Biomechanics of stationary exercise: An option for weight management

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Abstract

Children carrying excess mass have difficulty performing exercises requiring whole body movement with horizontal displacement, such as walking and running. While previous research strongly suggests that overweight children adapt their gait to accommodate for moving excess mass horizontally, very little research has investigated the biomechanical characteristics of simple exercises that focus on vertical displacement, such as stationary exercise. In addition, aquatic exercise has not been considered as an alternative solution for this population. Therefore, the purpose of this thesis was to compare the biomechanical differences between aquatic- and land-based stationary exercises in normal-weight and overweight children.

Methods

This thesis involved four parts; literature review, technical note, biomechanics of land- and aquatic-based stationary exercise. The literature review includes a summary about the prevalence of paediatric obesity and its related physical dysfunction, as well as the drafted literature review manuscript on biomechanical differences in exercises overground and within shallow water. It is followed by a technical note study to examine the accuracy of the camera setup by comparing the angular kinematics collected using a recreational, low-cost sports video camera (GoPro, Inc) and commercial inertial motion sensors, in both land and water environments. Following the validation study, there are two cross-sectional studies that investigate the differences in lower extremity kinematics, spatiotemporal parameters, rate of perceived exertion (RPE) and muscle activation patterns, in normal-weight and overweight children during water- and land-based stationary exercises.

Results

The literature review revealed that the previous aquatic biomechanical research is limited to aquatic gait in adults and elderly people. The lack of aquatic research in children is of great concern, as aquatic sports provide a low weight bearing activity that diminishes the likelihood of injuries in children and provides a solid foundation for physically activity throughout the lifespan.

We demonstrated that the GoPro camera derived angular velocity measurements underwater and in air are accurate when compared to data from inertial sensors and known motion of the clock's second hand and a driven limb segment model. Thus, the accuracy of thesis protocol was established.

The findings of the two cross-sectional studies demonstrated that children with excess body mass experienced significantly greater RPE and muscle activation with more extended joints during land-based stationary exercises. However, these differences diminished between groups in water with a lower RPE in overweight children and a more upright posture for both groups.

Conclusions

These findings suggested that children with excess body mass may adopt a more active neuromuscular strategy and a more upright posture in order to provide greater stability and propulsion during land-based stationary exercises. Higher RPE scores could indicate a greater level of difficulty and lack of enjoyment when performing stationary exercise on land. However, these differences did not exist in water. Thus, these findings support stationary exercises in water as a desirable way to reduce functional differences and subsequently promote physical activity in overweight children.

Preface

There are a number of people who deserve to be acknowledged and thanked for their contribution to this thesis: I wish to express my heartfelt appreciation to the most important people in my life, my partner Heather and our lovely daughter Winnie, and my parents for their never-ending help, support, and understanding during this "juggling act". There is not any way that I could have done this without them.

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Chapter 1: Introduction

Introduction

Paediatric obesity persists as one of the most serious public health challenges worldwide (Llewellyn, Simmonds et al. 2015, Wang, Cai et al. 2015). Despite policies implemented in different countries, the worldwide prevalence of childhood obesity still shows an upward trend and rates are expected to increase further (Lobstein, Jackson-Leach et al. 2015, Kumar and Kelly 2017). Based on the Organization for Economic Co-operation and Development (OECD) reports, one in six children is overweight or obese in OECD countries and about one-third of children in New Zealand are classified as either overweight or obese (Weerasekera, Johnston et al. 2017). These findings indicate a need for effective programs or preventive interventions to stop and reverse anticipated trends (Rajput, Tuohy et al. 2014, Wang, Cai et al. 2015).

Recent evidence suggests that sedentary behaviour and low physical activity level are major contributing factors of paediatric obesity and a negative correlation exists between obesity and physical activity in children (Deforche, De Bourdeaudhuij et al. 2009, Katzmarzyk, Barreira et al. 2015). There is also a strong negative association between physical activity and cardiorespiratory fitness (Fogelholm, Stigman et al. 2008), which suggests that poor physical performance in an obese child may have more to do with physical inactivity than weight status. Thus, the intensity of physical activity and amount of physical inactivity are key determinants for the prevention and treatment of adiposity (Janssen, Katzmarzyk et al. 2005). Additionally, adequate levels of child participation in low impact and organised physical activity can improve motor competency and fitness, which is associated with numerous health benefits (Hills, Andersen et al. 2011).

Paediatric obesity has a well-documented association with multiple musculoskeletal disorders, pain and orthopaedic conditions (Paulis, Silva et al. 2013, Smith, Sumar et al. 2013). Specifically, numerous studies have determined strong associations between high BMI and musculoskeletal dysfunction, injury and pain, particularly within the lower extremity (Sabharwal and Root 2012, Smith, Sumar et al. 2013). Musculoskeletal pain and discomfort increases the difficulty of physical activity participation in children with excessive body mass (Shultz, Anner et al. 2009). Previous research has shown that overweight children walk with a stiffer, more upright posture as a result of insufficient sagittal plane range of motion, specifically at the hip and knee (Shultz, D'Hondt et al. 2014). Overweight children respond differently when moving extra body mass during locomotion (Hung, Gill et al. 2013) and exhibit increased lower extremity joint moments (Gushue, Houck et al. 2005) and power (Shultz, Hills et al. 2010), ground reaction forces (Gill and Hung 2014) and muscle activation during gait (Blakemore, Fink et al. 2013). In addition, it has been suggested that changes in the locomotor strategy by overweight children reduce mechanical efficiency and produce greater demands on musculature (McMillan, Auman et al. 2009, Gill and Hung 2012), which decreases performance in fitness skills requiring whole body movement with horizontal displacement, such as in walking and running (Gushue, Houck et al. 2005, Shultz, Sitler et al. 2009).

While previous research strongly suggests that overweight children adapt their gait to accommodate for moving excess mass horizontally (McGraw, McClenaghan et al. 2000), very little research has investigated the biomechanical characteristics of simple exercises that focus on vertical displacement. More vertically oriented exercises (such as stationary exercise) could benefit this cohort as they seem to diminish metabolic cost and neuromuscular activity in comparison to modalities that involve horizontal displacement of body, such as walking and running (Kelly, Roskin et al. 2000, Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2015). Stationary exercise is one of the most convenient and frequently prescribed exercises in circumstances where a sufficiently large area for running is not available or the necessary equipment has not been resourced. Stationary exercises can also be recommended for health promotion and rehabilitation as they incorporate basic movement patterns and have benefits to musculoskeletal and cardiovascular systems (Haddock, Siegel et al. 2009, Alberton, Cadore et al. 2011). Previous research indicated that stationary running at submaximal intensity has less loading rate (abrupt force) in comparison to running (at less than 5 m/s) during foot contact (Keller, Weisberger et al. 1996, Fontana, Ruschel et al. 2015). Because stationary exercise mainly involves vertical displacement of the centre of mass, adults who perform these activities experience very low anterior-posterior and medial-lateral forces relative to the vertical ground reaction force (GRF), particularly in comparison to running (Keller, Weisberger et al. 1996, Fontana, Haupenthal et al. 2012, Fontana, Ruschel et al. 2015, Alberton, Pinto et al. 2017). Thus, stationary exercise at submaximal intensities may be an alternative for people who need to perform exercises that diminish shear stress on lower extremity joints, such as individuals who have a history of overweight, osteoarticular diseases or reconstruction surgery (Shelbourne and Nitz 1990, Jones, Meredith-Jones et al. 2009, Fontana, Ruschel et al. 2015). Based on this research in adults, we believe that stationary exercise could also be a safe and effective exercise option for weight loss and general improvement of physical conditioning and coordination in overweight children.

Land-based stationary exercise produces similar vertical ground reaction forces to running (Fontana, Haupenthal et al. 2012) and thus, can be considered high-impact with potential to increase wear and tear on joints. The increased injury risk during repetitive, high impact exercise is especially true in obese children, who often complain about musculoskeletal pain (Shultz, Anner et al. 2009, Shultz, Sitler et al. 2009) and resulting in lower adherence and enjoyment (Ekkekakis and Lind 2006). The buoyant effect of water reduces the weight-bearing stress on muscles and mechanical loads on joints during aquatic activity (Torres-Ronda and del Alcázar 2014). Thus, aquatic exercise could provide an effective and less injurious alternative to over ground activities. However, there has been little published research investigating the biomechanical benefits of water-based physical activity in children. This research will provide a more extensive biomechanical understanding of stationary exercise performed by children of varying body size and could support the development of adapted weight management interventions. Therefore, the purpose of this thesis is to compare the biomechanical differences between stationary aquatic- and land-based exercises in children. Specifically, lower extremity joint kinematics and electromyography will be assessed during stationary running, frontal kick and butt kick exercises in water and land.

Thesis structure and general research aims

The PhD thesis is structured by publication and includes four manuscripts: a literature review manuscript, followed by a technical note and two experimental manuscripts as follows:

Chapter 1: Introduction

Chapter 1 includes an overall review of the relevant literature and the purpose of the thesis. This is followed by thesis structure and general research aims.

Chapter 2: Literature Review

The literature review chapter is structured in three parts. The first part includes a summary of the prevalence of paediatric obesity and its related physical dysfunction, as well as the association between obesity and physical activity. The second part of the literature review is comprised of the drafted literature review manuscript on biomechanical differences in exercises overground and within shallow water. The manuscript aims to provide a descriptive literature review of the biomechanical parameters of shallow water exercise in comparison to land-based equivalents. Finally, the third part explores the benefits of aquatic exercise for overweight/obese children. This chapter is currently under review for publication to *International Journal of Aquatic Research and Education*.

Chapter 3: Technical Note

Chapter 3 examines two-dimensional comparison of a GoPro camera-based video analysis system with inertial motion sensors for underwater and land applications. The technical note aims to compare the angular kinematics collected using a recreational, low-cost sports video camera (GoPro, Inc) and commercial inertial motion sensors, in both land and water environments. By making this comparison, the accuracy of the thesis protocol was established.

Chapter 4: Stationary exercises in overweight and normal-weight children

The purpose of this study is to examine the differences in lower extremity kinematics and muscle activation patterns between normal-weight and overweight children during stationary exercises at submaximal intensity. In this first chapter containing original research, the foundation is created to understand the differences between normal-weight and overweight children. This chapter has been published in *Pediatric Exercise Science*.

Chapter 5: Kinematic comparison of aquatic –and land-based stationary exercises in overweight and normal-weight children

This chapter builds on the previous chapter's findings of stationary exercise by including various environments for participation. Specifically, this study aims to examine the differences in lower extremity kinematics and spatiotemporal parameters in normal-weight and overweight children during water- and land-based stationary exercises at submaximal intensity. This chapter has been published in *Pediatric Exercise Science*.

Chapter 6: Conclusion

The conclusion chapter summarizes the findings of the research and highlights implications for physical activity participation in children with obesity.

Chapter 2: Literature review

Part 1: Summary of the prevalence of paediatric obesity, its relation to physical dysfunction and the association between obesity and physical activity

Prevalence of child obesity

The incidence of paediatric obesity has increased rapidly in recent decades, with an estimated 200 million children (school-aged) world-wide categorised as overweight or obese and a further 92 million children at risk of becoming overweight (Ng, Fleming et al. 2014, Llewellyn, Simmonds et al. 2015). The worldwide prevalence of paediatric obesity increased 2.5% between 1990 and 2010. This trend is expected to increase and reach 9.1% in 2020 (Wang and Lim 2012, Llewellyn, Simmonds et al. 2015). However, some evidence suggests that the rise in prevalence of global paediatric obesity has slowed and plateaued. This recent evidence should not divert attention from the problem, since the levelling off has been followed by further increases in some countries (Peneau, Salanave et al. 2009, Cattaneo, Monasta et al. 2010, Olds, Maher et al. 2011).

The New Zealand Medical Association (NZMA) reported in 2014 that obesity and its related complications are potentially the greatest public health threat New Zealand faces in the next decade. Based on the Organization for Economic Co-operation and Development (OECD) reports, New Zealand is the third most obese country in the world, with significant variety in ethnicities affected (Roos, Mason et al. 2012, Sharpe, Templeton et al. 2013). The recent New Zealand Health survey found an increasing trend in obesity within the past 16 years, with approximately one million adults and 255,000 children have extra body weight. Based on these findings, the need for effective programs or preventive interventions to stop and reverse anticipated trends is essential (Sharpe, Templeton et al. 2013, Rajput, Tuohy et al. 2014).

Physical dysfunction of obesity

Paediatric obesity has a well-documented association with multiple musculoskeletal disorders and orthopaedic conditions, particularly within the lower extremity (Gettys, Jackson et al. 2011, Sabharwal and Root 2012, Paulis, Silva et al. 2013). Several studies have indicated that childhood obesity has a negative impact on the musculoskeletal system by changing the musculoskeletal structure in the lumbar spine and lower limbs (de Sa Pinto, de Barros Holanda et al. 2006, Jannini, Doria-Filho et al. 2011). Previous research has revealed that greater BMI is associated with the occurrence of slipped capital femoral epiphysis, due to increased weight-bearing forces on the femoral head and decreased femoral anteversion in children who are obese during regular over-ground locomotor tasks (Choung and Yang 2003, Wearing, Hennig et al. 2006). Additionally, greater body weight in children is associated with increased likelihood of osteoarthritis. Obesity during the growth period may contribute to the development and progression of degenerative osteoarthritis and cartilage breakdown of the lower joints (Sabharwal and Root 2012). This is exacerbated particularly in knee joints, because of greater exposure to joint loading in obese individuals (Loder 1996, Messier, Mihalko et al. 2013). Researchers have found an increased prevalence of both genu valgum and varum deformities associated with increased BMI in children (Wills 2004, Shim, Lee et al. 2010). However, the risk of knee osteoarthritis increases in obese children with genu varum more than genu valgum; thus, higher BMI is associated more with medial tibiofemoral osteoarthritis (Anderson and Felson 1988, Sharma, Lou et al. 2000). The effect of excess mass on foot structural dysfunction has been determined by previous studies and could be identified by foot pain and flat foot (O'Malley, Hussey et al. 2012, Shultz, Sitler et al. 2012). Previous studies have indicated that obese children have greater foot length and width than non-obese children (Morrison, Durward et al. 2007). Excessive weight bearing may cause a lower longitudinal and medial arch, thereby resulting in a larger contact area of the foot, which increases pressures within medial parts of the foot during the activities of daily living tasks (Hills, Hennig et al. 2002, Pfeiffer, Kotz et al. 2006). Thus, this structural dysfunction could cause stress fractures and foot discomfort during participating in physical activities (Dowling and Steele 2001, Dowling, Steele et al. 2001).

Goulding et al. (2001) showed that bone mineral content in children who are overweight and obese is significantly less than normal weight children (Goulding, Jones et al. 2001). Conversely, other studies have reported that the bone mineral density in overweight children is similar or greater than non-obese children (Leonard, Shults et al. 2004). However, this normal bone strength is not sufficient to overcome the higher kinetic energy of impact that is generated in case of a fall by overweight children (Ehehalt, Binder et al. 2011). Because of this disparity between normal bone strength and excess body weight, obese children may have twice the risk of skeletal bone fracture than non-obese children (Goulding, Taylor et al. 2002, Whiting 2002).

Musculoskeletal injuries and pain are the most reported orthopaedic complications in overweight children, particularly in the lower extremity. Studies have determined strong associations between high BMI and back, hip, knee and foot pain during weight-bearing modes of physical activity (Taylor, Theim et al. 2006, Stovitz, Pardee et al. 2008, Sabharwal and Root 2012). Musculoskeletal pain and discomfort increases the difficulty of physical activity in children with excessive body mass, resulting in less participation of overweight and obese children in physical activity (Shultz, Anner et al. 2009, Adams, Kessler et al. 2013). Therefore, clinicians treating musculoskeletal pain in obese children should consider pain as a symptom of higher body weight and prescribe tailored therapeutic exercise programs (Stovitz, Pardee et al. 2008, Tsiros, Buckley et al. 2013).

Previous gait studies have found that children who are overweight and obese sustain increased medial/lateral ground reaction force and increased joint moments during walking (Shultz 2008). Likewise, Gushue et al. (2005) hold the view that obese children sustain more cumulative stress on knee joints, during normal gait and normal repetitive loading tasks, which can increase the risk of developing osteoarthritis and knee deformities (Gushue, Houck et al. 2005). Jumping and landing are common in sports and general physical activities for children and assist in normal motor development and improved bone mineral density (Fuchs, Bauer et al. 2001). However, obese children sustain very high ground reaction forces and increased momentum during a jump-landing activity due to their increased mass (Kulas, Zalewski et al. 2008). Additional muscular forces around the joints will be necessary to control the momentum when landing from a jump (Tyler, McHugh et al. 2006). This view is supported by de Carvalho et al. (2012), who found children with excess body mass revealed greater muscle activity in the after-fall phase of jump tasks and less efficient muscle activity pattern during gait comparing to their normal-weight counterparts (de Carvalho, Figueira Martins et al. 2012). These kinetic and muscle activity changes in obese children's locomotion diminish the efficiency of transferring mechanical work compared to normal weight children (Nantel, Brochu et al. 2006) and develop musculoskeletal dysfunction at the lower extremity (McMillan, Auman et al. 2009).

Thus, a good integration of biomechanical specificities might help optimize energy expenditure and musculoskeletal comforting (Aull, Rowe et al. 2008).

Association between obesity and physical activity/sedentary behaviour

Recent evidence suggests that paediatric obesity correlates with a reduction of quality of life and lower physical function, including the capacity to perform locomotor skills (Bout-Tabaku, Briggs et al. 2013, Tsiros, Buckley et al. 2013). Several studies have been carried out to investigate the relationship of physical activity, physical fitness and motor skill competency with the development of excessive body mass in children (Pathare, Haskvitz et al. 2013, Gill and Hung 2014). Many studies indicated that physical inactivity is a major contributing factor of paediatric obesity and they found a negative correlation between obesity and physical activity in obese children (Bar-Or and Baranowski 1994, Ward, Trost et al. 1997, Wittmeier, Mollard et al. 2008, Deforche, De Bourdeaudhuij et al. 2009, Hills, Andersen et al. 2011), while others found no link between physical inactivity and childhood obesity (Grund, Dilba et al. 2000, Deforche, Lefevre et al. 2003).

There is an inverse association between body fat and weight bearing physical fitness components, which require support or mobility of the total body weight (Minck, Ruiter et al. 2000, Esmaeilzadeh and Ebadollahzadeh 2012). Similarly, Fogelholm (2008) asserts that there is a stronger negative association between physical activity and cardiorespiratory fitness (Fogelholm, Stigman et al. 2008), which suggests that poor physical performance in an obese child may have more to do with physical inactivity than weight status (Tsiros, Coates et al. 2011). Other studies have found a negative relationship between physical activity and body fatness in children (Marshall, Biddle et al. 2004). Normal weight children spent 20 minutes more per day in moderate and vigorous physical activity than overweight peers (Deforche, De Bourdeaudhuij et al. 2009). It has been suggested that one hour of moderate and vigorous physical activity per day reduces body fat and BMI in children (Wittmeier, Mollard et al. 2008).

Sedentary behaviour has been positively associated with increased body mass in children (Must and Tybor 2005). The range of sedentary behaviours (e.g. less active transport), is increased, which reduces the levels of habitual physical activity in children (Sisson and Katzmarzyk 2008). The subsequent decreases in habitual physical activity in children is not enough to maintain a healthy body weight (Trost, Kerr et al. 2001, Hills and Byrne 2006, Huang, Sallis et al. 2009). Hence, the intensity of physical activity and less sedentary behaviours are key determinants for the prevention and treatment of adiposity (Janssen, Katzmarzyk et al. 2005). Additionally, regular physical activity during the growing years can evolve into a physically active lifestyle (Huang, Sallis et al. 2009). Therefore, adequate levels of child participation in low impact and organised physical activity can improve motor competency and fitness, which is associated with numerous health benefits (Hills, Andersen et al. 2011).

Part 2: Biomechanical properties of shallow water aquatic exercise: a review of literature

Abstract

Due to the different physical properties of an aquatic environment compared to on land, changes in the response to biomechanical aspects of human movement are expected. It is easier to compare exercises in shallow water (i.e. participants are able to maintain contact with the bottom of the pool) to land based exercises that involve a

similar movement pattern because ground reaction forces are present in both cases. This review focuses mainly on the biomechanics literature of shallow water exercise. During shallow-water aquatic exercise, the level of muscle activity is similar or less in submaximal intensity in comparison to on land. At maximal intensities, however, the muscle activity was similar or higher in water than on land. the kinematics of shallow water exercises were different in comparison to equivalent exercises on land and other biomechanical characteristics such as ground reaction forces, lower extremity joint moments and the speed of motion, were lower in water than on land. Thus, due to biomechanical differences between shallow water exercises and land equivalents, trainers and rehabilitation specialists should provide an appropriate exercise prescription, which is adapted to the biomechanical characteristics of shallow water exercise. Few studies have been reported examining the kinematics of shallow water aquatic exercise with regard to different groups, such as age, gender, physical disability and injury status. This indicates that there is a lot of useful research in this area still to be done. The standardisation of the protocols used in biomechanical aquatic research is essential for future studies to be directly compared.

Introduction

The physical properties of water differ from those of air and make aquatic exercise particularly useful during situations that require a reduction in impact loading on the body. Specifically, the mechanical characteristics of water (buoyancy, hydrostatic pressure and drag force) can reduce the risk of injury and assist in ease of movement. These benefits are especially important for people who need to perform rehabilitative exercises under less intense mechanical load while maintaining an effective range of motion (Heywood, McClelland et al. 2016). Additionally, water exercises can be used for physical conditioning and health promotion. The general fluid drag equation

($F_d = ½pAv^2C_d$) (Lord Rayleigh 1917) indicates that water resistance (drag force) is positively correlated to the shape and size of the projected area and velocity squared of movement in water . Thus, changes to the speed of the exercise, or implementing aquatic devices to change the surface area will affect the mechanical demand placed on the individual, making aquatic exercise useful for both therapeutic and conditioning purposes in different populations. Understanding of the applied biomechanics of aquatic exercises is necessary for practitioners and users in order to structure effective programs and achieve desired outcomes that are related to the unique features of movement in water.

