 24 hours on a day without exercise.

After this initial meeting, participants will be randomized to start with either aquatic or land treadmill testing. The rest of the visits will occur in random order with a minimum of 48 hours between exercise sessions. Phone calls will be made to monitor adherence to ambulatory blood pressure monitor readings.
The second visit will consist of two aquatic walking sessions to ensure safety during treadmill exercise. Data collection procedures will last approximately 2 hours which will include: 1) a participant will perform three 5-minute stages of walking on an overground treadmill. Blood pressure will be measured at the end of every stage, 2) after a 15 minute break, the participant will perform a graded treadmill test at slow speed to a treadmill walking speed at 70% of a participants’ predicted maximum oxygen consumption (taken from the “initial visit”), 3) participants will be given an ambulatory blood pressure monitor to assess their blood pressure for 24 hours on a day without exercise.

The third visit will consist of two aquatic walking sessions to ensure safety during aquatic treadmill exercise. Data collection procedures will last approximately 2 hours which will include: 1) a participant will perform three 5-minute stages of walking on an aquatic treadmill. Blood pressure will be measured at the end of every stage, 2) after a 15 minute break, the participant will perform a graded treadmill test at slow speed to a treadmill walking speed at 70% of a participants’ predicted maximum oxygen consumption (taken from the “initial visit”), 3) participants will be given an ambulatory blood pressure monitor to assess their blood pressure for 24 hours on a day without exercise.
exercise.

The fourth visit will last approximately 2 hours and 15 minutes which will include: 1) 25 minutes of walking on a land or aquatic treadmill, 2) 1 hour of seated rest, 3) blood pressure will be analyzed for 24 hours following exercise via 24 hour ambulatory blood pressure monitor on a day without exercise.

The fourth visit will last approximately 2 hours and 15 minutes which will include: 1) 25 minutes of walking on a land or aquatic treadmill. If the participant walked on an overground treadmill during the fourth visit, the participant will walk on an overground treadmill during the fifth visit and vice-versa, 2) 1 hour of seated rest, 3) blood pressure will be analyzed for 24 hours following exercise via 24 hour ambulatory blood pressure monitor on a day without exercise, 4) the participant will be debriefed and the lead graduate researcher will coordinate a day that the Meditech ABPM-05 can be picked up at their home or dropped off at the Center of Achievement.

Risks While you understand that we strive to prevent any possible complications or injuries, there are risks involved in participation such as: cardiovascular complications, dehydration, pain, soreness, falling, drowning, physical/psychological fatigue, skin irritation, muscle cramps, other water safety issues, dizziness,
and nausea. In an attempt to minimalize these risks, certain precautions will be taken such as: 1) physician clearance will be obtained to ensure participants do not have any contraindications for the exercise protocol, 2) participants will be allowed water when necessary in order to keep themselves hydrated during data collection, 3) research assistants will be used as active spotters during the transition from the lobby to the equipment and off of the equipment back to the lobby at the conclusion of the exercise session, 4) emergency services (911) will be contacted and participants will be referred will be referred to their primary care physician.

Benefits

The benefits of this study will be having participants complete organized exercise sessions. The knowledge obtained from this study may contribute to creating an alternate non-pharmacological method of blood pressure regulation in stroke-survivors. The only alternative to participation in this study is not to participate.

Compensation, Costs, and Reimbursement

You will not be paid for your participation in this research study. There is no cost to you for participation in this study. Parking passes will be provided by the Center of Achievement. You will not be reimbursed for any out of pocket expenses, such as transportation fees.
Withdrawal
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
All identifiable information that will be collected about you will be removed at the end of data collection and replaced with a code.

All virtual research data will be stored on a laptop computer that is password protected and owned by the Center of Achievement at California State University Northridge.

All physical records or identifiable information will be kept in a locked desk in the Center of Achievement through Adapted Physical Activity in the main office where only the primary investigator, Byron Lai, and faculty advisor, Dr. Taeyou Jung have access.