Shallow water exercises are widely recommended to individuals who cannot be subjected to physical activities with high impact on the lower limbs. Shallow water exercises, also known as head-out exercises, are usually performed in a depth typically at the axillary, xiphoid or hip levels. During shallow water exercises, participants are propelling themselves through water and they are able to maintain contact with the bottom of the pool without a need for flotation devices (Gappmaier, Lake et al. 2006). This mode of exercise can be beneficial as the impact force on the lower limb joints can be controlled by changing the immersion level and the speed of movement (Miyoshi, Shirota et al. 2004). In addition, buoyancy reduces loading ground reaction forces (GRFs) at impact in shallow water exercise while increased resistance to movement (drag force) requires the subject to exert greater propulsion force than land based exercise (Orselli and Duarte 2011). There is a substantial volume of literature that supports the potential value of using shallow water exercises as a cross-training for performance enhancement in athletes and as an active recovery between competitive events (Thein and Brody 1998, Bento, Pereira et al. 2012).

Locomotive exercises such as walking and stationary running, are some of the most popular forms of aquatic exercise and can be performed in both shallow and deep water. However, the absence of ground reaction forces during deep water locomotion makes biomechanical comparison between similar exercises across aquatic and land conditions difficult. During land-based and shallow water locomotion, the ability to push off the ground and bottom of the pool, respectively, provides force that is not present during deep water locomotion (Masumoto, Applequist et al. 2013). Thus, there is no stance phase during deep water locomotion, whereas the gait cycle in land-based and shallow water includes toe off and ground contact (Masumoto, Horsch et al. 2014). Without the propulsive force provided during stance phase, muscle and joint coordination during deep water exercise may not always mimic running on land and shallow water (Miyoshi, Shirota et al. 2005, Killgore, Wilcox et al. 2006, Masumoto, Applequist et al. 2013). In addition, deep water exercises involve an extra constant cardiovascular component that cannot be accurately compared with land-based exercises due to the need to tread water. Therefore, it would be inaccurate to directly compare the biomechanical responses (kinematic, kinetic and muscle activity) of land-based and shallow water exercises with deep water exercises.

Due to the similarities of having a GRF phase in shallow water and over ground locomotion this review article will focus on the biomechanical comparison of shallow water and land-based exercise with particular interest in the potential physical benefits of participating in aquatic activity. This review article will highlight how the biomechanical characteristics of aquatic activities help to create an environment that is beneficial to a variety of populations who are pursuing physical activity. Specifically, this type of exercise can be beneficial for athletes for conditioning and rehabilitation purposes, as well as an excellent exercise alternative for the elderly, obese and clinical populations (Dowzer, Reilly et al. 1998, Kaneda, Sato et al. 2008, Greene, Lambert et al. 2009). The insights gained will help the aquatic therapist and sport medicine practitioners to better utilize appropriate aquatic exercises for patients and athletes.

Biomechanics of walking in water

Muscle activity of walking in water

Recently, there has been significant interest in understanding muscle activity in varying aquatic environments (Chevutschi, Lensel et al. 2007, Pinto, Liedtke et al. 2010, Mercer, Applequist et al. 2014, Yaghoubi, Esfehani et al. 2015). The increase in published research is most likely due to the constant progression of water-proofing technology; laboratory equipment is now capable of being water resistant, thus allowing for real-time electromyographic (EMG) data collection under water. However, an individual's personal characteristics (age, gender, body composition, familiarity with aquatic exercise) and the testing environment (water temperature, immersive depth, exercise intensity) can be variable between studies and significantly impact the EMG recordings (Cuesta-Vargas and Cano-Herrera 2014) (Table 2.1). For example, elderly people display different levels of muscle activation (in particular increased amplitude of rectus femoris and biceps femoris and decreased amplitude of gastrocnemius) but maintain similar temporal patterns of muscle activity in comparison to young adults while walking in water (Barela, Stolf et al. 2006, Shono, Masumoto et al. 2007). Exercise intensity (such as walking speed or jet water propulsion) is an important contributing factor to muscle activity due to its specific relationship to the drag force, which increases proportional to the speed-squared. For example, when walking is performed at self-selected walking speed and similar levels of perceived exertion, there is approximately 30% less muscle activity (Masumoto, Takasugi et al. 2004, Masumoto, Takasugi et al. 2005, Tsourlou, Benik et al. 2006, Kaneda, Ohgi et al. 2013) and lower peak muscle amplitude (Pöyhönen, Kyröläinen et al. 2001, Barela, Stolf et al. 2006, Barela and Duarte 2008) in water compared to on land. However, when walking is performed at identical speeds, there is higher muscle activity in the aquatic environment in order to overcome the drag force (Pöyhönen, Kyröläinen et al. 2001, Miyoshi, Nakazawa et al. 2006). Similarly, when the speed of walking increases, there is a subsequent increase in muscle amplitude (Frangolias and Rhodes 1996, Silvers, Bressel et al. 2014). Drag force can also be increased with increased water flow, requiring subsequent increases in muscle amplitude (Silvers, Bressel et al. 2014). While drag force during horizontal movement in water increases agonist muscle activity, the buoyancy force of water facilitates the vertical movement and decreases the required work of the weight-bearing and antagonist muscles (Harrison, Hillman et al. 1992, Kaneda, Ohgi et al. 2013). The reduction of weight bearing coupled with the hydrostatic pressure on the neuromuscular system decreases the need for muscles to prepare for shock absorption at heel contact and reduced stimulation of gravity receptors within muscles in water in comparison to on land (Dietz, Horstmann et al. 1989, Pöyhönen and Avela 2002). Because of the variety of potential confounding variables (e.g. water depth, locomotion speed, using underwater treadmill or shallow water), contradictory results exist for muscle activity between similar experiments in water (Table 2.1).

Within the trunk region, findings are least consistent in the anterior musculature. For example, Kaneda et al. (2013, 2009) found lower activity for rectus abdominis and external obliques when walking in water than over ground at slow and all speeds, most likely due to less body twisting (Kaneda, Sato et al. 2009, Kaneda, Ohgi et al. 2013). Other studies have since contradicted Kaneda's findings and presented higher rectus abdominis activity at heel contact when walking at self-selected speeds in water compared to on land (Barela, Stolf et al. 2006, Barela and Duarte 2008). Because EMG findings can be strongly impacted by differences in methodology in particular EMG normalization and walking speed, the variability in the rectus abdominis activity could be a result of these differences (Figure 2.1). Conversely, the findings associated with erector spinae have consistently shown higher muscle activity at the end of stance to swing phase when walking at self-selected and fast speeds in the water versus on land (Barela, Stolf et al. 2006, Chevutschi, Lensel et al. 2007, Barela and Duarte 2008, Kaneda, Sato et al. 2009), as postural activity is necessary to overcome drag while the trunk is propelling forward (Kaneda, Sato et al. 2009, Kaneda, Ohgi et al. 2013). The effect of buoyancy increases upper body instability during walking in water, which explains the measured increases in erector spinae activation to maintain a neutrally positioned vertebral column. The elevated muscle activity is further increased when walking backward in shallow water, where water resistance would require more postural control to maintain an upright trunk (Masumoto, Takasugi et al. 2007).

There have been more consistent findings within the EMG recordings of thigh muscles that cause hip movement. Gluteal muscles (maximus and medius) and tensor fasciae latae elicited higher activity when walking shallow water (Kaneda, Sato et al. 2009, Kaneda, Ohgi et al. 2013). In addition, adductor longus EMG activity was also higher during the swing phase when walking in the water (Barela and Duarte 2008, Kaneda, Sato et al. 2009). Although frontal plane motion has not been frequently studied (Costa, Oliveira et al. 2011), the EMG findings suggest that increases in the muscle activity of hip abductors and adductors are necessary to provide pelvic stability that is lacking when the leg is not in contact with the ground. Rectus femoris activity was higher during the entire gait cycle when walking in water at self-selected (Chevutschi, Lensel et al. 2007), moderate and fast speed (Kaneda, Wakabayashi et al. 2008). Similarly, the biceps femoris and vastus lateralis showed higher activities during the stance phase of walking in the water at self-selected speeds (Barela, Stolf et al. 2006, Barela and Duarte 2008). Biceps femoris was also more responsive to changes in walking speed when walking took place in the water (Miyoshi, Shirota et al. 2004). During typical gait, the majority of lower limb work is completed at the hip and within the sagittal plane (Winter and Eng 1995). The addition of drag force occurring primarily in the sagittal plane exacerbates the demands on these muscle groups to propel the thigh forward. Although EMG studies on the thigh musculature are frequently consistent, studies by Masumoto et al. (Masumoto and Mercer 2008, Masumoto, Shono et al. 2008) found contradicting results; specifically there was lower muscle activity for rectus femoris, vastus medialis and biceps femoris during walking in water at all speeds . However, the differences in the findings are most likely due to different testing situations (e.g. walking on underwater treadmill versus shallow water) (Table 2.1).

Within the shank, muscle activity of gastrocnemius and soleus decreased during plantar flexion at self-selected and moderate speeds of walking in water compared to on land (Masumoto, Takasugi et al. 2004, Miyoshi, Nakazawa et al. 2006, Chevutschi, Lensel et al. 2007). However, this is in contrast to other studies, which found similar or higher activity in gastrocnemius when walking in the water at self-selected speed (Barela, Stolf et al. 2006, Kaneda, Wakabayashi et al. 2008). There is greater consensus within the research on the response of ankle plantar flexors muscles to walking speed and weight loading; specifically, muscle activity of the gastrocnemius and soleus increase more when walking in water than on land when there are increases in speed and mechanical load (Miyoshi, Satoh et al. 2000, Miyoshi, Nakazawa et al.

2006). There is a lack of consistent findings regarding tibialis anterior EMG activity. Some research indicated greater muscle activity for tibialis anterior in stance (Kaneda, Wakabayashi et al. 2008) and swing phases (Barela, Stolf et al. 2006) or through the entire gait cycle when walking in water to stabilize the ankle joint against water resistance (Kato, Sugagima et al. 2002, Barela and Duarte 2008). Conversely, lower tibialis anterior activity has been shown in aquatic gait (Masumoto, Takasugi et al. 2004), while others found no differences between the water and land environments (Miyoshi, Shirota et al. 2004, Kaneda, Wakabayashi et al. 2007). The inconsistencies could be due to high variability in individuals, instruction (Miyoshi, Nakazawa et al. 2006) and testing procedures when walking in water (Table 2.1).

Table 2.1. Overview studies of shallow water walking forward/backward and running

Study	Locomotion	Mean age (SD)	Participants (n [sex])	Condition	Device	Speed instructions (Average Speed in m/s)	Depth	Main Outcomes
Barela 2008	Walk Forward	70(6) & 29(6)	Healthy elderly (10 [6M, 4F]) and adults (10 [4M, 6F])	SW & DL	NS	Self-selected (SW=0.5, DL=1.3)	X	Significantly shorter stride length and slower walking speed in SW compared to DL Significantly lower GRF_Z and increased horizontal impulse in SW than DL Significantly lower knee ROM, and increased plantar-flexion and knee flexion at the initial contact during walking in SW compared to DL
Barela 2006	Walk Forward	29(6)	Healthy adults (10 [4M, 6F])	SW & DL	NS	Self-selected (SW=0.5, DL=1.4)	X	Significantly slower walking speed, increased stride duration, lower GRF_Z, always-positive GRF_x in SW than DL No significant differences in ankle, knee and hip ROM in SW compared to DL The EMG patterns appear more tonic (flatter) when walking in SW than DL
Barreto 2016	Walk Forward	21(3)	Healthy young adults (49 [18M, 31F])	SW & DL	NS	Self-selected (N/S)	X	The force platform is relaiable for assessing the vertical (Fz) and antreoposterior (Fx) components of GRF during walking in SW Only positive (propulsive) values were found for GRF_x during walking in SW in comparison to DL
Chevutschi 2007	Walk Forward	23(2)	Young adults (7 [7F])	SW & DL	NS	Self-selected (SW=0.8, DL=1.8)	H	Erector spinae and rectus femoris activities (integrated EMG) were significantly greater, while soleus activity was lower in SW Significantly reduced walking speed and stride length in SW compared DL
Degani 2007	Walk Forward	63	Healthy older adults (8 [N/S])	SW & DL	NS	Self-selected (N/S)	X	Not significant diferences in hip and knee ROM, but significantly lower ankle ROM and limb segmental velocity in SW than DL Increased knee flexion at the initial contact and reduced knee extension during gait cycle in SW compared to DL

Jung 2018	Walk Forward	37(11)	Healthy adults (15 [9M, 6F])	SW	TR	Self-selected (SW=0.5)	X, W, N	Significantly increased in SL and ankle ROM, while cadence and hip ROM decreased significantly as the water depth rose during walking in SW
Kaneda 2009	Walk Forward	25(2)	Healthy young adults (9 [9M])	SW & DL	NS	Self-selected (SW=0.3, DL=0.8), moderate (SW=0.5, DL=1.1) and fast (SW=0.6, DL=0.1.5)	X	Significantly greater %MVC of the erector spinae as the walking speed increased in SW
Kaneda 2008	Walk Forward	25(2)	Healthy young adults (9 [9M])	SW & DL	NS	Self-selected (SW=0.3, DL=0.8), moderate (SW=0.5, DL=1.1) and fast (SW=0.6, DL=0.1.5)	X	The %MVC of the rectus femoris was Significantly higher in SW than DL, while vastus lateralis was lower in SW than DL The lower limb joints were more flexed in SW than DL at the fast walking speed
Kaneda 2007	Walk Forward	25(2)	Healthy young adults (9 [9M])	SW & DL	NS	Self-selected (SW=0.3, DL=0.8), moderate (SW=0.5, DL=1.1) and fast (SW=0.6, DL=0.1.5)	X	The %MVC of the soleus and gastrocnemius were significantly greater in SW than DL at different walking speed
Kato 2002	Walk Forward	20(1)	Healthy active adults (6 [6M])	SW & DL	TR (FL)	Self-selected (SW & DL=0.4), moderate (SW & DL=0.6) and fast (SW & DL=0.8)	W	The relative integrated EMG of the tibilais anterior, gastrocnemius, vastus medialis and rectus femoris were significantly greater in SW than DL at fast walking speed
Masumoto 2008	Walk Forward	62(4)	Healthy older adults (9 [9F])	SW & DL	TR (FL)	Self-selected (SW=0.3, DL=0.6), moderate (SW=0.5, DL=1.0) and fast (SW=0.6, DL=0.1.3)	X	Significantly lower stride length and cadence in SW than DL Significantly lower %MVC of the rectus femoris, vastus meidalis, biceps femoris and gastrocnemius in SW than DL at the same speed
Masumoto 2007	Walk Forward	63(3) & 22(1)	Healthy older (6 [6F]) and young adults (6 [N/S])	SW	TR (FL)	Self-selected (SW=0.5), moderate (SW=0.6) and fast (SW=0.8)	X	Significantly greater %MVC of rectus femoris and biceps femoris of the older participants than younger adults, while the %MVC of the gastrocnmius was lower in older adults during SW Significantly greater cadence in older than younger adults in SW
Masumoto 2004	Walk Forward	23(1)	Healthy adults (6 [6M])	SW & DL	TR (FL)	Self-selected (SW=0.5, DL=1.0), moderate (SW=0.6, DL=1.3) and fast (SW=0.8, DL=0.1.6)	X	The %MVC of the gluteus medius, rectus femoris, vastus medialis, biceps femoris, tibialis anterior, gastrocnemius, rectus abdominis were significantly lower in SW than DL at similar intensity

Miyoshi 2006	Walk Forward	24(5)	Able-bodied adults (10 [6M,4F])	SW	NS	Self-selected (SW=0.5), moderate (SW=1.0) and fast (SW=1.5-2.0)	X	The averaged EMG activity of soleus was more dependednt on the load than walking speed, while the gastrocnemius activity was more dependent on the walking speed in SW
Miyoshi 2005	Walk Forward	22(3)	Healthy young adults (16 [12M, 4F])	SW & DL	NS	Self-selected (SW=0.4, DL=0.5), moderate (SW=0.5, DL=1.0) and fast (SW=0.9, DL=0.1.4)	X	The ankle plantar-flexion and knee extension moments significantly increased with additional weight load during SW walking The hip extension moment increased significantly as the walking speed rose in SW
Miyoshi 2004	Walk Forward	23(4)	Healthy young adults (15 [15M])	SW & DL	NS	Self-selected (SW=0.4, DL=0.5), moderate (SW=0.5, DL=1.0) and fast (SW=0.9, DL=0.1.4)	X	Only positive values were found for GRF_x, while GRF_y patterns were similar during walking in SW in comparison to DL The hip and ankle joint angular displacements were similar in SW and DL Significantly lower knee ROM and lower limb joint moments in SW than DL Significantly greater hip extensor muscle EMG activity as walking speed rose in SW
Miyoshi 2003	Walk Forward	23(2)	Healthy young adults (8 [8M])	SW & DL	NS	Self-selected (N/S)	X	Similar lower limb joints ROM between SW and DL during stance Significantly lower joint moments at lower limb joints in SW walking compared to DL Only hip extension joint moment at the stance phase during walking in SW than DL
Miyoshi 2000	Walk Forward	23(3)	Healthy young adults (8 [8M])	SW	NS	Self-selected (N/S)	X	Significantly greater soleus and gastrocnemius EMG activity levels as the walking speed increased in SW.
Orselli 2011	Walk Forward	24(3)	Healthy young adults (10 [4M, 6F])	SW & DL	NS	Self-selected (N/S)	X	Significantly longer stride duration in SW than DL, while stride length was similar Significantly lower angular velocity, moment, power, and compressive and shear forces in lower limb joints during walking in SW compared to DL Similar lower limb joints ROM in SW and DL
Roesler 2006	Walk Forward	23(5)	Healthy young adults	SW & DL	NS	Slow (SW=0.4, DL=0.4), and quick (SW=0.5, DL=0.7)	X & A	Significantly 20-40% of body weight lower GRF_z during walking in SW compared to DL Significantly 8-20% of body weight lower GRF_x during walking in SW compared to DL

			(60 [32M, 28F])					
Shono 2007	Walk Forward	61(4)	Healthy older adults (8 [8F])	SW & DL	TR (FL)	Slow (SW=0.3, DL=0.7), moderate (SW=0.5, DL=1.0) and fast (SW=0.7, DL=0.1.3)	X	Significantly lower knee ROM and angular velocity during walking in SW than DL Significantly greater integrated EMG of the tibialis anterior, vastus medialis and biceps femoris at similar walking speed in SW and DL, while gastrocnemius and rectus femoris activities were similar
Cadenas-Sánchez 2016	Walking Forward/Backward	22(1)	Healthy young adults (8 [4M, 4F])	SW	NS	Walking forward (slow=0.6, fast=0.9), Walking backward (slow=0.5, fast=0.8)	X	Significantly lower walking speed, stride length and stance phase in SW than DL, while the asymmetry of step increased in SW Increased lower limb joints flexion at stance phase during walking forward in SW than DL Increased hip and ankle flexion during walking backward in SW than DL
Cadenas-Sánchez 2015	Walking Forward/Backward	22(1)	Healthy young adults (8 [4M, 4F])	SW & DL	NS	Walking forward (SW=0.6, DL=0.9), Walking backward (SW=0.5, DL=0.6)	X	The step length asymmetry were significantly increased at faster speed in SW gait Significantly longer stance duration during walking forward than backward in SW Increased lower limb joints flexion during walking forward than backward in SW
Carneiro 2012	Walking Forward/Backward	24(3)	Able-bodied adults (22 [11M, 11F])	SW & DL	NS	Walking forward (SW=0.4, DL=1.2), Walking backward (SW=0.3, DL=0.7)	X	Significantly lower GRF_z during walking forward and backward in SW than DL Increased knee and hip flexion during walking forward and backward in SW compared to DL
Chevutschi 2009	Walking Forward/Backward	23(2)	University students (31 [16M, 15F])	SW & DL	NS	Spontaneous forward (SW=0.4, DL=1.3), Spontaneous backward (SW=0.4, DL=0.1.1), maximal forward (SW=0.6, DL=2.0) maximal backward (SW=0.5, DL=2.0)	X	The spontaneous and maximal speeds of walking forward and backward were significantly reduced in SW compared to DL for the female and male participants
Masumoto 2007	Walking Forward/Backward	23(1)	Healthy young adults (10 [10M])	SW	TR (FL)	Walking forward and backward at slow (SW=0.5), moderate (SW=0.7) and fast (SW=0.8)	X	Significantly greater %MVC of the paraspinal, vastus lateralis and tibialis anterior during walking backward than forward on SW treadmill

Masumoto 2005	Walk Backward	24(1)	Healthy adults (6 [6M])	SW & DL	TR (FL)	Walking backward at slow (SW=0.5, DL=1.0), moderate (SW=0.6, DL=1.3) and fast (SW=0.8, DL=1.6)	X	Significantly lower %MVC of the rectus abdominis, gluteus medius, rectus femoris, vastus medialis, biceps femoris, tibialis anterior and gastrocnemius during walking backward in SW compared to DL, with the exception of paraspinal muscles
Kato 2001	Walking/Running Forward	20(1)	Healthy active adults (6 [6M])	SW & DL	TR	Started with walking (SW & DL=0.5), gradually speed increased to running (SW & DL=3.3)	W	Significantly lower cadence and transition speed from walking (1.11 m/s) to running in SW compared to DL Significantly greater knee joint flexion as the treadmill speed increased in SW
Haupenthal 2013	Run Forward	23(3)	Recreational athletes (20 [10M, 10F])	SW	NS	Running slow (X & H=0.6), and fast (X=0.9, H=0.7) at two immersion levels	H & X	Significantly greater GRF_z in both genders as the speed of running increased in SW Significantly greater GRF_x in males participants than females only during fast running speed in SW Significant increase in loading rate as the water level reduced in SW running
Haupenthal 2010	Run Forward	23(3)	Healthy young adults (22 [11M, 11F])	SW	NS	Self-selected (X=0.7, H=0.9) at two immersion levels0	H & X	GRF_z corresponded to 0.80-0.98% of body weight at X & H immersion levels during running in SW respectively GRF_x corresponded to 0.26-0.31% of body weight at X & H immersion levels during running in SW respectively
Huth 2015	Run Forward	19(1)	Healthy young adults (15 [15F])	SW & DL	NS	Running at (SW=0.9, DL=5.6)	X	Significantly lower cadence, stride length and stance phase duration, while swing phase duration was longer during running in SW compared to DL
Macdermid 2015	Run Forward	30(13)	Competitive runners (6 [N/S])	SW & DL	TR	Running at (SW & DL=2.8)	H	Significantly lower cadence, while stride length was longer during treadmil runing in SW compared to DL Significantly reduced accelerations on impact at the heel contact in SW comapred to DL
Silvers 2014	Run Forward	26(5)	Recreational runners (12 [12M])	SW & DL	TR	Running at 3 levels (SW & DL=2.9), (SW & DL=3.3) and (SW & DL=3.8)	X	Significantly lower %MVC of the vastus medialis and gastrocnemius, while the %MVC of the rectus femoris, tibialis anterior and biceps femoris were increased during treadmil running in SW compared to DL

Condition abbreviations: SW shallow water, DL dry land; *Participants abbreviations:* M male, F female, N/S not specified; *Device abbreviations:* TR treadmill, FL flow-mill, NS normal surface; *Depth abbreviations:* N neck, X xiphiod, A axillary, H hip, W waist; *Main Outcomes:* EMG electromyography, GRF_z vertical ground reaction force, GRF_x anterior-posterior ground reaction force, GRF_y medial-lateral ground reaction force, ROM range of motion, %MVC maximal voluntary contraction.

Kinetics and kinematics of walking in water

There are conflicting reports of changes that occur to kinetic and kinematic gait parameters during walking in water in comparison to walking on land at different speeds. The variability in results is most likely a consequence of the differences in human propulsion in the two different environments (Table 2.1). The propulsion on land mainly depends on the ground reaction force while the propulsion associated with gait in shallow water will be influenced by drag and buoyancy forces, as well as ground reaction force. Biomechanical research has also been conducted into GRFs during aquatic activities compared to land-based equivalents and the reliability of the kinetic gait parameters with force plate has been confirmed recently in aquatic environment (Barreto, Dela Bela et al. 2016).

The shape and magnitude of the GRFs were affected along all three axes (vertical, anterior-posterior, medial-lateral) during walking in water (Miyoshi, Shirota et al. 2004, Roesler, Haupenthal et al. 2006, Barela and Duarte 2008). The GRF patterns appear more tonic (flatter) when walking in water with less variability throughout stance phase. Several studies have shown that the vertical GRF peaks (transient and active impact forces) are decreased during walking in water than on land due to buoyancy and possibly lower speed (Miyoshi, Shirota et al. 2005, Barela, Stolf et al. 2006, Carneiro, Michaelsen et al. 2012). In the anterior-posterior axis, GRF remains a propulsive force during the entire stance phase of walking in water, whereas walking on land exhibits both braking and propulsive GRFs (Miyoshi, Shirota et al. 2004, Barela, Stolf et al. 2006, Roesler, Haupenthal et al. 2006, Barela and Duarte 2008). This result suggests that when walking in water, the drag force against body (and specifically against the plantar surface of the foot) could assist as a braking force to decelerate the body before heel contact and thus does not require a braking GRF. The

GRF pattern demonstrates the necessity to generate a propulsive impulse that will accelerate body at push off and overcome the drag force in order to maintain the walking speed in water (Miyoshi, Shirota et al. 2004, Barela, Stolf et al. 2006, Barela and Duarte 2008). The GRF components can be modified by changing the submersion level in water, weight load (Miyoshi, Shirota et al. 2005) and walking speed (Miyoshi, Nakazawa et al. 2006, Roesler, Haupenthal et al. 2006). Previous research has shown vertical GRF to be negatively correlated with water level but positively correlated with walking speed during aquatic gait (Roesler, Haupenthal et al. 2006). Also, it has been shown that vertical GRF is more affected by the immersion level and weight load than walking speed (Miyoshi, Shirota et al. 2004) while anterior-posterior GRF was significantly increased with increased walking speed (Miyoshi, Shirota et al. 2004, Roesler, Haupenthal et al. 2006).

The supportive effects of buoyancy reduce mechanical loads on the body when walking in water, thus decreasing joint force and moments in ankle plantar flexion and knee extension at stance phase (Miyoshi, Shirota et al. 2005, Orselli and Duarte 2011). The magnitude of this reduction in ankle and knee joint moments during walking in water can be related to the level immersion or weight load and walking speed (Miyoshi, Shirota et al. 2005, Orselli and Duarte 2011). When walking in water, there was only one peak knee extensor moment in late stance instead of the two extensor peaks that appeared in early and late stance phase while walking on land. These findings suggest the knee joint played a minimal role in weight absorption at heel contact and complement the absence of a posterior GRF when walking in water (Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004, Miyoshi, Shirota et al. 2005). Previous studies have shown the dominant contribution of hip extensor moment throughout stance phase as a major source of propulsive force during walking in water

(Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004, Miyoshi, Shirota et al. 2005, Orselli and Duarte 2011). Thus, it is not surprising that Orselli et al. (2011) observed similar moment peaks at the hip joint between walking in water and on land (Orselli and Duarte 2011). The hip extensor moment was more sensitive to changes in walking speed than weight loads during walking in water. For example, hip extensor moment increased as the walking speed increased but there was no relation between hip extensor moment and weight loads (Miyoshi, Shirota et al. 2004, Miyoshi, Shirota et al. 2005). Because walking in water requires only one-third and one-half of the lower extremity compressive joint forces at chest and waist water level respectively needed when walking on land, inter-joint coordination (joint moment contribution to the function of support and propulsion at the stance phase) is also modified (Miyoshi, Shirota et al. 2005, Orselli and Duarte 2011). Thus, water exercises involving human locomotion incorporate large-muscle activities while the joint forces are minimised (Miyoshi, Shirota et al. 2005) and the immersion level and moving velocity will also affect the musculoskeletal loads (Orselli and Duarte 2011).

The kinematic differences that are evident between gaits in water and on land can be explained by the variations in the physical properties of both environments. For example, participants showed different body posture and segment range of motion in aquatic gait due to the water resistance (Barela, Stolf et al. 2006). Specifically, participants adopted a more neutral trunk position when walking in water compared to the forward leaning position that is adopted when walking on land (Barela, Stolf et al. 2006, Barela and Duarte 2008, Kaneda, Sato et al. 2009). A number of studies did not find significant differences in the range of motion of all joints at stance phase (Miyoshi, Shirota et al. 2003) or kinematic patterns of the lower extremities during walking in the water and land (Miyoshi, Shirota et al. 2004, Barela, Stolf et al. 2006).

There are conflicting reports on ankle joint kinematics, as most authors did not find significant differences in range of motion (Miyoshi, Shirota et al. 2004, Barela, Stolf et al. 2006) but others have reported both decreased (Degani and Danna-dos-Santos 2007) and increased ankle range of motion (Kaneda, Wakabayashi et al. 2008) during aquatic gait at self-selected speed and xiphoid-depth. Differences in kinematic patterns seem to be more consistent with increased plantar flexion at the end of stance phase and throughout swing phase during walking in water at the xiphoid process with self-selected speed (Barela, Stolf et al. 2006, Degani and Danna-dos-Santos 2007, Cadenas-Sanchez, Arellano et al. 2015). Some literature has also reported increased dorsiflexion at the middle of stance phase (Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004, Kaneda, Wakabayashi et al. 2008). These results would suggest that higher variability of ankle joint motion could be due to different walking technique, speed and the level of immersion, which also explains the variability between studies in dorsiflexion muscles (Table 2.1).

Knee kinematic patterns and range of motion were roughly similar during walking in water and land (Barela, Stolf et al. 2006, Degani and Danna-dos-Santos 2007, Barela and Duarte 2008, Cadenas-Sanchez, Arellano et al. 2015) except when aquatic walking speed has been increased to match the speed selected over ground; in this case, knee joint range of motion was significantly greater in water than land (Kato, Onishi et al. 2001) and at higher stride frequencies in water (Cadenas-Sánchez, Arellano et al. 2016). During stance phase, several studies reported that the knee joint was more flexed at the beginning of stance phase (Miyoshi, Shirota et al. 2004, Degani and Danna-dos-Santos 2007, Barela and Duarte 2008, Kaneda, Wakabayashi et al. 2008, Cadenas-Sanchez, Arellano et al. 2015) and throughout the stance phase during walking in water than land (Degani and Danna-dos-Santos 2007, Cadenas-Sanchez, Arellano et al. 2015, Cadenas-Sánchez, Arellano et al. 2016). In contrast, some other studies showed a more extended knee during stance phase when walking in water than land (Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004, Barela, Stolf et al. 2006) as an effect of buoyancy requiring less weight absorption, thus diminishing the required amount of knee joint range of motion and angular velocity (Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004). During swing phase, the knee joint was also more flexed during walking in water than land in order to reduce the water resistance by reducing the trajectory area of the shanks (Kato, Onishi et al. 2001, Degani and Danna-dos-Santos 2007, Shono, Masumoto et al. 2007).

Most literature showed that the hip joint was more flexed throughout (Miyoshi, Shirota et al. 2003, Miyoshi, Shirota et al. 2004) and at the beginning (Cadenas-Sanchez, Arellano et al. 2015) and end of stance phase (Barela and Duarte 2008, Kaneda, Wakabayashi et al. 2008) during walking in water than on land. It was also reported that hip joint and thigh range of motion were similar at self-selected speed in water and over ground (Barela, Stolf et al. 2006, Degani and Danna-dos-Santos 2007) with increased hip kinematics during fast walking speed in water (Miyoshi, Shirota et al. 2004, Kaneda, Sato et al. 2009). Trunk range of motion was also greater during walking in water than land at self-selected (Barela, Stolf et al. 2006) and fast speed (Kaneda, Sato et al. 2009). Additionally, medial-lateral and vertical pelvic displacements were increased during aquatic gait (Kaneda, Sato et al. 2009, Cadenas-Sanchez, Arellano et al. 2015). These results could be due to the different body posture adaptations (i.e. closer to neutral position) against water resistance and lifting force, which would be adapted to provide greater stability in water (Barela, Stolf et al. 2006, Cadenas-Sanchez, Arellano et al. 2015).

The physical properties of water reduce walking speed to about 50% of self-selected speed over ground (Barela and Duarte 2008, Chevutschi, Alberty et al. 2009, Kaneda, Sato et al. 2009, Cadenas-Sanchez, Arellano et al. 2015). Stride frequency and length decreased (Barela, Stolf et al. 2006, Masumoto, Shono et al. 2008, Orselli and Duarte 2011) while asymmetry between legs increased (Cadenas-Sanchez, Arellano et al. 2015, Cadenas-Sánchez, Arellano et al. 2016) when walking in water at self-selected speed. Temporally, longer stride duration (Barela, Stolf et al. 2006, Kaneda, Sato et al. 2009) and swing phase (Kato, Onishi et al. 2001, Kaneda, Wakabayashi et al. 2008), as well as shorter stance phase (Barela and Duarte 2008, Orselli and Duarte 2011, Cadenas-Sanchez, Arellano et al. 2015) were associated with walking in water. When the speed of walking in water is set to the same speed of walking on land, the spatiotemporal relationship is altered. While stride frequency remains lower in water (Kato, Onishi et al. 2001, Masumoto, Shono et al. 2007, Shono, Masumoto et al. 2007), stride length and duration are now longer in comparison to walking on land (Shono, Masumoto et al. 2007). Despite a slower self-selected speed, lower stride frequency and length, and longer stride duration during walking in water than land, it was recently suggested that the physical properties of water likely generated greater instability and resulted in less controlled movements and increased asymmetry (Cadenas-Sánchez, Arellano et al. 2016), as well as potential changes to proprioception (Pöyhönen and Avela 2002, Poyhonen, Sipila et al. 2002). Thus, it is important to consider the existing potential of instability, higher variability and less control of movement during aquatic locomotion for developing rehabilitation programs (Table 2.1 and Figure 2.1).

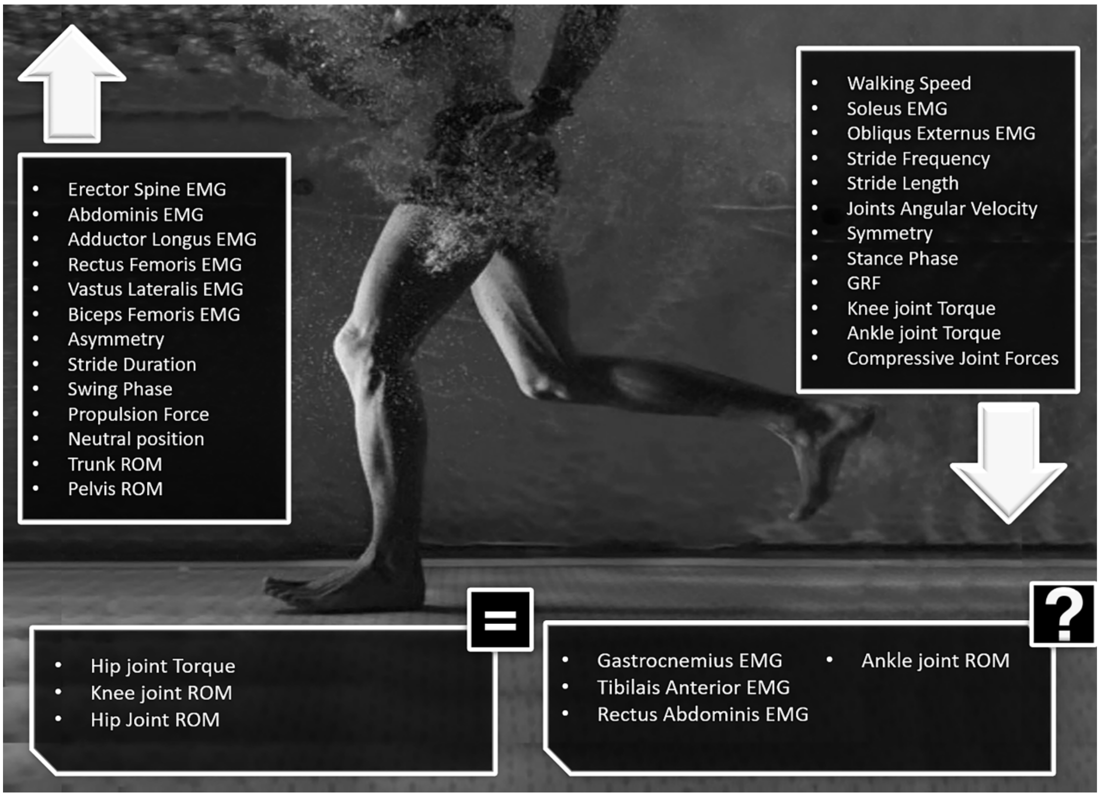

Figure 2.1: Biomechanical changes that occur when running underwater, compared to overground. Variables increased (up arrow), decreased (down arrow), remained unchanged (=), or had contradictory results (?) within the research.

Biomechanics of running in water

Running in shallow water can be an alternative or supplemental exercise for injury prevention, rehabilitation and sport specific training. Similar to walking in water, the resistive forces of water affect several temporal variables when running. Specifically, shallow water running showed significantly lower stride frequency, stride length, stride duration and speed (Kato, Onishi et al. 2001, Haupenthal, Ruschel et al. 2010, Huth, Schmidt et al. 2015) with the only similarities to running over ground occurring in stance and swing phase durations. Transition speed from walking to running also occurs at a slower speed (1.11 m.s-1) in shallow water (Kato, Onishi et al. 2001) than on land. When lower extremity joint kinematics were investigated, only knee joint range of motion was significantly greater during running in shallow water than land at matched treadmill speeds (Kato, Onishi et al. 2001). When lower extremity muscle activation was investigated during aquatic treadmill, the duration of rectus femoris, vastus lateralis, gastrocnemius, tibialis anterior and biceps femoris were increased compared to treadmill running at different speed (Silvers, Bressel et al. 2014).

The buoyancy forces associated with water significantly reduce the impact forces associated with running (Huth, Schmidt et al. 2015, Macdermid, Fink et al. 2015). In shallow water running, the values of GRFs are affected by changes in buoyancy (the level of immersion), density (related to body composition), and resistance (speed dependant) forces (Haupenthal, Fontana et al. 2013). For example, when running in shallow water at chest level, vertical GRF (0.5-0.9 BW) was lower than when the body was only immersed to hip level (1-1.2 BW) (Roesler, Haupenthal et al. 2006, Haupenthal, Fontana et al. 2013). The lack of vertical GRF requires a new source for generating a propulsive impulse. Thus, the anterior-posterior GRF (0.15-0.41 BW) during shallow water running was higher than stationary running in water and similar to land running (0.4-0.5 BW) (Roesler, Haupenthal et al. 2006, de Brito Fontana, Haupenthal et al. 2012, Haupenthal, Fontana et al. 2013). The increase in gait speed during running has a greater effect on water resistance than is seen during shallow water walking. In order to account for the large increases in water resistance, individuals modify their running technique by leaning the body forward and performing only the push off phase (70-80% of support phase). The gait adaptation is evident in the absence of a posterior, or braking, component of the anterior-posterior GRF curve (Dowzer, Reilly et al. 1998, Haupenthal, Ruschel et al. 2010). Increased running speed and the level of immersion also increases the vertical and anterior GRF and range of motion, which can generate an increase in plantar flexor muscle activity (Miyoshi, Shirota et al. 2003, Kaneda, Wakabayashi et al. 2008, Jung, Kim et al. 2018). Therefore, shallow water running, despite the lower values of vertical GRF and stride frequency and absence of negative impact peak, showed similar anterior GRF with running on land (Haupenthal, Ruschel et al. 2010, Haupenthal, Fontana et al. 2013).

Biomechanics of walking backward in water

Although backward walking is not commonly performed over ground, this gait activity is often practiced in the water since the water viscosity provides postural support improving the safety of this exercise compared to on land (Becker 2009, Carneiro, Michaelsen et al. 2012). Backward walking in water can be a beneficial mode of exercise for patients with patella-femoral pain syndrome or hamstring strains during rehabilitation protocols (Masumoto, Takasugi et al. 2005, Kachanathu, Hafez et al. 2013). There is more hip flexion, knee flexion, and ankle plantarflexion at initial contact when walking backward in the water compared to on land (Carneiro, Michaelsen et al. 2012, Cadenas-Sanchez, Arellano et al. 2015). There is also more ankle plantarflexion at toe-off when participants walked backward in water compared to walking backward on land. The increased plantarflexion could be a consequence of buoyancy force creating less heel contact with the floor during walking backward in water (Kodesh, Kafri et al. 2012, Cadenas-Sanchez, Arellano et al. 2015, Cadenas-Sánchez, Arellano et al. 2016). However, Carneiro et al. (2012) did not find significant differences for ankle angle during backward walking between environments (Carneiro, Michaelsen et al. 2012). When direction is considered, there is more knee flexion but less hip flexion when walking backward compared to forward in water (Carneiro, Michaelsen et al. 2012, Cadenas-Sanchez, Arellano et al. 2015).

At initial contact, the knee and hip were more flexed in water than land during walking backward and when comparing the directions of walking (forward versus backward) the knee was more extended while the hip was more flexed during walking forward than backward in water (Carneiro, Michaelsen et al. 2012, Cadenas-Sanchez, Arellano et al. 2015). At final stance, the knee was more extended and hip was more flexed during walking backward than forward in water. When comparing environments (water versus land), the hip was more flexed in water than on land (Cadenas-Sanchez, Arellano et al. 2015) while there were no significant differences observed in the knee angle during walking backward between environments (Carneiro, Michaelsen et al. 2012). The role of the knee is further diminished in backward walking, as compressive forces at the patellofemoral joint are reduced when compared to forward walking in water (Flynn and Soutas-Little 1993). Therefore, these results suggest that gait adaptations during walking backward in the water could be a mechanism to reduce projected area and avoid drag to achieve more efficient movements (Cadenas-

Sanchez, Arellano et al. 2015), as well as increase vertical movements to reduce lift forces, in order to achieve greater mechanical efficiency.

Similar to the temporal differences discussed in forward walking, support phase duration is reduced when walking backward in water compared to over ground (Barela and Duarte 2008, Cadenas-Sanchez, Arellano et al. 2015). The combination of buoyancy force being applied during double limb support and the increase in drag force during swing phase could result in a diminished double limb support phase and overall reduced support phase duration (Pöyhönen, Keskinen et al. 2000, Cadenas-Sanchez, Arellano et al. 2015). When considering direction, stride frequency was increased while stride length was decreased when walking backward in the water in comparison to walking forward in water; the differences can most likely be attributed to unfamiliarity of participants with the task (Masumoto, Hamada et al. 2009, Cadenas-Sanchez, Arellano et al. 2015). While there were no differences between the self-selected speeds of forward and backward walking in water, walking forward elicited higher self-selected speeds than walking backward when on land (Chevutschi, Alberty et al. 2009, Carneiro, Michaelsen et al. 2012, Cadenas-Sanchez, Arellano et al. 2015). The directional differences that are prevalent on land but absent in the water can be explained by the effect of hydrodynamic properties of water (drag force, buoyancy and lower instability) (Barela, Stolf et al. 2006, Masumoto, Hamada et al. 2009, Carneiro, Michaelsen et al. 2012, Cadenas-Sanchez, Arellano et al. 2015). It has been suggested that the absence of a difference between directions of walking in water could be due to water resistance (Carneiro, Michaelsen et al. 2012) and reduced maximal friction and GRFs applied to the floor surface in water (Cadenas-Sanchez, Arellano et al. 2015).

Biomechanics of non-gait exercises in water

Stationary exercises are performed with minimal displacement and frequently used in aerobic gymnastics classes and sport training sessions, as well as during rehabilitation and aquatic programs. Stationary exercises in water are one of the most common exercises performed in aquatic fitness classes with the intention of reducing impact on the lower limbs. These exercises focus on vertical propulsion of the body, which potentially minimises the risk of injuries and maximises musculoskeletal function in the aquatic environment.

During stationary running at maximal intensity, the muscle activity (vastus lateralis, biceps femoris, rectus femoris, semitendinosus and lateral gastrocnemius) was similar between on land and shallow water, while at submaximal intensities the selected muscles showed lower activity in water than land (Alberton, Cadore et al. 2011). For example, an increase in the submaximal cadences was not followed by a similar increase in the muscle activity in water, as was seen on land (Alberton, Pinto et al. 2015) and this could be due to the greater influence of velocity of movement on water resistance. Alberton et al. (2014) found lower activity in leg muscles with the exception of gastrocnemius during stationary running than other stationary exercises (i.e. frontal kick and cross country sliding skiing) in water but all of the stationary exercises presented similar increasing pattern in the muscle activity as the intensity of exercises increased (Alberton, Pinto et al. 2014). This result can be explained by the lower drag force (smaller projected area against the water flow) during stationary running than other exercises. In addition, the assistance of buoyancy caused less heel contact and increased hip range of motion during stationary running in shallow water compared to on land (Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2014). Greater muscle activity of gastrocnemius can also be explained by the important role of plantar flexor muscles in producing vertical propulsion especially during single stance exercises (i.e. stationary running and frontal kick) (Alberton, Pinto et al. 2014, Alberton, Pinto et al. 2015).