The researcher and faculty advisor named on the first page of this form will have access to your study records. 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.

The researchers intend to keep the research data until the research is published and then it will be destroyed.

Concerns

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 are unable to reach a member of the research team listed on the first page of the form and have general questions, or you have concerns or complaints about the research study, research team, or questions about your rights as a research subject, please contact Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, or phone 818-677-2901.

Voluntary Participation

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 future 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.

CONSENT

I agree to participate in the study.

___________________________________________________  ________________

Subject Signature  Date

___________________________________________________

Printed Name of Subject

___________________________________________________  ________________

Researcher Signature  Date

___________________________________________________

Printed Name of Researcher
Appendix B

FUGL-MEYER ASSESSMENT

ID:

LOWER EXTREMITY (FMA-LE)

Date: Assessment of sensorimotor function
Examiner:


<table>
<thead>
<tr>
<th>E. LOWER EXTREMITY</th>
<th>none</th>
<th>can be elicited</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Reflex activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>supine position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexors: knee flexors</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Extensors: patellar, Achilles</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Subtotal I (max 4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| II. Volitional movement within synergies | non | partial | full |
| supine |      |         |      |
| Flexor synergy: Maximal hip flexion (abduction/external rotation) | 0 | 1 | 2 |
| Hip flexion Knee flexion Ankle | 0 | 1 | 2 |
maximal flexion in knee and ankle joint (palpate distal tendons to ensure active knee flexion).

**Extensor synergy:** From flexor synergy to the hip.

<table>
<thead>
<tr>
<th>Extensor synergy</th>
<th>Hip</th>
<th>non</th>
<th>partial</th>
<th>full</th>
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<tr>
<td>ext</td>
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<td>0</td>
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</table>

**III. Volitional movement mixing synergies,** sitting position, knee 10cm from the edge of the chair/bed

<table>
<thead>
<tr>
<th>Knee flexion from actively or passively extended knee</th>
<th>no active motion</th>
<th>0</th>
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<tbody>
<tr>
<td></td>
<td>no flexion beyond 90°, palpate tendons of hamstrings</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>knee flexion beyond 90°, palpate tendons of</td>
<td>2</td>
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</tbody>
</table>

**Ankle dorsiflexion compare with**

| no active motion | 0 |
| limited dorsiflexion | 1 |

**Subtotal III (max 4)**

**IV. Volitional movement with little or no synergy,** standing position, hip at 0°

<table>
<thead>
<tr>
<th>Knee flexion to 90° hip at 0°, balance support is allowed</th>
<th>no active motion / immediate and simultaneous hip flexion</th>
<th>0</th>
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<tr>
<td></td>
<td>less than 90° knee flexion or hip flexion during movement at least 90° knee flexion without simultaneous hip flexion</td>
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</table>

**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

<table>
<thead>
<tr>
<th>Reflex activity knee flexors, Achilles, patellar</th>
<th>0 points on part IV or 2 of 3 reflexes markedly hyperactive</th>
<th>0</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1 reflex markedly hyperactive or at least 2 reflexes lively maximum of 1 reflex lively, none hyperactive</td>
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</table>

**Subtotal V (max 2)**
Appendix C

Raw Data in PASW Cording Format

Table C1. Mixed model ANOVA mean diastolic blood pressure post-exercise

Table C2. Mixed model ANOVA mean systolic blood pressure post-exercise

Abbreviations used for coding for statistical analysis

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<td>Overground Treadmill</td>
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<tr>
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<td>Aquatic Treadmill</td>
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</table>

<table>
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<tr>
<td>BP</td>
<td>Blood Pressure</td>
</tr>
<tr>
<td>SBP</td>
<td>Systolic Blood Pressure</td>
</tr>
<tr>
<td>DBP</td>
<td>Diastolic Blood Pressure</td>
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Table C1. Mixed Model Anova Diastolic Blood Pressure Post-Exercise

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Table C2. Mixed Model Anova Systolic Blood Pressure Post-Exercise

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