Stationary exercises including stationary running (running on the spot), frontal kick and cross country skiing, showed significantly lower vertical GRFs (48 to 68% BW) and loading rate in shallow water compared to land. The magnitude of vertical GRFs was also affected by the intensities, type of exercises and the level of immersion. For example, cross country skiing, abductor hop and jumping jack (0.5-0.6 BW) showed the lower vertical GRFs in comparison to frontal kick and stationary running (1.1 BW) in water. These differences may be due to the inclusion of a single stance impact in the frontal kick and stationary running activities that is absent in the other exercises (de Brito Fontana, Haupenthal et al. 2012, Alberton, Tartaruga et al. 2013, Alberton, Finatto et al. 2015). Vertical GRFs also increased as intensity increased during stationary exercises as a mechanism to overcome the greater drag force in water (Haupenthal, Ruschel et al. 2010, de Brito Fontana, Haupenthal et al. 2012, Alberton, Pinto et al. 2014, Alberton, Finatto et al. 2015). In addition, significantly lower GRF was observed with increased immersion level during stationary exercises in water (Alberton, Tartaruga et al. 2013). Furthermore, there was more variability in peak GRF in water compared to land; the variability was exacerbated at lower intensities. This could be explained by variations in the technique of execution between environments which is associated with different contact time and intensities (Alberton, Finatto et al. 2015). There was a reduction of the EMG activity in the aquatic environment during isolated knee flexion and extension exercises compared with on ground, which again could be attributed to physical properties of water. Therefore, it is believed that water resistance exercises can be performed early in rehabilitation, facilitating the prevention and treatment of musculoskeletal disorders (Santos, Mendes et al. 2015).

There have been several studies in the literature reporting the effectiveness of aquatic plyometric exercises (Martel, Harmer et al. 2005, Colado, Tella et al. 2009, Triplett, Colado et al. 2009). Buoyancy has been associated with reducing GRFs, stretch reflex and placing less stress on the lower extremity joints and musculature during landing, which potentially decreases the risk of injuries and muscle soreness (Thein and Brody 1998, Miller, Berry et al. 2002, Martel, Harmer et al. 2005, Triplett, Colado et al. 2009). While aquatic plyometric training reduces force transition through the body, there is a concurrent increase in resistance due to water drag forces (Kobak, Rebold et al. 2015). Several studies have reported that the aquatic-based plyometric movements improve jump performance (Robinson, Devor et al. 2004, Kobak, Rebold et al. 2015, Louder, Searle et al. 2016), mechanical power (Colado, Tella et al. 2009, Ploeg, Miller et al. 2010, Louder, Searle et al. 2016), height of vertical jumps (Martel, Harmer et al. 2005, Ploeg, Miller et al. 2010, Jurado-Lavanant, Fernández-García et al. in press), balance (Whitehill, Constantino et al. 2010), agility (Whitehill, Constantino et al. 2010), isokinetic strength and concentric peak moment (Stemm and Jacobson 2007, Triplett, Colado et al. 2009, Kobak, Rebold et al. 2015) while diminishing ground impact forces. Previous studies have also showed higher intensity (increase of 26% in concentric force peaks) and dynamic stability while the vertical components of GRF were reduced (33-59%) during contact phases (braking and propulsion phases of contact) of aquatic jumps in comparison to the land equivalent (Colado, Tella et al. 2009, Triplett, Colado et al. 2009, Colado, Garcia-Masso et al. 2010, Donoghue, Shimojo et al. 2011).

Temporal analysis of drop and countermovement jumps revealed longer durations for both flight and contact phases in water, which could affect the function of muscle stretch-shortening cycle in water (Ruschel, Dell Antonio et al. 2016). Conversely, Louder et al. (2016) found a shorter propulsive phase and non-linear relationship between take-off velocity and flight time during counter-movement jumps in water and at increasing immersion level than land (Louder, Searle et al. 2016). There are some reports that resistance aquatic devices effectively increase the workload while diminishing the impact force of jumping in water (Colado, Tella et al. 2009, Colado and Triplett 2009, Triplett, Colado et al. 2009, Colado, Borreani et al. 2013), thus providing a low-impact alternative or supplemental mode of exercise for land based plyometric training. Furthermore, aquatic-based plyometric movements could be an effective tool in physical therapy and rehabilitation programs as they improve performance with less risk of injuries and joint stress (Miller, Berry et al. 2002, Martel, Harmer et al. 2005). The effect of aquatic-based training in reducing body fat for individuals with a large body mass was previously shown (Colado, Tella et al. 2009) to be due to improved muscle force production in a more efficient and less injurious way than land based plyometric training.

Conclusions

The purpose of this paper was to provide a descriptive literature review of the biomechanical parameters of shallow water exercise in comparison to land-based equivalents. The physical properties of water make movements slower with reduced loading at impact while the joint range of motion can be increased due to water-assisted body weight support. Previous research has recommended that exercise in water could be a safer environment without fear of falling and injury; however, recent studies revealed more instability, asymmetry and variability during aquatic exercises.

The variability is affected by changes in buoyancy due to immersion level and resistance forces (e.g. intensity, speed) and can affect both research and clinical applications. Despite the large number of research studies published investigating the biomechanics of aquatic activities, there is a lack of consensus in the results. The inconsistency in the findings is directly related to the lack of standardized protocols in aquatic research (Miyoshi, Shirota et al. 2004). Thus, devising standardised protocols would increase the reliability and quality of future aquatic research.

Previous aquatic biomechanical research is limited to aquatic gait in adults and elderly people. The lack of aquatic research in children is of great concern, as aquatic sports provide a low-weight bearing activity that diminishes the likelihood of injuries in children and provides a solid foundation for physically activity throughout the lifespan. Biomechanical research with different types of aquatic devices (such as aqua bikes or elastic tether) for conditioning and rehabilitation purposes is also required so that practitioners can better prescribe aquatic exercise based on the appropriate intensity, water depth, technique and mode.

Part 3: Why is aquatic exercise good for obese children?

Exercise is efficacious for tackling obesity in children and adolescents (Kelley and Kelley 2013). In particular, aerobic exercise training is known to counteract obesity by promoting reductions in body weight (Gappmaier, Lake et al. 2006). Despite the proven health benefits of aerobic exercise training, traditional modes, such as locomotion and other over ground activities, require supporting body weight at each step. In particular, physical activities such as jogging, aerobic dance, and cross training are considered high-impact and have the potential to increase wear and tear on joints. Children who have an excess of body weight sustain additional loads on their lower extremities, which can lead to various musculoskeletal discomfort and/or pain. Pain and injury from repetitive high-impact exercises are often cited as reasons for discontinuing exercise training (Belisle, Roskies et al. 1987). Thus, alternative non-weight bearing locomotor activities (e.g. aquatic exercise) would reduce difficulties due to excess body mass. The buoyant effect of water reduces the weight-bearing stress on muscles and mechanical loads on joints (Barela, Stolf et al. 2006), thus making aquatic activity effective in improving aerobic fitness and body composition in overweight adults and children (Gappmaier, Lake et al. 2006, Lee and Oh 2014).

The effectiveness of aquatic activities lies within the unique qualities of the water environment, including buoyancy and resistance. The buoyant effect of water reduces gravitational acceleration associated with an increased density (compared with air) (Becker 2009). As a result, the movements become rather slow in the water environment with lower weight-bearing stress on muscles and joints (Takahashi, Ishihara et al. 2006), making aquatic exercises more effective for children with all levels of physical fitness (Frangolias and Rhodes 1996). The resistance of water is in proportion to the square of the velocity of the moving object, thus increased resistance in the aquatic environment can be achieved by raising the velocity of movement of the exercises (Edlich, Towler et al. 1987). Bartles, Lund et al (2007) have also found that aquatic exercise has some beneficial effects for osteoarthritis patients (Bartels, Lund et al. 2007). Furthermore, the hydrostatic effect may also relieve pain by reducing peripheral edema (Gabrielsen, Videbaek et al. 2000) and by damping sympathetic nervous system activity (Fam 1991). Thus, aquatic exercise can be a valid alternative to more traditional land-based exercise, especially in children with severe lower extremity alignment issues and/or significant joint instability (McMillan, Auman et al. 2009, McMillan, Pulver et al. 2010).

Chapter 3: Two-dimensional comparison of GoPro camera video analysis system with inertial motion sensors for underwater and land applications

Abstract

The two-dimensional comparison of a sports camera (GoPro) based motion capture system is reported for simple motion underwater and overground. Reflective markers were placed in a two-dimension position on the center of inertial motion sensors for each segment of a leg model to track simulated hip flexion-extension in air and underwater conditions. Also, the angular velocity of a clock's second hand was measured underwater and overground via a reflective marker attached to its distal end. Mean angular velocities measured by reflective markers were not significantly different to measurements received by inertial motion sensors in the leg model. Likewise, angular velocity measured by reflective markers was not significantly different (p<.001) to the expected velocity of the clock's second hand. There was a very high correlation (R>.980) between the tracked markers and the inertial sensor attached to the leg model. These results confirm that the sports camera-based motion capture system is sufficiently accurate for measuring simple motion in both underwater and air conditions.

Introduction

Sports such as swimming, diving and water polo, have aspects of motion both in and outside of the water. Thus, the ability to analyse human movement in these two different environments is an essential tool for biomechanical analysis for sport and rehabilitation applications. Historically, video analysis has been used in aquatic research. Specifically, previous research regarding kinematic effects of aquatic exercises has used video-based camera setups for two and three-dimensional analysis (Puel, Morlier et al. 2012, Alberton, Pinto et al. 2015, Garcia-Ramos, Feriche et al. 2015, Bernardina, Cerveri et al. 2016, Cadenas-Sánchez, Arellano et al. 2016). However, there are few high-speed motion capture systems available that can be deployed for underwater measurement. And those that are available are expensive, complicated, and limited to laboratory settings (Weinhandl, Armstrong et al. 2010).

The use of inertial motion sensors has become popular among researchers when tracking human movement outside of the laboratory, and specifically in aquatic environments. The sensors potentially provide a wider field of acquisition, faster set-up, and a simple calibration protocol, with reliable accuracy, reported when analysing joint kinematics in the sagittal plane (Brodie, Walmsley et al. 2008, Brodie, Walmsley et al. 2008, Fantozzi, Giovanardi et al. 2015). However, more errors exist when calculating joint position and displacement from inertial motion sensor data compared to video data (McGinley, Baker et al. 2009). The development of high-tech sports video cameras could provide a simpler, less expensive alternative to the laboratory-based motion capture systems. Thus, the purpose of this study was to compare the angular kinematics collected using a recreational, low-cost sports video camera (GoPro, Inc) and commercial inertial motion sensors, in both land and water environments. While the GoPro was also assessed using a known motion, (i.e. movement of a clock's second hand), the primary comparisons between motion capture and inertial motion sensors occurred within the assessment of a more ecologically valid leg model driven at known speeds. We hypothesised that the angular kinematics collected using the GoPro camera video analysis system would have a high level of agreement (R>.9) with angular velocity of inertial motion sensors, and no significant differences (p>.05) between measured and expected angular velocities.

Methods

A single GoPro (Hero 4 Black) camera enclosed in a modified waterproof housing was used (Table 3.1). The basic camera set-up and the distance (3 m) from the camera to the objects, were consistent during the study. The camera was mounted with a tube mount on a rigid bar (Figure 3.1A). The GoPro camera Wi-Fi signal was boosted with a passively coupled range extender (TP-Link AC750), permitting a cable to be extended out of the water to a small aerial. This set-up enabled wireless control and monitoring of the camera from a nearby laptop computer using the GoPro camera control software (version 2.0.5 for windows). The GoPro camera was positioned in a sagittal view, perpendicular to the physical model, focusing on the centre of the acquisition volume. After acquisition, the videos were converted to AVI movie format in the GoPro studio software.

A waterproof chessboard was used to perform 2D plate calibration in dry and aquatic conditions (Figure 3.1B) (Zhang 2000). The chessboard was moved in front of the camera at different positions and orientations spanning the entire working volume. The camera 'Calibration Toolbox' for Matlab was used for parameter estimation (www.vision.caltech.edu/bouguetj/calib_doc/index.html). Extrinsic calibration was performed by means of a four control-point calibration (1m×1m) for the 2D plane. Nonlinear DLT (direct linear transformation) was used to refine parameters with high accuracy in both conditions (Silvatti, Salve Dias et al. 2012, Silvatti, Cerveri et al. 2013).

Table 3.1. GoPro camera settings.

Model	GoPro Hero 4 Black
Frequency	240 Hz
Resolution	1280x720 pixels
View angle	127°
Protune	On
ISO Limit	1600
Color	GoPro
Sharpness	High
White balance	Auto
Spot meter	Off

A physical cylindrical segment model (length: 0.9 m, projected frontal area: 0.13 m^2) was developed to simulate human leg movement pivoting in the sagittal plane, that is, hip extension and flexion (Figure 3.1D). Motion capture data from a pilot study of 10 children (5 males, 5 females; 10-13 years old) was used to determine the range of motion used in the underwater model. The mean range of motion of hip flexion and extension was derived from both underwater and over ground trials (Vicon Motus). The model was attached to a turning force with a fixture arm to both sides of the pool. The direction of movement of the model and its range of motion (about 150°) simulated hip flexion-extension of a stiffened leg during the frontal kick movement in children. Previous research in stationary exercises has found that angular velocity is three times faster in air conditions compared to underwater environments (Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2015). Thus, the angular velocities of the power-head (Biodex isokinetic dynamometer) used to drive the model were set to 30 deg/s (19 cycles) and 10 deg/s (10 cycles) for air and underwater conditions respectively. The model and camera were set up in a 3 x 1.5 x 2 m pool.

Kinematic data measured from analysis of the GoPro video were compared to data from three tri-axial inertial motion units, with a reported accuracy 0.0012 ms^2 Hz^{-1} (accelerometers + gyroscopes + magnetometers; Emerald, APDM, Portland, OR, USA). The inertial motion sensors were calibrated at the beginning of the acquisition session and waterproofed with adhesive tape (3M, USA). The sensors were fixed along the leg segment model and reflective markers were attached exactly on the center of the motion sensors for each segment of the physical model, in order to track the movement in the sagittal plane. The markers were tracked with motion capture software (Vicon Motus) and synchronised inertial motion sensors data were collected with the Motion Studio Software (APDM, USA). The camera and inertial motion sensors were synchronised through a light trigger (LED system) visible in video camera field of view and a trigger to switch on the sensors respectively. The reflective markers were digitized manually in Vicon Motus. In order to improve reliability of outcome variables, the trials were digitised twice by the researcher and twice by an investigator with experience in digitisation. The inter-and intra-observer agreements were calculated using intra-class correlation coefficients (ICC). The intra-observer ICC ranged from 0.96 to 0.99 and inter-observer ICC ranged from 0.97 to 0.99. Overall, these results show a high reliability of the digitisation process (Cadenas-Sanchez, Arellano et al. 2015). All inertial motion sensor data was sampled at 128 Hz, logged to a standard personal computer, converted to a hierarchal data format file (.h5), and processed using Matlab R2015. Root mean square (RMS) of the angular velocity (acquired from gyroscope data) was measured along the physical model over the time series. Finally, an 8 Hz 2nd order Butterworth low-pass filter was applied to all angular velocities measured by inertial sensors and video data.

An analogue clock with a smooth sweep clock's second hand (100 twitches per second, 31 cm diameter, Time Company) was used as part of the camera validation (Figure 3.1C). Because the motion of the clock's second hand is a known quantity, the results of the digitised image can be compared to the theoretically correct values. The attachment of an IMU would add substantial weight to the clock's second hand, and would most likely change the known movement; thus, the only system assessed by the analogue clock was motion capture. The angular velocity of the clock's second hand was measured from the GoPro video during five cycles of 60 seconds in water and dry-land conditions. A reflective marker was attached to the tail of the clock's second hand to track the movement. The markers on the second hand were tracked with motion capture software (Vicon Motus).

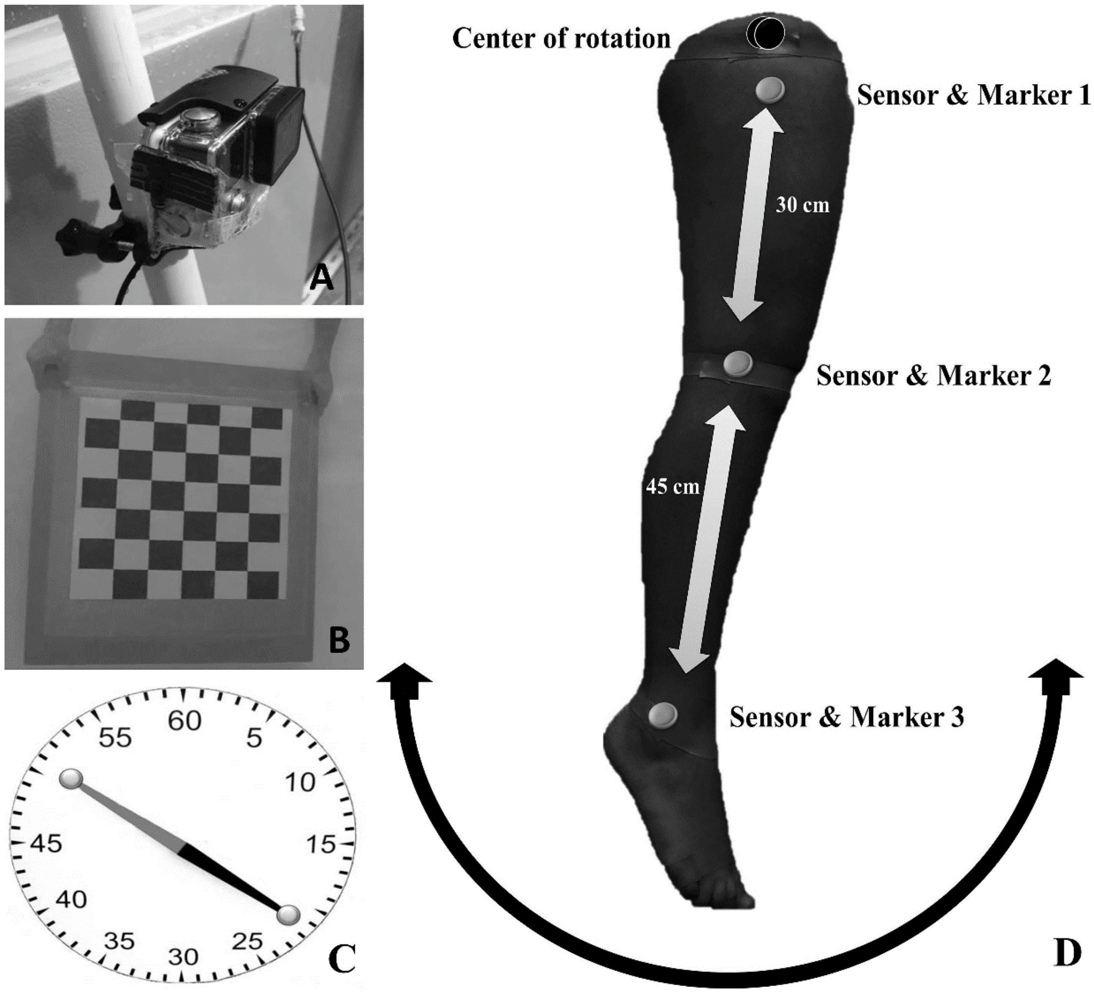

Figure 3.1: (A) Camera setup. (B) Chessboard used for 2D plate calibration. (C) An analogue clock with reflective markers attached to the tail of the clock's second hand. (D) Fixed markers and sensors along the leg model.

Statistical analysis

Data processing and analysis was performed using Matlab R2015b (Mathworks Inc., Natick, MA, USA). Pearson's cross-correlation analysis was used to assess the absolute agreement between the angular velocities measured by the inertial sensors and the markers placed on the segmental leg model. One sided t-tests were used to compare measured the velocities from the inertial sensors and the velocities derived from tracking the markers, in air and water, to the expected angular velocity of the leg segment model. One-sided t-tests were also used to compare the angular velocity derived from the tracked markers in air and water to the expected angular velocity of the clock hand. Statistical significance was set at $p<.05$.

Results

The nonlinear DLT showed a static mean re-projection error of 0.21 ± 0.04 and 0.28 ± 0.05 (mm/pixel) for air and underwater conditions respectively.

Figure 3.2 shows a comparison between the measured angular velocity on the leg model from one trial of the inertial motion sensors and the optically tracked markers for both the air and underwater conditions. The result of cross correlation analysis between the measured angular velocity from the three inertial motion sensors and the derived angular velocity from optically tracked markers, showed there is a high level of agreement ($R>.980$; $p<.001$) between each pair of measurements in all cases (Table 3.2). The mean angular velocity measured along the leg model was not significantly different for marker ($p<.852$) or sensor ($p<.578$) when compared to the expected velocity of 30 deg/s; likewise, marker ($p<.927$) and sensor ($p<.673$) measurements were similar to expected 10 deg/s underwater velocity (Table 3.2).

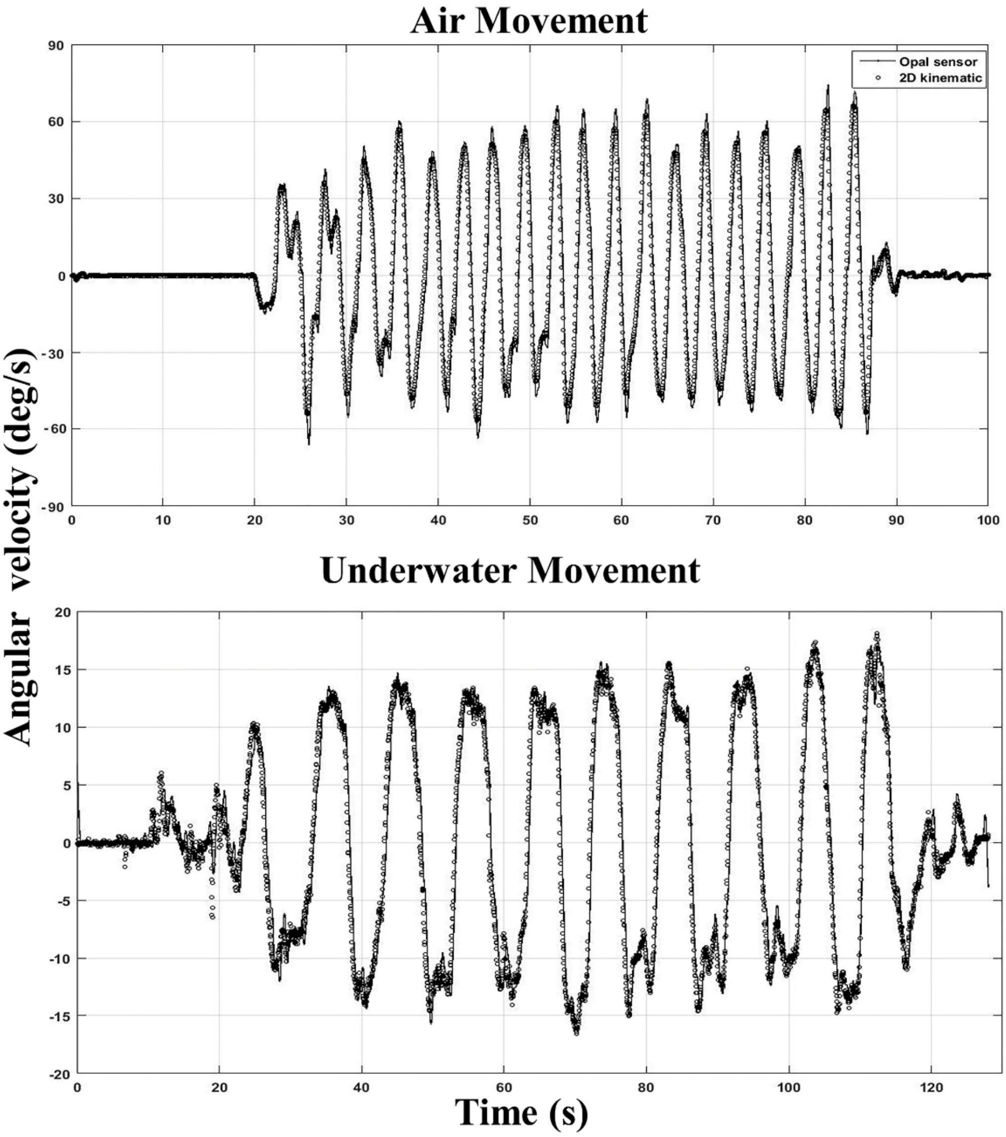

Figure 3.2: Measured angular velocity on the leg model of the inertial motion sensor (continued-line) and markers (dashed-line) in air and underwater conditions.

The expected mean angular velocity of the optically tracked marker located on the distal end of the wall clock's second hand (6 deg/s) was not significantly different to the values measured in air ($p<.626$) and underwater ($p<.157$) (Table 3.2). The standard deviation was higher for the optically tracked marker attached to the wall clock's second hand than the markers attached to the limb segment model, in air and underwater (Table 3.2 and Figure 3.3).

Table 3.2. Mean (SD) angular velocity for markers and inertial motion sensors and clock's second hand, and cross-correlation analysis between angular velocity of sensors and markers in air and underwater conditions.

Condition	Angular velocity (deg/s)			Cross-correlation		
	Clock's second hand	Model - Marker	Model - Sensor	Sensor 1 & Marker 1	Sensor 2 & Marker 2	Sensor 3 & Marker 3
Air	5.99 ± 0.23	29.90 ± 1.79	30.19 ± 1.05	0.992*	0.985*	0.980*
Underwater	6.09 ± 0.44	9.97 ± 0.73	10.09 ± 0.68	0.996*	0.994*	0.991*

Note. * $p<.001$, significant differences between measured and expected angular velocities.

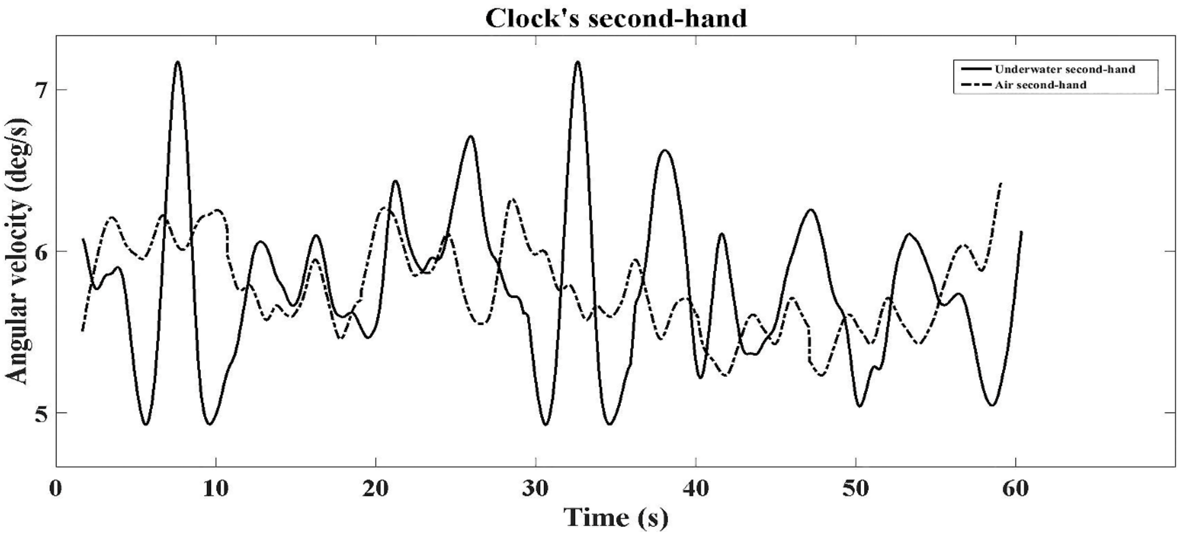

Figure 3.3: Measured angular velocity on the clock's second hand in air (dashed-line) and underwater (continued-line).

Discussion and implications

This study compared the angular kinematics derived from tracked optical markers using video recorded by a GoPro Hero 4 Black camera and inertial motion sensors, in underwater and air conditions. The results of nonlinear DLT showed that the mean re-projection error is within an acceptable range for the pixel accuracy in both conditions based on previous research reports (Silvatti, Salve Dias et al. 2012, Balletti, Guerra et al. 2014, Bernardina, Cerveri et al. 2016, Bernardina, Cerveri et al. 2017). In addition, the expected mean angular velocity of the wall clock's second hand and leg model for marker derived data and inertial sensor data, were not significantly different from the measured and expected values in both conditions. Therefore, the results of this study indicate that the GoPro camera with manual digitization provides an inexpensive system to measure angular movement derived from tracked markers in air and underwater conditions with an adequate sampling rate. Additionally, we found the use of black markers with a white colored background provided a better background-foreground contrast for tracking the 2D markers manually with higher intra-class CC than only white or black markers in the underwater and air. This is consistent with previous findings (Bernardina, Cerveri et al. 2016, Bernardina, Cerveri et al. 2017). The system provided accurate kinematic data when compared to the results of inertial motion sensors and also for the known motion of a second hand of a clock and the driven physical model. Although the kinematic data measured along the leg model were not significantly different for markers or sensors when compared to the expected velocities in both conditions, the p values for sensors were smaller than markers. The smaller p values for sensors could be due to measurement errors exist in inertial motion sensors in comparison to tracked optical markers (Cutti, Ferrari et al. 2010). Greater variability in the angular velocity of the wall clock can be explained through the differences in the length of the clock's second hand compared to the length of the limb segment. Specifically, small errors in the tracking of the marker displacement on the clock hand would correspond to a larger angular error with the shorter segment length. Also, greater variability in underwater condition could be due to water transparency, the difference between water and air refractive index, water disturbance and illumination of the pool, which can lead to deterioration of marker detection quality on the images (Bernardina, Cerveri et al. 2016).

There were some limitations to this study. 3D measurements between inertial sensors and GoPro camera could provide more comprehensive comparison in underwater and air conditions. In addition, the noise level can be sometimes higher for inertial sensor than motion capture system. While, despite of the higher acquisition frequency for GoPro camera (240 Hz), the image resolution was low with wide field of view, which can affect the accuracy of the tracking markers in both conditions.

Conclusion

The findings suggest that the inexpensive and easily constructed sport camera system can provide adequate video capture for analysis of movement in air and underwater conditions. We demonstrated that the GoPro camera derived angular velocity measurements underwater and air are accurate when compared to data from inertial sensors and known motion of the clock's second hand and a driven limb segment model. Therefore, it can be used for research and training purposes.

Chapter 4: Stationary exercises in overweight and normal-weight children

Abstract

Purpose: This study examined differences in lower extremity kinematics and muscle activation patterns between normal-weight (NW) and overweight (OW) children during stationary exercises (running in place, frontal kick, butt kick) at submaximal intensity.

Methods: Healthy children, aged 10-13 years were stratified into OW (N=10; BF%: 34.97±8.60) and NW (N=15; BF%: 18.33±4.87). Electromyography was recorded for rectus femoris, vastus lateralis, biceps femoris, gastrocnemius and tibialis anterior. Additionally, the ratings of perceived exertion (RPE) and range of motion (ROM) of hip, knee and ankle joints were collected during stationary exercises. Repeated measures ANOVA compared muscle activation, ROM and RPE between groups and exercises. Friedman test examined sequencing of muscles recruitment.

Results: Compared to NW, OW experienced significantly greater RPE (13.66±0.77 vs 11.68±0.74; $p<0.001$) and EMG amplitude in all muscles apart from vastus lateralis during stationary exercises. In addition, NW children used more consistent muscular recruitment patterns in comparison to OW children. The ROM was similar between groups at all joints.

Conclusion: OW children may adopt a more active neuromuscular strategy in order to provide greater stability and propulsion during stationary exercises. Stationary exercise can be prescribed to strengthen lower extremity muscles in overweight children, but mode and intensity must be considered.

Keywords: biomechanics, electromyography, stationary running, frontal kick, butt kick

Introduction

The incidence of paediatric obesity has increased rapidly in recent decades, with an estimated 200 million children (school-aged) world-wide categorised as overweight or obese and a further 92 million children at risk of becoming overweight (de Onis, Blossner et al. 2010, Wang and Lim 2012). Physical activity is a key component in the prevention and management of obesity in children (Hills, Andersen et al. 2011). Previous research has shown that overweight children walk with a stiffer, more upright posture as a result of insufficient sagittal plane range of motion, specifically at the hip and knee (Shultz, D'Hondt et al. 2014). Overweight children respond differently when moving extra body mass during locomotion (Hung, Gill et al. 2013) and exhibit increased lower extremity joint moments (Gushue, Houck et al. 2005) and power (Shultz, Hills et al. 2010), ground reaction forces (Gill and Hung 2014) and muscle activation during gait (Blakemore, Fink et al. 2013). In addition, it has been suggested that changes in the locomotor strategy by overweight children reduce mechanical efficiency and produce greater demands on musculature (McMillan, Auman et al. 2009, Gill and Hung 2012), which decreases performance in fitness skills requiring whole body movement with horizontal displacement, such as in walking and running (Gushue, Houck et al. 2005, Shultz, Sitler et al. 2009). While previous research strongly suggests that overweight children adapt their gait to accommodate for moving excess mass horizontally (McGraw, McClenaghan et al. 2000), very little research have investigated the biomechanical characteristics of simple exercises that focus on vertical displacement. The more vertically oriented exercises (i.e. stationary exercise) could benefit this sub-population as they seem to diminish metabolic cost and neuromuscular activity in comparison to modalities that involve horizontal displacement of body (i.e. walking and running) (Kelly, Roskin et al. 2000, Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2015).

Stationary exercise is one of the most convenient and frequently prescribed exercises in circumstances where a sufficiently large area for running is not available or the necessary equipment has not been resourced. Stationary exercises can also be recommended for health promotion and rehabilitation as they incorporate basic movement patterns and have benefits to musculoskeletal and cardiovascular systems (Haddock, Siegel et al. 2009, Alberton, Cadore et al. 2011). Previous research indicated that stationary running at submaximal intensity has less loading rate (abrupt force) in comparison to running (at less than 5 m/s) during foot contact (Keller, Weisberger et al. 1996, Fontana, Ruschel et al. 2015). Because stationary exercise mainly involves vertical displacement of the centre of mass, adults who perform these activities experience very low anterior-posterior and medial-lateral forces relative to the vertical ground reaction force (GRF), particularly in comparison to running (Keller, Weisberger et al. 1996, Fontana, Haupenthal et al. 2012, Fontana, Ruschel et al. 2015, Alberton, Pinto et al. 2017). Thus, stationary exercise at submaximal intensities may be an alternative for people who need to perform exercises that diminish shear stress on lower extremity joints, such as individuals who have a history of overweight, osteoarticular diseases or reconstruction surgery (Shelbourne and Nitz 1990, Jones, Meredith-Jones et al. 2009, Fontana, Ruschel et al. 2015). Based on this research in adults, we believe that stationary exercise could also be a safe and effective exercise option for weight loss and general improvement of physical conditioning and coordination in overweight children. However, previous research has not investigated this modality in children.

Several studies have investigated the biomechanics of stationary exercises in adults, but have focused their comparison on environmental conditions (usually aquatic versus dry land) and intensity of one activity (typically stationary running) (Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2015). Even the recent investigations into multiple stationary exercises (stationary running, frontal kick and cross-country skiing) primarily focus on the biomechanical differences between aquatic and dry land environments (Alberton, Antunes et al. 2013). Despite the popularity of stationary exercise as a fundamental component of rehabilitation and training protocols (Fontana, Haupenthal et al. 2012, Fontana, Ruschel et al. 2015, Alberton, Pinto et al. 2017), there are no studies, to our knowledge, that focus on the biomechanical variables of diverse stationary exercises in children. Without fully understanding the biomechanical differences that occur between stationary exercises in children, these activities cannot be accurately integrated into existing exercise prescription, particularly for children carrying excess mass. Therefore, the purpose of this study was to examine the differences in lower extremity kinematics and muscle activation patterns in normal-weight (NW) and overweight (OW) children during stationary exercises (stationary running (SR), frontal kick (FK), butt kick (BK)) at submaximal intensity on dry land. These stationary exercises are widely used in fitness classes because of the relative simplicity of the movements (Alberton, Cadore et al. 2011, Raffaelli, Galvani et al. 2012, Kruel, Beilke et al. 2013), which could be performed by overweight children. Likewise, the exercises mainly involve sagittal plane displacement of the lower extremity with increased neuromuscular activation of the hip, knee and ankle flexor and extensor muscles (Fontana, Haupenthal et al. 2012, Alberton, Tartaruga et al. 2013, Fontana, Ruschel et al. 2015) that will improve muscular strength and endurance. Additionally, information will be gathered on ratings of perceived exertion between exercises, in order to better inform physiological efficacy of exercise prescription. Due to both deconditioning and the higher mechanical demand associated with moving excess mass in OW children, it was hypothesized that muscle activation patterns will be different between OW and NW children at similar heart rate (HR) and range of motion (ROM) for all stationary exercises.

Methods

Participants

Twenty-five children, aged 10-13 years (12 males, 13 females) were recruited through local schools to participate in the study. Participants were classified as overweight (N=10; age: 12.10 ± 1.22; mass: 73.93 ± 17.11kg; height: 1.59 ± 0.11m; body fat percentage: 34.97±8.60, maximum heart rate: 198.10 ± 2.49bpm) and normal-weight (N=15; age: 12.23 ± 1.08; mass: 43.16 ± 7.54kg; height: 1.57 ± 0.11m; body fat percentage: 18.33 ± 4.87, maximum heart rate: 202.33 ± 3.30bpm). Participants were excluded from the study if they had a previous orthopaedic surgery or lower limb injury within 6 months, skin allergy or skin condition that would be affected by the application of self-adhesive electrodes and markers, moderate to severe asthma that might be affected by physical activity, or any other condition that affected locomotion. Prior to participation, the study and risks were explained to the parents/guardians and children who then signed the consent and assent forms, respectively. The study was approved by the Massey University Human Ethics Committee (Southern A Application 14/08).

Height and weight were measured using a stadiometer (Milton Ltd, Zhejiang, China) and electronic scale (model EA150FEG-1, Sartorius AG, Germany), respectively, while participants wore their swimsuit. Body mass index (BMI; kg/m^2) was then calculated. Bio-electrical impedance analysis (BIA; Bodystat 1500, Bodystat Ltd, Douglas, British Isles) measured body fat percentage (BF%). These measurements were carried out after 20 minutes of quiet lying in the supine position, the skin of the right hand and foot was swabbed with alcohol pads before the electrodes were attached on previously established positions for the source and sensing electrodes (Rush, Puniani et al. 2003). Child reference curves for BF% were used to classify participants as OW and NW (McCarthy, Cole et al. 2006). Participants were matched between groups with attention to age and sex.

Familiarization

An initial session was held to collect anthropometry measures and familiarize participants with SR, FK, and BK exercises and Borg's rating of perceived exertion (RPE) 6-20 category scale (Borg and Kaijser 2006). Participants viewed videos demonstrating each exercise and then attempted to perform each exercise, with feedback provided to ensure the correct technique was used and appropriate range of motion was maintained (Alberton, Tartaruga et al. 2013, Alberton, Pinto et al. 2017). The maximum heart rate was obtained through the performance of a ramp test on a treadmill; participants also familiarised themselves with using the RPE scale during this test. For the incremental protocol, heart rate (Polar; model T31C) and RPE values were monitored with the participant at rest and at the end of each stage. The protocol began at an initial speed of 5 km/hr (with 0 inclination) for 2 minutes and speed was increased by 1km/hr in 1-minute stages until the participants failed to demonstrate an increase in heart rate and reached a RPE of >17 on Borg's 6-20 scale (Howley, Bassett et al. 1995, Ferguson 2014). An interval of 48 hours was allowed between the initial and testing sessions.

Equipment setup and data collection

A digital camera (GoPro Hero 4 Black capturing at 240 Hz) was used to record kinematic data of lower extremity movement during stationary exercises, as previous research demonstrated strong accuracy using this protocol (Bernardina, Cerveri et al. 2017). The camera was synchronised with six EMG channels from an 8-channel wireless electromyography (EMG) system (Model 542 DTS EMG, Noraxon USA Inc., Scottsdale, AZ) to record kinematic data and muscle activation of rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), medial and lateral heads of the gastrocnemius (GAS-M and GAS-L) and tibialis anterior (TA), during stationary exercises. Three foot switches (Noraxon US Inc., Scottsdale, AZ USA) were placed bilaterally on the base of the first and fifth metatarsals, and the distal phalanx of the hallux to identify foot contact with the ground (Blakemore, Fink et al. 2013). The signals provided by the foot switches were used to determine initial contact and toe-off of the stationary exercise phases, which was synchronised with the EMG system and kinematic data. The EMG electrodes were placed on the belly of muscle parallel to the orientation of the muscles fibres with 2 cm inter-electrode distance, in accordance with SENIAM guidelines (Hermens, Freriks et al. 2000). Prior to electrode placement, the skin surface was prepared by shaving and abrading with alcohol pads (Figure 4.1). Surface Ag/AgCl biopolar electrodes (11 mm diameter; BlueSensor N, Ambu, Denmark) were used. EMG data (input impedance: > 100 MΩ; CMRR: > 100 dB; baseline noise: < 1μV RMS; gain: 500) were collected at a frequency of 1500 Hz. To enable the normalisation of the EMG signals, three sets of maximal voluntary isometric contractions (MVICs) were performed (5 seconds) for the selected muscles, in a randomized order, on previously established positions for the leg muscles using the recommendations of SENIAM organization (Hermens, Freriks et al. 2000).

Contraction angles were measured and adjusted with a goniometer (BASELINE; New York, USA) during the MVICs tests. Tests were performed against manual resistance in both the flexion and extension directions at the knee and ankle joints (Alberton, Pinto et al. 2014, Alberton, Pinto et al. 2015). Previous research has reported that the MVC's performed at different joint angles have no significant effect on maximal EMG amplitude (Burden 2010).

The camera set-up was positioned perpendicular to the participants and the distance (3m) from the camera to the participants, were consistent during the study (Balletti, Guerra et al. 2014). Reflective markers were placed on the anterior superior iliac spine (ASIS), iliac crest, greater trochanter, lateral femoral epicondyle, lateral malleolus and calcaneus in order to determine the hip, knee and ankle joints range of motion (ROM) throughout the stationary exercises (Figure 4.1).

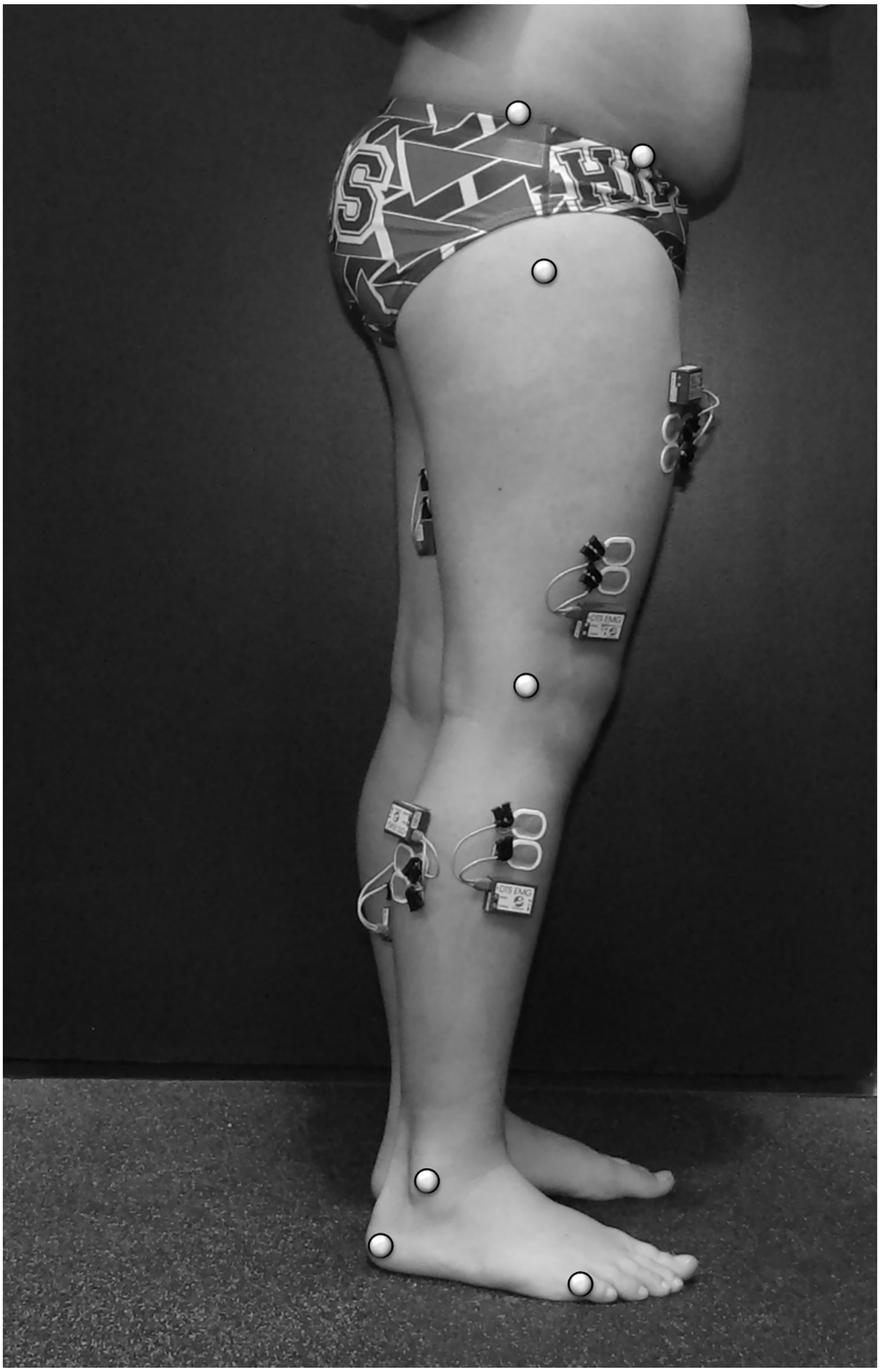

Figure 4.1: Positions of the EMG electrodes and markers.

Experimental Protocol

A target heart rate of 60% max HR was calculated from the maximal heart rate measured in the familiarisation session and used to control the intensity level achieved during the testing session. SR was characterized with the hip and knee flexion to 90° and extension (Figure 4.2A) (Alberton, Tartaruga et al. 2013, Alberton, Pinto et al. 2017). FK was characterized with the hip flexion to 45° and extension with the extended knee (Figure 4.2B) (Alberton, Tartaruga et al. 2013, Alberton, Pinto et al. 2017). BK was characterized with knee flexion to 90° and extension with the extended hip (Figure 4.2C). In addition, the upper extremity performed minimal shoulder flexion followed by extension with the flexed elbow at 90° to maintain balance during exercises. The right and left limbs performed these movements alternately across all exercises, which were fully described for SR and FK in previous literature (Alberton, Tartaruga et al. 2013, Alberton, Pinto et al. 2017). Each exercise was conducted for 5 minutes; EMG signals, kinematic data, heart rate and RPE were collected from the 3rd to the 4th minute of each trial (Alberton, Pinto et al. 2015). All participants wore either compression shorts or a swim suit to allow for proper placement of the heart rate monitor, EMG transmitters and the reflective markers. All exercises were performed barefoot. A 5 to 10-minute warm-up preceded all trials and consisted of stationary exercises at a submaximal speed. A single researcher (MY) with 6 years of experience in exercise prescription provided verbal feedback regarding the participants' heart rate intensity and technique during each exercise. The order of the exercises was randomly chosen, and the participants had an interval of 5 minutes rest between exercises.

Kinematic and EMG data processing

The mean of five selected cycles was measured for the presentation of the ROM and EMG data. From kinematic data, the selected consecutive strides were identified as those having low kinematic variability (lower extremity joint ROM ±5°) (Alberton, Pinto et al. 2015). The exercises were divided into four phases, including stance, early float, swing and late float using foot switches and visual inspection of the kinematic data (Figure 4.2) (Chan and Rudins 1994). Initial ground contact of right foot was defined as the beginning of stance phase until both feet lost their contact to the ground, which was known as the end of stance phase and beginning of the early float phase. Then initial ground contact of left foot was defined as the beginning of swing phase until both feet lost their contact to the ground, which was the end of swing phase and beginning of the late float phase. The duration of each sub-phase were calculated as the time spent in stance, early float, swing, and late float phases. The absolute time spent was normalised to the full gait cycle and duration was presented as a percentage.

EMG data were rectified and filtered using a bidirectional (zero lag) 8th order Butterworth bandpass filter (10-500 Hz). All EMG data were reported as a percentage of root mean square (RMS) values obtained in MVICs, allowing data to be compared between exercises, weight groups, and muscles (Soderberg 1992, Soderberg and Knutson 2000). To assess total EMG activity over the course of a phase, area under the normalised RMS EMG curve (RMS-iEMG) relative to phase duration, is reported. RMS-iEMG controls for potential differences in phase duration and EMG signal between participants and exercises (Walaszek, Ransom et al. 2017). The muscles were considered active when the EMG signal was above the average threshold of three standard deviations of a baseline value for 50 ms duration (Li and Aruin 2005, Yaghoubi, Esfehani et al. 2015). The average of a 100-ms window prior to the preengagement phase was used to calculate the baseline value for each muscle. Reliability analysis was performed to assess the degree of error in determining the onset and offset point using the subjective visual inspection technique (Ives and Wigglesworth 2003).

The reflective markers were digitised manually in Vicon Motus into two-dimensional coordinates. In order to improve reliability of outcome variables, the trials were digitised twice by two independent researchers. The inter- and intra-observer agreements were calculated using intra-class correlation coefficients (ICC). The intra-observer ICC ranged from 0.97 to 0.99 and inter-observer ICC ranged from 0.96 to 0.99. Overall, these results show a high reliability of the digitisation process (Cadenas-Sanchez, Arellano et al. 2015). All digitised data were filtered bidirectionally using a second order Butterworth low-pass filter with a cut-off frequency of 6 Hz.

The kinematic data processing was performed using Matlab R2015b (Mathworks Inc., Natick, MA, USA) and MRXP Master Edition, version 1.08.17 (Noraxon USA Inc., Scottsdale, AZ).

Figure 4.2: Schematic of: A) Stationary running; B) Frontal kick and; C) Butt Kick phases. The percentage of phase duration for each activity is represented by means ± standard deviations within the grey bars.

Statistical analysis

The Shapiro-Wilk test confirmed the normality of data across dependent variables (SPSS Statistics version 22 software, IBM Crop, New York, USA). Thus, [2 (group) × 3 (exercise)] repeated measures analyses of variance (ANOVA) was used to compare RPE, HR, temporal parameters, muscle activity patterns and ROM between groups (NW and OW), and exercises (SR, FK and BK). There were no main group differences for the duration of phases across all exercises and phases; thus, the related data for both groups were pooled together to plot the percent of stationary exercises' cycle. However, there was a significant difference between groups for cadence, and it was considered as a covariate. When applicable, Bonferroni post hoc tests were used to localize the significant differences. In addition, when the interaction was significant, the main factors were further subjected to a pairwise post hoc analysis using paired t-tests. An alpha level of $p < 0.05$ was used for all statistical tests. To understand the sequencing of muscle activation, a Friedman rank test ordered the onset of muscle activation. Kendall's W was used as a non-parametric assessment of effect size pertaining to group difference in sequencing patterns. with a significant level also set at $p < 0.05$.

Results

Heart rate and RPE

Descriptive statistics for each group can be found in Table 4.1. There was no significance main effect for HR ($p > 0.05$) when comparing between groups or exercises. The RPE responses were significantly greater in OW children than NW children across all exercises ($p < 0.001$), whereas the main effect of exercise type was not significant on perceived exertion ($p > 0.05$) (Table 4.1). Thus, all participants completed each of the three exercises at a similar submaximal intensity.

Table 4.1. Mean (± SD) values for Heart Rate (60%) and Rating of Perceived Exertion scale (Borg's scale).

Stationary running (SR)	**Overweight**	**Normal-weight**
HR (60%)	124.93 ± 4.14	123.40 ± 7.39
RPE (Borg's 6-20)	13.80 ± 0.63*	11.66 ± 0.72
Frontal-kick (FK)		
HR (60%)	127.12 ± 4.59	123.74 ± 5.63
RPE (Borg's 6-20)	13.90 ± 0.73*	11.80 ± 0.67
Butt-kick (BK)		
HR (60%)	122.12 ± 4.25	121.60 ± 7.66
RPE (Borg's 6-20)	13.30 ± 0.94*	11.60 ± 0.82

Values are mean ± SD. * Significant differences between groups ($p < 0.001$).

Kinematics

There was no significant main effect for ROM between groups at any joint ($p = 0.194$). As there was also no significant interaction between group and exercise, the ROM data for both groups were pooled together to quantify the differences between exercises and joints. Significant differences were observed between joints ($p < 0.001$), exercises ($p < 0.001$) and exercise*joint interaction ($p < 0.001$) for ROM variable. At the ankle joint, there was no difference observed between exercises ($p > 0.062$). Knee ROM was significantly greater during BK than SR and FK ($p < 0.001$) and knee ROM was also significantly greater during SR than FK ($p < 0.001$). Hip ROM was significantly different between each exercise, with the greatest amount of hip ROM occurring during SR, and the least amount occurring during BK. ($p < 0.001$).

Table 4.2. Mean (± SD) values for Range of motion of the ankle, knee and hip joints for stationary exercises.

Stationary Exercises	Ankle	Knee	Hip
Stationary running (SR)	31.52 ± 4.37†	49.33 ± 6.67*	40.61 ± 5.66*
Frontal-kick (FK)	30.85 ± 4.39	34.98 ± 5.385	30.81 ± 4.33
Butt-kick (BK)	36.52 ± 5.53†	60.21 ± 8.17	25.88 ± 3.296

Values are mean ± SD. *Significant differences between exercises ($p<0.05$). †Significant differences between joints ($p<0.001$).

EMG

Figure 4.3 demonstrates the muscle activity patterns for the RF, VL, GAS-M, GAS-L, TA and BF during SR, FK and BK. The RF activation pattern was greater in the OW group compared to the NW group across all exercises ($p = 0.04$). OW participants also had greater activation of GAS-M and GAS-L in comparison to NW peers during FK ($p < 0.001$) and BK ($p < 0.001$). The OW group showed significantly higher activation of TA ($p < 0.001$) and BF ($p < 0.001$) in all exercises compared to NW. VL activation was similar between groups across all exercises ($p = 0.32$). RF activation was significantly higher in SR ($p = 0.002$) and FK ($p = 0.01$) compared to BK in both groups. VL activation was similar between exercises in both groups ($p = 0.268$). No difference was observed in both heads of gastrocnemius muscle between exercises in NW group (GAS-M: $p = 0.479$; GAS-L: $p = 0.334$). However, GAS-M and GAS-L in OW group was more active in FK and BK than during SR ($p < 0.001$). Similarly, TA activation was similar between exercises in NW group ($p = 0.912$). In contrast to the GAS-M and GAS-L, TA showed greater activation in SR than other exercises within the OW group ($p < 0.001$). Biceps femoris activation was greater in BK in comparison to FK ($p = 0.001$) and BK ($p = 0.002$) in both groups.

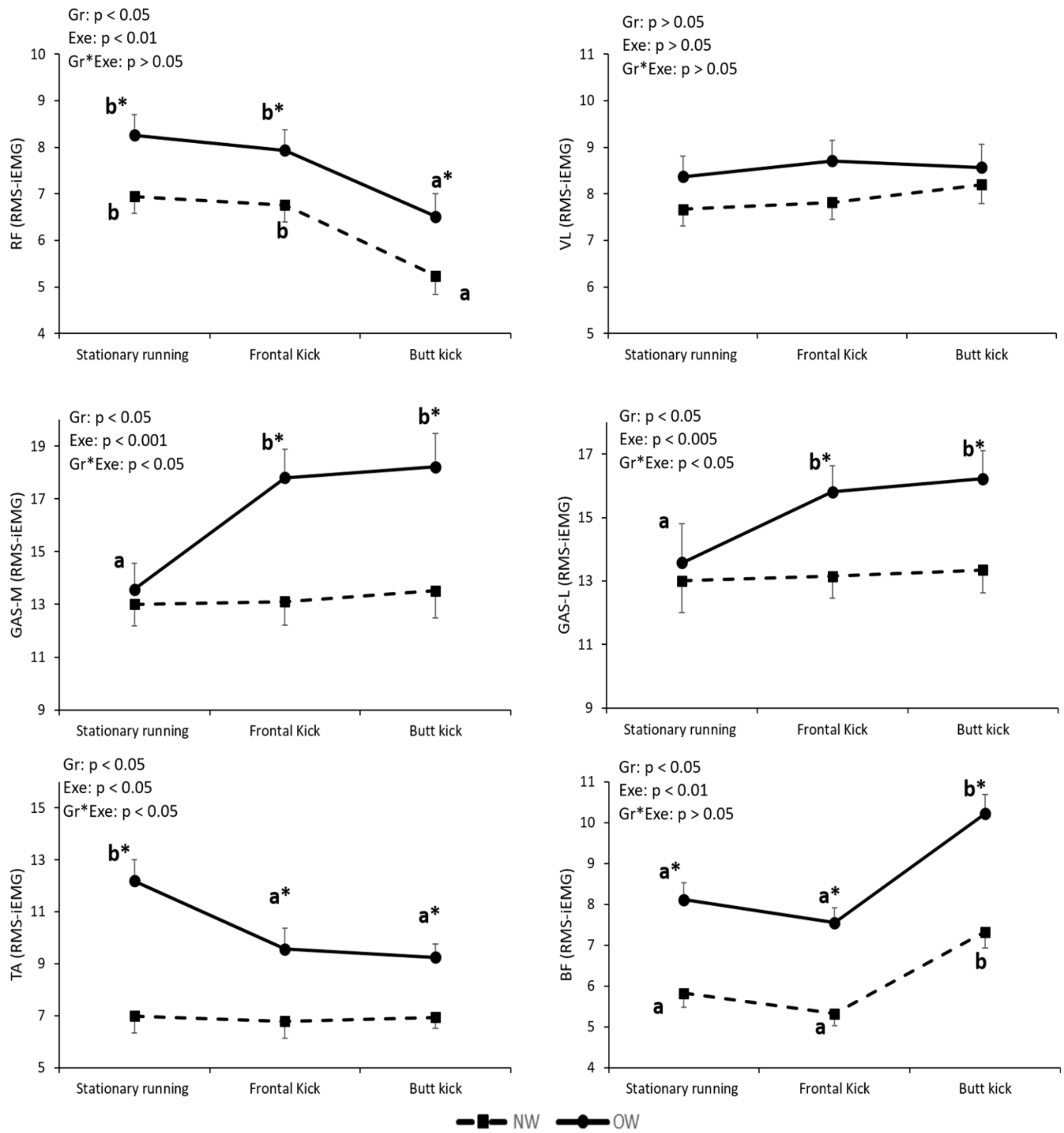

Figure 4.3: EMG activation pattern of rectus femoris (RF), vastus lateralis (VL), gastrocnemius medialis (GAS-M), gastrocnemius lateralis (GAS-L), tibialis anterior (TA) and biceps femoris (BF) between normal weight (NW) and overweight (OW) groups (Gr) during different stationary exercises (Exe). Different letters indicate significant differences between exercises: b > a; * indicates significant differences between groups.

Table 4.2 contains the mean ranks of muscle sequencing examined in the NW and OW groups during stationary exercise. The mean ranks were able to quantify the sequence of muscle activation onset; in this study, a higher mean rank indicates that the muscle onset occurred earlier than muscles with a lower rank (Yaghoubi, Esfehani et al. 2015). The Friedman test revealed that there was significant sequencing among muscle activities in the NW group. The sequential muscle activities in the NW group were significant (Friedman test $p < 0.05$), indicating consistent patterns in muscle sequencing. However, sequential muscle activities in the OW group were not significant, indicating uncoordinated rates of firing muscle patterns observed in the OW group during stationary exercises.

Table 4.3. Mean ranks of muscles' sequencing examined in the normal-weight and overweight groups during stationary exercise

		RF	VL	GAS-M	GAS-L	TA	BF	Kendell's W
Stationary Running (SR)								
Mean Rank	NW	3.25*	3*	4.375*	5.5*	3.25*	1.625*	0.595
	OW	2.13	2.5	4.13	4.38	3.63	4.25	0.234
Frontal Kick (FK)								
Mean Rank	NW	4.67*	3.39*	3.1*	4.89*	3.89*	1.06*	0.549
	OW	3.14	2.57	4.14	4.43	4.29	2.43	0.230
Butt Kick (BK)								
Mean Rank	NW	3.22*	3.56*	1.67*	3*	4.44*	5.11*	0.410
	OW	3.71	3.57	2.71	3.14	3.14	4.71	0.137

Note: Friedman test assessment scores. *$p < 0.001$, significant differences between normal-weight and overweight groups. RF: Rectus Femoris, VL: Vastus Lateralis, GAS-M: Gastrocnemius Medialis, GAS-L: Gastrocnemius Lateralis, TA: Tibialis Anterior, BF: Biceps Femoris.

Discussion

This study compared perceived exertion, lower extremity ROM, and lower extremity muscle activation patterns between NW and OW children during sub-maximal SR, FK and BK exercises. The OW children had greater RPE values and muscle activation during stationary exercises. In addition, NW children used more consistent muscle recruitment pattern in comparison to OW children. ROM was not found to be significantly different between both groups. Combined, these results strongly support our hypothesis that muscle activation patterns will be different between OW and NW children during stationary exercises performed at the same physiological intensity.

The results of this study showed that RPE was significantly higher in OW children during all exercises. This difference in RPE occurred despite the fact that HR was controlled between groups and exercises. The RPE results were also consistent with the EMG results of this study, as OW children had to utilise a higher percentage of their muscle activation capacity to perform the stationary exercises at a similar HR to their NW peers. The increased muscle activation and RPE support the suggestion that OW participants may work at a higher relative percentage of their capacity. These adaptations could be due to deconditioning, higher load during moving excess mass and less healthy muscle tissue (i.e. muscle quality) available to produce the necessary contractions in OW children (Lee, Kim et al. 2012). Additionally, the higher RPE scores could indicate a lack of enjoyment when performing stationary exercise, which is consistent with previous studies associating higher RPE values with lower rating of pleasure in OW participants (Ekkekakis and Lind 2006).

Compared to NW peers, OW children had greater activation of the RF, TA, and BF during all exercises. The increase in excess mass would require greater force coupling of the RF and BF to propel the child during all exercises (Shultz, Hills et al. 2010), as well as to maintain stability (Blakemore, Fink et al. 2013). The largest group difference in TA activation was seen during SR. This exercise was performed by OW children with more ankle dorsiflexion and a subsequent flatter foot posture than the other exercises. Thus, it would seem that children who carry excess mass adopt landing strategies across multiple modes of locomotion (Blakemore, Fink et al. 2013). Blakemore et al hypothesised that the increased gastrocnemius activity provided a more stable landing for overweight children during walking. In stationary exercises, where there is more vertical displacement, the OW could use the flatter foot for greater force absorption and stability upon landing from flight phase. As a consequence, there was a greater TA activation observed during SR than FK and BK in this group, which was consistent with previous literature (McMillan, Auman et al. 2009, McMillan, Phillips et al. 2010). VL activation was consistent and not significantly different between groups and exercises. The role of the VL muscle as a knee stabilizer could have required such large activation demands in both groups that differences in any exercises were not significant (Alberton, Pinto et al. 2014).

OW children also produced greater gastrocnemius activity during FK and BK, although it was similar in SR between groups. The findings align with previous gait research (Blakemore, Fink et al. 2013) that found longer duration of activation for gastrocnemius in OW children during walking. It was suggested that the greater impact during landing with excess body mass and a desire to increase stability at stance phase resulted in these higher activations within OW children. Also, OW children may rely on greater gastrocnemius activation during FK and BK because of the required forefoot support, which was not present in the flatter foot posture during SR. In addition, gastrocnemius muscles showed significantly greater activation than other muscles ($p < 0.001$) in both groups, as the musculature is required to assist in vertical propulsion and absorb impact with forefoot strikes during stance phase of stationary exercises (Fontana, Haupenthal et al. 2012, Alberton, Pinto et al. 2014).

In comparison to other exercises, BK performed with greater knee flexion and extension and limited hip ROM during flight phase resulting in greater knee flexors activation than other exercises for both groups. Based on these results, it can be concluded that BK presents a neuromuscular economy in hip flexors when compared to SR and FK exercises in both groups. Thus, BK could be recommended if the purpose is to reduce muscular activity of knee extensors and hip flexors (with limited hip ROM) in comparison to other exercises. In contrast, the emphasis on knee extension and hip flexion in the SR and FK activities resulted in significantly higher RF activation compared to BK. These findings are consistent with previous research reporting higher RF activation in FK compared to other stationary exercises (Alberton, Pinto et al. 2014). Therefore, FK and SR could be prescribed when higher ROM at knee and hip joints are targeted with less activation of knee flexors in both groups.

The result of the Friedman test indicates that muscle sequencing patterns were significantly meaningful in NW group, while muscle sequencing patterns were inconsistent in the OW group across all stationary exercises. These findings could suggest that a lower level of neuromuscular coordination occurs in OW children in comparison to their NW peers when performing stationary exercises. The lower level of neuromuscular coordination in OW children could coincide with previously reported lower levels of physical fitness and motor competency in comparison to NW children (Cattuzzo, dos Santos Henrique et al. 2016). This finding is consistent with previous studies reporting deficiency in motor skill competence of OW and obese children (Deforche, De Bourdeaudhuij et al. 2009, Lopes, Stodden et al. 2012).

Additionally, OW children showed distinct differences in muscle activation patterns between exercises that were not evident in the NW group. When combined, these results suggest that the lower extremity muscle activation strategy in OW children is more greatly affected by the type of stationary exercises than in NW children. Therefore, exercise practitioners should consider promoting improvements in strength, power, neuromuscular coordination and endurance that will augment simple and safe stationary exercises, and help to increase the enjoyment and the ability of children with excess mass to safely participate in weight management interventions.

Conclusion

The OW children showed higher RPE and muscle activation during stationary exercise, suggesting that strength has not increased proportionally with excess body mass in OW children. Subsequently, OW children need to use a greater percentage of their muscle activation when performing submaximal stationary exercises. The increased muscle activation in OW groups, as well as between exercises, indicates that stationary exercise can be prescribed to improve lower extremity muscle strength and endurance in overweight children, but mode and intensity must be considered. To inform injury risk as well as physical function, future research should include the analysis of ground reaction force, as well as implementation of other stationary exercises in a variety of weight bearing environments.

Statement of contribution to doctoral thesis containing publications

DRC 16

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STATEMENT OF CONTRIBUTION
TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Mostafa Yaghoubi

Name/Title of Principal Supervisor: Philip Fink

Name of Published Research Output and full reference:

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Chapter 5: Kinematic comparison of aquatic –and land-based stationary exercises in overweight and normal-weight children

Abstract

Objectives: Children carrying excess mass have difficulty performing exercise; however, aquatic exercise has not been considered as an alternative solution for this population. This study examined lower extremity kinematics in normal-weight and overweight children during water- and land-based stationary exercises (stationary running, frontal kick, butt kick).

Design: Cross-sectional.

Methods: Participants included 10 overweight and 15 normal-weight children, aged 10-13 years. Spatiotemporal data and lower extremity joint kinematics were collected during water- and land-based stationary exercises. Ratings of perceived exertion (RPE) were collected during all trials. Repeated measures ANOVA compared kinematic variables and RPE between groups and environments. A polygon area function was used to compare the coordination patterns between environments.

Results: RPE responses were significantly greater in overweight than normal-weight children across all exercises on land, whereas the RPE responses were similar between groups in water ($p > 0.05$). Overweight children were significantly more extended than normal-weight during land-based exercise, while there were no differences observed between groups in water. Similar ROM and duration of phases were seen between groups, regardless of exercise or condition. The duration of stance and swing phases, angular velocity, and cadence across all exercises were significantly lower in water than land.

Conclusions: Compared to normal-weight, overweight children performed stationary exercises in a stiffer, more upright posture on land, with a corresponding increase in RPE. However, these differences did not exist in water. Thus, aquatic-based exercises may be effective in minimising the effects of excess mass on overweight children's ability to complete physical activity.

Keywords**:** pediatric obesity, physical fitness, biomechanics

Introduction

Physical activity is a key component for tackling obesity in children and adolescents (Kelley and Kelley 2013). In particular, aerobic exercise training is known to counteract obesity by promoting reductions in body weight (Gappmaier, Lake et al. 2006). However, aerobic exercise training is normally undertaken in a weight-bearing environment and may not be practical for overweight children. Previous studies have found that children who are overweight and obese sustain increased ground reaction forces (Gill and Hung 2014), joint moments (Shultz, Hills et al. 2010), muscle activities (Blakemore, Fink et al. 2013) and less efficiency of transferring mechanical work (Nantel, Brochu et al. 2006, Gill and Hung 2012) compared to normal-weight children during general physical activities on land. It is believed that these changes in lower extremity biomechanics can increase the risk of musculoskeletal dysfunction, injury, and pain (Belisle, Roskies et al. 1987, McMillan, Auman et al. 2009). Therefore, exercise prescription should consider alternatives that reduce force and loading to the joints of children with obesity (Shultz, Anner et al. 2009). To this end, aquatic exercise could be particularly effective in improving aerobic fitness and body composition in overweight children without putting undue stress on the musculoskeletal system.

Stationary exercises can be performed in shallow-water (i.e. participants are able to maintain contact with the bottom of the pool) and land, and are commonly prescribed in aquatic aerobic programs and land-based sport training sessions alike (Fontana, Haupenthal et al. 2012, Alberton, Pinto et al. 2014). Stationary exercises can also be recommended for health promotion and rehabilitation as they incorporate basic movement patterns and have benefits to the musculoskeletal and cardiovascular systems (Haddock, Siegel et al. 2009, Alberton, Pinto et al. 2014). However, land-based stationary exercises produce similar vertical ground reaction forces to running (Fontana, Haupenthal et al. 2012) and thus, can be considered high-impact with potential to increase wear and tear on joints. Children who are carrying excess mass may be particularly at risk of increased injury during repetitive high impact exercise, resulting in lower adherence and enjoyment (Shultz, Anner et al. 2009, Shultz, Sitler et al. 2009). The hydrostatic effect of water decreases impact on lower extremity joints and stress on the musculoskeletal system respective to the level of immersion, while hydrodynamic properties of water can create challenges that promote health during stationary exercise in water (Harrison, Hillman et al. 1992, Batterham, Heywood et al. 2011, Alberton, Tartaruga et al. 2013). In addition, overweight children experience a lower hydrostatic weight in water than normal-weight children, due to the density properties of excess fat mass (Haupenthal, Fontana et al. 2013). Thus, stationary exercise in water can provide an effective and less injurious alternative for weight loss and general improvement of physical conditioning and enjoyment in overweight children.

Because of the frequent use and health benefits of stationary exercises in shallow water and land, stationary exercise has recently been investigated in the literature (Alberton, Finatto et al. 2014, Alberton, Pinto et al. 2015, Fontana, Ruschel et al. 2015). However, the literature has only focused on biomechanical and physiological parameters in adults and there has been little published research investigating the biomechanical benefits of water-based physical activity in children. More importantly, there are no studies that have undertaken biomechanical analysis of the lower extremity during stationary exercise in children with varying body size in shallow water and land. Without fully understanding the biomechanical differences that occur between performing stationary exercises in shallow water and land in children (and particularly those carrying excess mass), these activities cannot be accurately integrated into existing exercise prescription. Therefore, the purpose of this study was to examine the differences in lower extremity kinematics and spatiotemporal parameters in normal-weight (NW) and overweight (OW) children during stationary exercises (stationary running (SR), frontal kick (FK), butt kick (BK)) at submaximal intensity in shallow water (i.e. at xiphoid immersion level) and dry land. Additionally, information will be gathered on ratings of perceived exertion between exercises, to better inform physiological efficacy of exercise prescription. While it is anticipated that OW children will have higher 'rating of perceived exertion' (RPE) values and different kinematic strategies when performing exercise over ground, it is hypothesised that the physical properties of water and a lower body density due to excess fat mass will result in OW children producing similar RPE values and kinematical differences to NW children when exercising in the water.

Methods

Twenty-five children, aged 10-13 years (12 males, 13 females) were recruited through local schools to participate in the study. Participants were classified as overweight (N=10; age: 12.10 ± 1.22; mass: 73.93 ± 17.11kg; height: 1.59 ± 0.11m; body fat percentage: 34.97±8.60) and normal-weight (N=15; age: 12.23 ± 1.08; mass: 43.16 ± 7.54kg; height: 1.57 ± 0.11m; body fat percentage: 18.33 ± 4.87). Participants were excluded from the study if they had a previous orthopaedic surgery or lower limb injury within 6 months, skin allergy or skin condition that would be affected by the application of self-adhesive electrodes and markers, moderate to severe asthma that might be affected by physical activity, or any other condition that affected locomotion. Participants were familiar with aquatic environments and able to swim. Prior to participation, the study and risks were explained to the parents/guardians and children, who then signed the consent and assent forms, respectively. The study was approved by the Massey University Human Ethics Committee (Southern A Application 14/08).

Height and weight were measured using a stadiometer (Milton Ltd, Zhejiang, China) and electronic scale (model EA150FEG-1, Sartorius AG, Germany), respectively, while participants wore their swimsuit. Body mass index (BMI; kg/m^2) was then calculated. Bio-electrical impedance analysis (BIA; Bodystat 1500, Bodystat Ltd, Douglas, British Isles) measured body fat percentage (BF%) after 20 minutes of quiet lying in the supine position. Child reference curves for BF% were used to classify participants as OW and NW (McCarthy, Cole et al. 2006). Participants were matched between groups with attention to age and sex.

An initial session was held to collect anthropometry measures and familiarise participants with SR, FK, and BK exercises and Borg's rating of perceived exertion (RPE) 6-20 category scale (Borg and Kaijser 2006). Participants viewed videos demonstrating each exercise in both environments and then attempted to perform each exercise in water and land, with feedback provided to ensure the correct technique was used and appropriate range of motion was maintained (Alberton, Tartaruga et al. 2013, Alberton, Finatto et al. 2014). The maximum heart rate was obtained through the performance of a ramp test on a treadmill; participants also familiarised themselves with using the RPE scale during this test. For the ramp protocol, heart rate (Polar; model T31C) and RPE values were monitored with the participant at rest and at the end of each stage. The protocol began at an initial speed of 5 km/hr (with 0 inclination) for 2 minutes and speed was increased by 1km/hr in 1-minute stages until the participants failed to demonstrate an increase in heart rate and reached a RPE of >17 on Borg's 6-20 scale (Howley, Bassett et al. 1995, Ferguson 2014). An interval of 48 hours was allowed between the initial and testing sessions.

A digital camera (GoPro Hero 4 Black capturing at 240 Hz) was used to record kinematic data of lower extremities during stationary exercises in both environments. Three foot-switches (Noraxon US Inc., Scottsdale, AZ USA) were placed bilaterally on the base of the first and fifth metatarsals, and the distal phalanx of the hallux to identify foot contact with the ground (Blakemore, Fink et al. 2013). The signals provided by the foot switches were used to determine initial contact and toe-off of the stationary exercise phases, which was synchronised with the kinematic data. The camera set-up was positioned perpendicular to the participants; the distance (3m) from the camera to the participants was consistent during the study (Balletti, Guerra et al. 2014). Reflective markers were placed on the anterior superior iliac spine (ASIS), iliac crest, greater trochanter, lateral femoral epicondyle, lateral malleolus and calcaneus.

A target heart rate of 60% max HR was used to control the intensity level achieved during the testing session (Killgore, Wilcox et al. 2006). Participants performed the stationary exercises based on the demonstrated techniques, which were commonly used during aquatic programs and fully described in previous literature (Alberton, Tartaruga et al. 2013, Alberton, Finatto et al. 2014, Alberton, Pinto et al. 2017). Each exercise was conducted for 5 minutes in both environments; kinematic data, heart rate, and RPE were collected from the 3rd to the 4th minute of each trial. The land-based exercises were performed in a room with temperature between 23-26°C. The water-based exercises were conducted in a pool with temperature between 30-33°C. Depth reducers were used to ensure that the participants were immersed to the xiphoid process. All participants wore either compression shorts or a swim suit to allow for proper placement of the heart rate monitor and the reflective markers. All exercises were performed barefoot. A 5 to 10 minute warm-up preceded all trials and consisted of stationary exercises at a submaximal speed in both environments. Verbal feedback was provided regarding the participants' heart rate intensity and technique during each exercise. The order of the exercises and environments were randomly chosen, and the participants had an interval of 5 minutes rest between exercises.

The mean of five selected cycles was measured for the presentation of the kinematic and temporal data. From kinematic data, the selected consecutive strides were identified as those having low kinematic variability (defined as inter-stride range less than 5 degrees) (Alberton, Pinto et al. 2015). Visual inspection of the kinematic data divided each exercise into four phases: stance, early float, swing and late float (Chan and Rudins 1994). Stance phase occurred between initial ground contact and toe-off of the right. The early float phase occurred when both feet were off the ground prior to initial ground contact of the left foot. Swing phase occurred between initial ground contact and toe-off of the left foot. The late float phase occurred when both feet were off the ground prior to initial ground contact of the right foot. The duration of each sub-phase was calculated as the time spent between each gait event. The absolute time spent in each phase was normalised to the full gait cycle and duration was presented as a percentage (Figure 5.1).

The reflective markers were digitised manually in Vicon Motus (version 9.2) into two-dimensional coordinates. The angle between foot (heel and toe) and the shank (i.e. lateral malleolus, lateral femoral epicondyle) was obtained to measure the ankle joint angle. For the knee joint angle, the angle between the thigh (i.e. greater trochanter, lateral femoral epicondyle) and shank segments was used. The hip angle was measured using the angle between the thigh segment and the hip markers (i.e. ASIS, iliac crest). Angular reference for hip and knee kinematic variables is based on the anatomical position and the right-hand rule (that is, flexion described in negative, extension in positive directions). For ankle kinematic variables, ankle plantar-flexion is described as positive direction and ankle dorsi-flexion is described as negative.

To improve reliability of outcome variables, the trials were digitised twice by two independent researchers. The inter- and intra-observer agreements were calculated using intra-class correlation coefficients (ICC). The intra-observer ICC ranged from 0.96 to 0.98 and inter-observer ICC ranged from 0.95 to 0.97. Overall, these results show a high reliability of the digitisation process (Cadenas-Sanchez, Arellano et al. 2015).

All digitised data were filtered bi-directionally using a second-order Butterworth low-pass filter with a cut-off frequency of 6 Hz. The kinematic data processing was performed using Matlab R2015b (Mathworks Inc., Natick, MA, USA). As a way of quantifying the three-dimensional combined hip, ankle, and knee coordination patterns, a surface area enclosed by the Lissajou plots of hip, knee, and ankle motion was calculated. This was done by calculating the area of the plots projected on each plane separately using the polyarea function in Matlab, and then adding the areas together and dividing by two because each joint motion was used twice: $Area_{Ankle/knee\_Hip} = {}^{1}/_{2}\,[(P_{Ankle/Knee} \times A_{Ankle/Knee}) + (P_{Ankle/Hip} \times A_{Ankle/Hip}) + (P_{Knee/Hip} \times A_{Knee/Hip})]$ where P is perimeter and A is apothem.

In addition, the angular position (stance phase only), range of motion (ROM), and angular velocity for the hip, knee, and ankle throughout the gait cycle were analysed to compare between groups and environments.

The Shapiro-Wilk test was used to test the normality of data across all dependent variables (SPSS Statistics version 22 software, IBM Crop, New York, USA). A 2 (group) × 2 (environments) repeated measures analysis of variance (ANOVA) was used to compare HR, RPE, cadence, cycle duration (%), ROM, peak flexion-extension, angular position and angular velocity. There were no main group differences for the duration and ROM of phases across all exercises and phases; thus, the related data for both groups were pooled together to plot the percent of stationary exercises cycle in water and land (Figure 5.1). When applicable, Bonferroni post hoc tests were used to localise the significant differences. In addition, when the interaction was significant, the main factors were further subjected to a pairwise post hoc analysis using paired t-tests. An alpha level of $p < 0.05$ was used for all statistical tests.

Results

Descriptive statistics for each group can be found in Table 5.1. There was no significant main effect for HR ($p > 0.05$) when comparing between groups or exercises. The RPE responses were significantly greater in OW children than NW children across all exercises on land ($p < 0.001$), whereas the RPE responses were not significant between groups in water ($p > 0.05$) (Table 5.1). OW children demonstrated significantly decreased RPE values in water compared to land; however, NW children showed similar RPE responses between environments. Cadences were significantly higher in land than water for both groups in all exercises. On land, OW children showed similar cadence to NW children for FK and BK, but OW children had significantly lower cadence during SR than NW. The cadences between groups were similar for all exercises in water.

Table 5.1. Values for Heart Rate (60%), Rating of Perceived Exertion scale (Borg's scale) and cadence (steps per min) for both groups and environments.

	Land		**Water**	
Stationary running	**Overweight**	**Normal-weight**	**Overweight**	**Normal-weight**
HR (60%)	124.93 ± 4.14	123.40 ± 7.39	124.73 ± 3.65	123.50 ± 5.72
RPE (Borg's 6-20)	13.80 ± 0.63*†	11.66 ± 0.72	11.20 ± 0.91†	11.06 ± 0.88
Cadence (Steps per min)	76.76 ± 3.88*†	83.53 ± 5.18†	57.73 ± 6.94†	60.89 ± 8.29†
Frontal-kick				
HR (60%)	127.12 ± 4.59	123.74 ± 5.63	126.93 ± 6.12	123.50 ± 3.68
RPE (Borg's 6-20)	13.90 ± 0.73*†	11.80 ± 0.67	11.40 ± 0.51†	11.26 ± 0.79
Cadence (Steps per min)	78.09 ± 5.53†	80.30 ± 6.33†	57.31 ± 6.03†	57.99 ± 6.77†
Butt-kick				
HR (60%)	122.12 ± 4.25	121.60 ± 7.66	122.33 ± 7.55	121.22 ± 5.41
RPE (Borg's 6-20)	13.30 ± 0.94*†	11.60 ± 0.82	11.01 ± 0.66†	11.06 ± 0.88
Cadence (Steps per min)	77.39 ± 4.64†	81.22 ± 6.60†	58.94 ± 9.77†	61.90 ± 8.57†

Note: HR: Heart rate; RPE: Rating of Perceived Exertion. Values are mean ± SD.

*Significant differences between groups ($p<0.001$). †Significant differences between environments ($p<0.001$).

Figure 5.1 demonstrates the duration of phases of stationary exercises, which were normalised based on the whole cycle (%). As there was no significant group effect for phase duration during any of the stationary exercises, the data for both groups were pooled together to examine differences between environments. The duration of stance and swing phases were significantly lower in water than land, whereas the duration of early float and late float phases were significantly higher in water than land for both groups in all exercises. The combination of these increases and decreases in duration resulted in a more equivalent division of time between phases during water-based exercises compared to land-based.

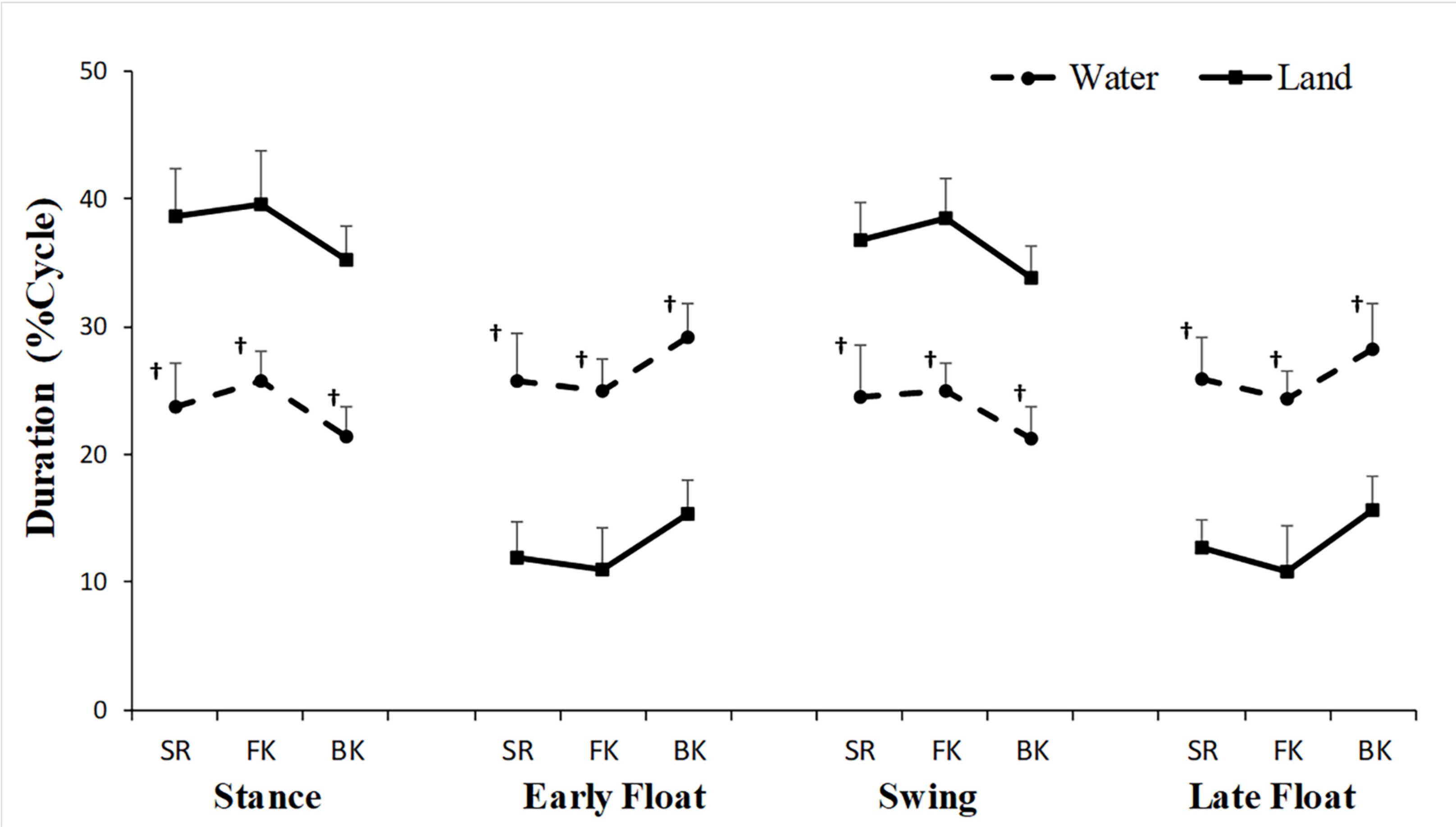


Figure 5.1: Comparison of phases during SR, FK, and BK cycles (%).*Significant differences between environments (P < .05). BK indicates butt kick; FK, frontal kick; SR, stationary running.

There was no significant main effect for ROM between groups at any joint ($p = 0.650$). Thus, the ROM data for OW and NW groups were pooled together to quantify the differences between environments for all exercises. There were no significant differences observed in ankle ROM in SR ($p = 0.296$) and FK ($p = 0.360$) between environments, however ankle ROM was significantly greater in land (39.28° ± 10.28) than water (28.56° ± 5.32) during BK ($p < 0.001$). No significant differences were observed in knee ROM during SR ($p = 0.645$), FK ($p = 0.185$) and BK ($p = 0.089$) in both environments. Hip ROM was significantly greater in water than on land during SR (Land: 56.05° ± 8.42, Water: 69.65° ± 10.7; $p < 0.001$) and BK (Land: 19.20° ± 3.18, Water: 27.86° ± 6.41; $p < 0.001$), but was not significantly different (Land: 34.61° ± 4.58, Water: 38.87° ± 6.20) during FK ($p = 0.058$).

Table 5.2 contains peak sagittal plane angular displacement of lower extremity joints in OW and NW groups in water and land during stationary exercises. Post hoc analysis showed significantly greater peak ankle dorsiflexion and hip flexion in NW than OW group during SR and FK in land. In addition, peak knee extension ($p = 0.003$) during BK and peak hip extension during SR ($p = 0.001$) and BK ($p = 0.002$) were significantly greater in OW than NW in land. However, there were no significant differences observed in sagittal plane peak flexion and extension kinematics of lower extremity joints between groups during any of the exercises when completed in water ($p < 0.05$).

Table 5.2. Means (SD) for peak sagittal plane angular displacement of lower extremity joints during stationary exercises.

	Stationary running						**Frontal kick**						**Butt kick**					
Condition	**Land**			**Water**			**Land**			**Water**			**Land**			**Water**		
Group	OW	NW	*P*	OW	NW	*P*	OW	NW	*P*	OW	NW	*P*	OW	NW	*P*	OW	NW	*P*
Peak ankle plantarflexion (°)	23.16 (6.65)	23.80 (5.23)	0.895	33.09 (10.70)	32.44 (9.45)	0.798	29.23 (5.04)	26.96 (5.33)	0.601	44.69 (7.26)	43.15 (7.26)	0.714	25.56 (7.40)	25.77 (7.76)	0.890	28.85 (4.86)	28.46 (7.63)	0.949
Peak ankle dorsiflexion (°)	-9.37 (4.24)*	-14.76 (7.00)*	***0.002***	-1.15 (2.09)	-1.32 (2.65)	0.981	-7.40 (3.29)*	-12.96 (2.88)*	***0.002***	8.68 (3.48)	7.15 (3.90)	0.530	-11.33 (4.40)	-15.90 (4.99)	0.056	1.27 (2.01)	-1.08 (2.17)	0.086
Peak knee flexion (°)	-102.18 (12.93)	-109.22 (15.89)	0.143	-102.03 (17.04)	-104.84 (15.10)	0.604	-33.85 (7.11)	-31.66 (6.84)	0.145	-29.37 (7.44)	-27.27 (10.21)	0.451	-119.15 (22.40)	-126.10 (24.54)	0.336	-121.15 (23.26)	-129.20 (17.45)	0.221
Peak knee extension (°)	-12.36 (5.84)	-16.30 (7.41)	0.075	-11.17 (3.48)	-11.24 (5.85)	0.892	7.80 (2.42)	10.65 (3.96)	0.086	10.25 (4.10)	10.56 (3.58)	0.230	-4.25 (2.24)*	-8.53 (2.63)*	***0.003***	-3.84 (1.24)	-3.81 (1.123)	0.910
Peak hip flexion (°)	-52.01 (10.06)*	-65.53 (11.38)*	***0.035***	-68.69 (8.25)	-70.94 (9.53)	0.225	-31.75 (6.44)*	-38.04 (5.88)*	***0.012***	-37.53 (7.10)	-37.06 (7.33)	0.910	-26.01 (10.61)	-29.10 (7.27)	0.249	-29.97 (6.65)	-32.06 (9.97)	0.351
Peak hip extension (°)	-0.62 (1.31)*	-4.76 (2.78)*	***0.001***	0.10 (2.18)	0.23 (1.82)	0.873	1.14 (3.36)	-1.68 (3.95)	0.354	1.57 (1.77)	1.58 (2.64)	0.896	-6.46 (3.47)*	-10.25 (3.54)*	***0.002***	-3.28 (1.13)	-3.03 (1.82)	0.750

Note: OW: Overweight; NW: Normal-weight. Values are mean ± SD.*Significant differences in peak flexion and extension between groups ($p<0.05$).

Figure 5.2 demonstrates the angular positions during stance phase and angular velocities of lower extremity joints during the whole cycle of stationary exercises. OW children performed stationary exercises with significantly more extended joints than NW during stance phase in land apart from knee and hip joints in FK. However, there was no significant difference observed between groups in water during stance phase of all exercises (Figure 5.2A, 5.2B, 5.2C). For both groups, lower extremity joints were significantly more extended in water than land during stance phase of all exercises, except for the hip joint in FK. Angular velocities of all joints were similar between groups during all exercises in water. Similarly, angular velocities of all joints were similar between groups during FK and BK in land. However, the angular velocities of knee and hip joints were greater in NW than OW during SR in land (Figure 5.2D, 5.2E, 5.2F). Both groups displayed significantly greater angular velocities across all lower extremity joints on land compared to in the water during all exercises, with the exception of hip angular velocity in BK, which maintained similar values between environments.

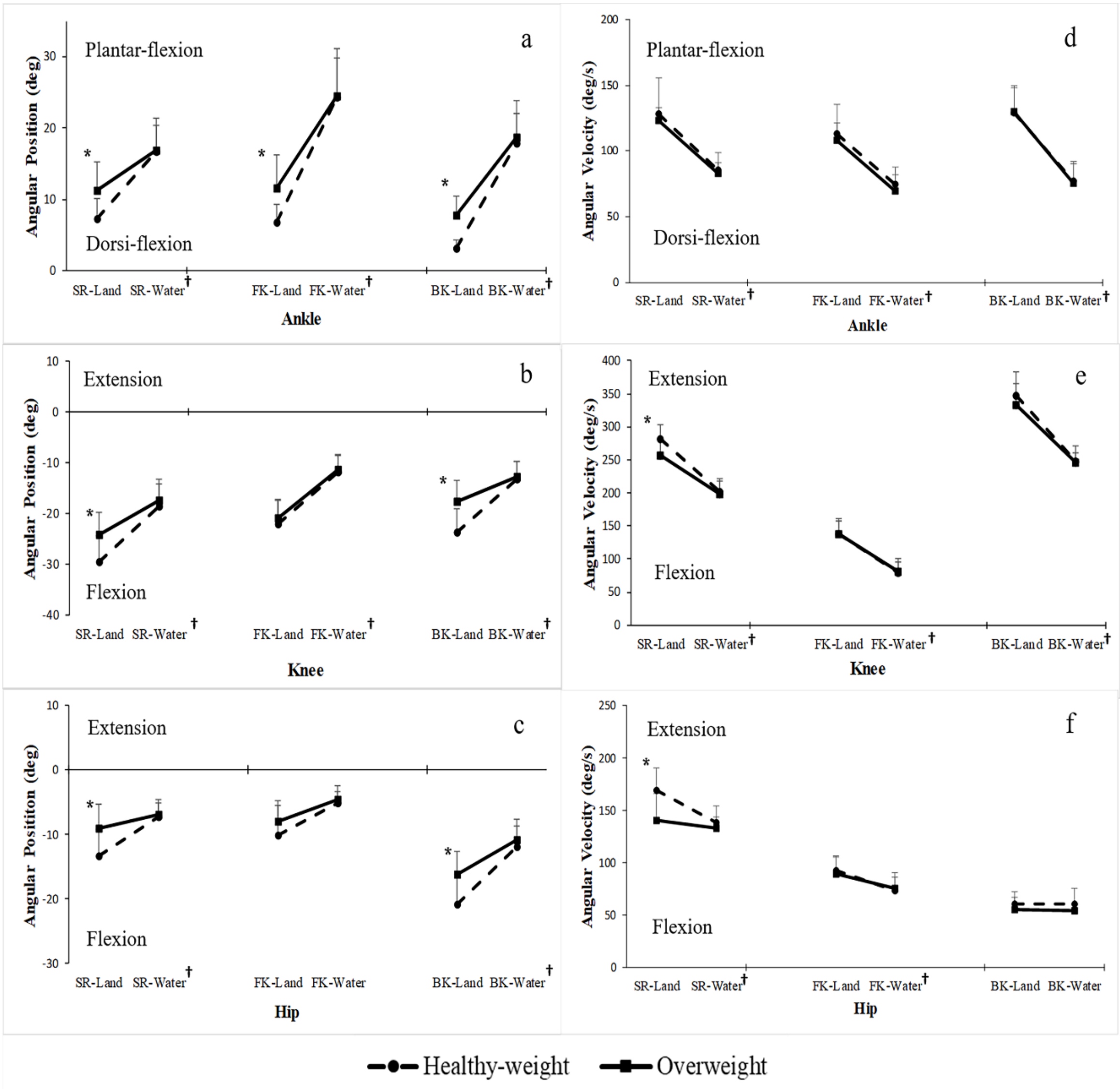
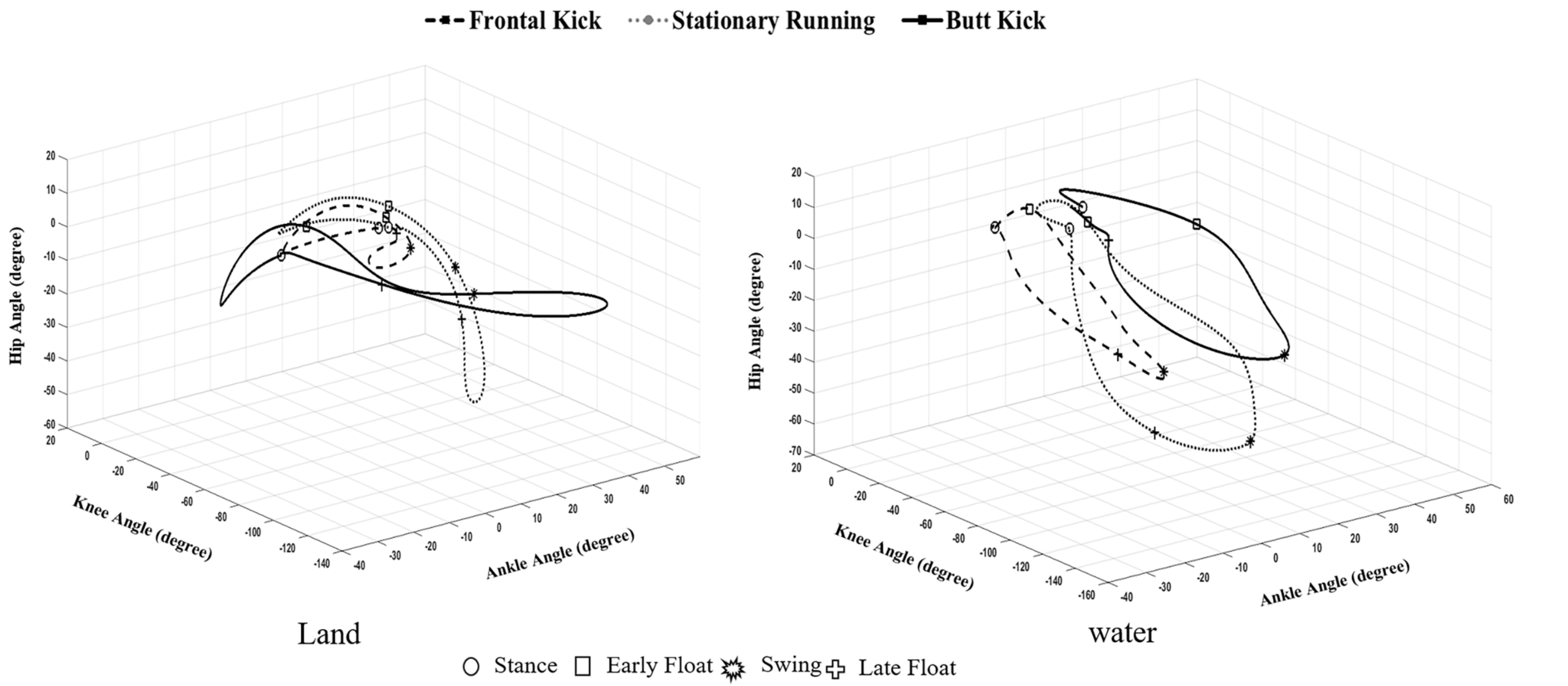


Figure 5.2: Differences in angular kinematics of lower extremities during SR, FK, and BK. Angular position (A, B, and C) and angular velocity (D, E, and F) are presented at ankle (A and D), knee (B and E), and hip (C and F) joints. *Significant differences between groups (P < .05). **Significant differences between environments (P < .05). BK indicates butt kick; FK, frontal kick; SR, stationary running.

There were no differences between groups for the 3D surface area of hip-knee-ankle plots during all exercises ($p < 0.05$). Thus, the related data for both groups were pooled together to compare the hip-knee-ankle plots of stationary exercises in water and land (Figure 5.3), where lower extremity coordination patterns were significantly different between environments. The hip-knee-ankle plots revealed a more expanded coordination pattern between joints throughout the phases of stationary exercises in water in comparison to land, which demonstrated a more linear pattern. These differences were emphasised by significantly greater 3D surface area of hip-knee-ankle plots during all exercises in water in comparison to land ($p < 0.05$).



	Stationary Running	*P*	Frontal Kick	*P*	Butt Kick	*P*
Land (degree²)	563.00 ± 156.99	***< 0.001***	307.51 ± 64.44	***< 0.001***	498.87 ± 142.68	***0.001***
Water (degree²)	1205.89 ± 320.42		495.35 ± 124.62		709.08 ± 182.74	

Figure 5.3: Typical hip-knee-ankle plot and means (SD) of the surface areas during stationary exercise phases at submaximal intensity.

Discussion

This study compared the exercise intensity (i.e. RPE), spatiotemporal parameters and lower extremity joint kinematics (ROM, peak flexion and extension, angular velocity, angular position and coordination patterns between joints) between NW and OW during SR, FK and BK exercises in shallow water and on land. OW children performed stationary exercises in a stiffer, more upright posture on land, with a corresponding increase in RPE when compared to NW children (Ekkekakis and Lind 2006). However, these differences did not exist in water (Table 5.1). Thus, the hypothesis has been supported. In addition, all children produced significantly lower cadence and angular velocity in water compared to land. Similar ROM and duration of phases were seen between groups, regardless of exercise or condition; however, the duration of early and late float phases for all exercises and groups increased significantly in shallow water compared to land, with subsequent decreases in duration of stance and swing phases.

The low weighted environment of water seems to be especially beneficial to OW children, who responded to improved enjoyment and musculoskeletal comfort by identifying significantly lower RPE values in water. Angular velocities across all lower extremity joints was significantly decreased in shallow water than land, for both groups in all exercises at similar HR, due to the hydrodynamic resistance of water (Figure 5.2D, 5.2E, 5.2F). Thus, lower angular velocities lead to reduced cadence in water, which is consistent with previous studies (Chevutschi, Alberty et al. 2009, Fontana, Ruschel et al. 2015). In addition, the cadences between groups were similar for all exercises in shallow water and land with exception of SR on land. SR also exhibited greater hip ROM than FK and BK; the increased ROM, combined with a heavier segmental mass of the thigh, could produce greater mechanical demands associated with moving excess mass in OW children.

Buoyant forces resulted in increased duration of early and late float phases and decreased the duration of the stance and swing phases during stationary exercises in water in comparison to land for both groups. The combination of these changes in duration of phases throughout the whole cycle (%) resulted in a more equivalent ratio of time between single limb support phases and double limb unsupported phases in shallow water than land at submaximal intensity. Thus, OW and NW children spent approximately 21% more time in floatation phases, which can assist them in controlling downward movement of the lower extremity during stationary exercises in shallow water than land (Figure 5.1).

The greater ROM at hip joint during SR and BK in water compared to land are consistent with previously published findings (Alberton, Cadore et al. 2011, Alberton, Pinto et al. 2015) and can be explained by the effect of buoyancy and facilitation of the movements in water. The buoyant effect of water assists in ascending (hip flexion) and the weight of the thigh segment facilitates descending (hip extension) of thigh segment during SR and BK. In contrast, FK presents similar ROM between environments for all joints and this can be due to the increased water resistance against thigh and leg segments movement in water. The FK presents hip flexion and extension movements associated with the extended knee during the whole cycle opposite to the SR and BK hip-knee pattern in which hip motion is associated with knee flexion and extension (Alberton, Pinto et al. 2014). The lack of differences in peak sagittal plane angular displacement of lower extremity joints between OW and NW during stationary exercises could be due to the different physical properties of the aquatic environment to land. Thus, performing stationary exercises in shallow water can diminish the differences in peak angular displacement of lower extremity joints between NW and OW. In addition, the peak sagittal plane angular displacement revealed that lower extremity joints are more extended during performing stationary exercises in shallow water in comparison to land due to the buoyant effect of water, which supports the body weight against gravity (Table 5.2).

OW children performed stationary exercises with less flexed/more extended joints than NW during stance phases in land, which is consistent with the previous literature in gait (Gushue, Houck et al. 2005, McMillan, Pulver et al. 2010) (Figure 5.2A, 5.2B, 5.2C). This could be a compensation for relatively weak hip and knee extensors or may also be a compensation for instability within the lower extremity joint structure of OW children during stationary exercises in land. In contrast, there were no differences observed between NW and OW children in angular position during stance phases of all exercises in shallow water. The similarity in angular positions between groups during stance phases in water compared to land could be due to lower mechanical load associated with moving excess mass in OW children when performing stationary exercises. In addition, the lower extremity joints were more extended in water due to reduction in the load required to support the body against gravity in both groups during stance phases of stationary exercises. The more extended/less flexed joints during stance phases in both groups were also consistent with the results of peak sagittal plane angular displacement (Table 5.2). Therefore, the use of hydrodynamic and hydrostatic principles can be used as an effective way of controlling extra body mass loads acting on body structure of OW children, while promoting health through stationary exercises. Performing exercises in aquatic environment can be an alternative option to on land, to help OW children to respond similarly to NW children, when moving their extra body mass. The 3D hip-knee-ankle angles plots showed different kinematic patterns between lower extremity joints during stationary exercises in shallow water in comparison to land (Figure 5.3). The wider angle-angle-angle pattern of lower extremity joints could be due to greater ROM, slower frequency (longer lag between flexion and extension of joints) and longer floatation phases in shallow water in comparison to land (Figure 5.3).

There were some limitations to this study. Specifically, the kinetic and muscle activity analysis were not possible, as the waterproof setup was not available. We acknowledge that a full kinematic, kinetic and muscle activity analysis could have provided greater insights. However, we still observed interesting differences between groups and environments that help to explain why aquatic exercises are a beneficial option for OW children. We focused on the sagittal plane kinematics, as flexion and extension are the primary movements to stationary exercises. However, we do acknowledge that three-dimensional, and particularly the frontal plane kinematics, would have been of interest to this population.

Conclusion

The OW children exhibited higher RPE and altered lower extremity kinematics during stationary exercises in land when compared to NW children. However, these differences diminished between groups in water with a lower RPE in OW children and a more upright posture for both groups. These results suggest that stationary exercises in shallow water can provide a desirable way of reducing functional differences and subsequently promoting physical activity in OW children. Future research will be necessary to study other important components of stationary exercises in children such as neuromuscular, ground reaction force and cardiorespiratory responses at different intensities in both environments.

Practical Implications

1. When completing exercise on land, overweight children show different movement patterns and increased perceived exertion than normal-weight children.
2. When completing exercise in water, kinematic and physiological differences do not exist between weight groups.
3. Aquatic exercise minimises the effects of excess mass, allowing overweight children to complete physical activity in a similar manner to normal-weight peers.

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Statement of contribution to doctoral thesis containing publications

DRC 16

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STATEMENT OF CONTRIBUTION
TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Mostafa Yaghoubi

Name/Title of Principal Supervisor: Philip Fink

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In which Chapter is the Published Work: Chapter 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  I have had full involvement in the study as the first author and preparation of the manuscript. I was also the corresponding author for the manuscript.

Mostafa Yaghoubi
Candidate's Signature

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16/02/2019
Date

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Chapter 6: Conclusion

The physical properties of water produce simultaneous reductions in movements throughout the cycle and loading at impact during stationary exercise. However, the joint range of motion can be increased due to water-assisted body weight support. Previous research has recommended that exercise in water could be a safer environment without fear of falling and injury (Arnold and Faulkner 2010, Zivi, Maffia et al. 2017). However, recent studies revealed more instability, asymmetry and variability during aquatic exercises (Cadenas-Sanchez, Arellano et al. 2015, Cadenas-Sánchez, Arellano et al. 2016). The variability is affected by changes in buoyancy due to immersion level and resistance forces (related to intensity and speed) and can affect both research and clinical applications. Despite the large number of research studies published investigating the biomechanics of aquatic activities, there is a lack of consensus in the results. Additionally, previous aquatic biomechanical research is limited to aquatic gait in adults and elderly people. The lack of aquatic research in children is of great concern, as aquatic sports provide a low-weight bearing activity that diminishes the likelihood of injuries in children and provides a solid foundation for physical activity throughout the lifespan.

Chapter 3 (technical note) examined an inexpensive and easily constructed sport camera-based motion capture system and showed that it provided adequate video capture for analysis of movement in air and underwater conditions. The GoPro camera derived angular velocity measurements underwater and air that are accurate when compared to data from inertial sensors and known motion of the clock's second hand

and a driven limb segment model. Therefore, it can be used for research and training purposes.

Chapter 4 showed that overweight children had higher muscle activation during land-based stationary exercise, suggesting that strength has not increased proportionally with mass in overweight children. Subsequently, overweight children need to use a greater percentage of their muscle activation when performing submaximal stationary exercises on land. The increased muscle activation in overweight groups, as well as between exercises, indicates that stationary exercise can be prescribed to improve lower extremity muscle strength and endurance in overweight children, but mode and intensity must be considered.

Chapter 5 demonstrated that overweight children exhibited higher RPE and altered lower extremity kinematics during stationary exercises in land when compared to NW children. However, these differences diminished between groups in water with a lower RPE in overweight children and a more upright posture for both groups. These results suggest that stationary exercises in water can provide a desirable way of reducing functional differences and subsequently promoting physical activity in overweight children. The same participants were participated in both studies (i.e. chapters 4, 5) and the land based stationary exercises data collected for chapter 4 were used in chapter 5 again to make the comparison between environments and groups.

This thesis has increased the knowledge of aquatic and land-based stationary exercises in normal-weight and overweight children, which has exposed several areas that require further research. These include:

1. The analysis of ground reaction force and cardiorespiratory responses as well as implementation of other stationary exercises at different intensities in a variety of weight bearing environments;
2. The physiological and biomechanical characteristics of overweight and normal-weight children's gait in aquatic environment.
3. Biomechanical analysis of various aquatic devices (such as aqua bikes or elastic tether) for conditioning and rehabilitation purposes.
4. The identification of biomechanical and anthropometric benefits of aquatic exercise (e.g. flippa ball) intervention on overweight and obese children.

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TE KURA HAUORA TANGATA

Appendix A

PARTICIPANT AND PARENT/CAREGIVER CONSENT FORM

The biomechanics of water-based and land-based exercises

Please circle Y or N for your response below:

I have read and I understand the information sheet for volunteers taking part in the study designed to examine the muscle activation patterns of lower limb muscles during a variety of jogging tasks.	Y N
I understand that it is my and my child's choice to participate in this study and he/she can withdraw at any time without giving any reason.	Y N
I understand that my child's participation in this study is confidential and that no material that could identify my child will be used in any reports or presentation in this study.	Y N
I have had time to consider whether my child will take part in the study.	Y N
I know who to contact if I have any questions about the study.	Y N
I wish to have my child's results from the study given to me.	Y N

Please choose one transportation option:

- ☐ I give permission for my child to leave school campus with the university researcher, and I understand that this could involve having my child ride in a car.
- ☐ I will provide transportation to Massey University for my child.

Signature of Parent or Caregiver: .... Date: ....

Full Name (Printed): ....

Witness by (name printed): ....

Witnessed by (signature): ....

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Statement of Child Assent

Your parent or caregiver has allowed you to be part of this research project. By signing your name below, you understand:

- What you will be asked to do during each testing session;
- That you are free to ask any question at any stage during the testing;
- That you can stop being part of the study at any time, without giving any reason.

If you would like to be part of the project, please sign your name on the line below.

Name: ....

Signature:..

Date .... / .... / ....

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Appendix B

Format for Confidentiality Agreement

Researchers must obtain a signed confidentiality agreement from anyone, such as research assistants, who will process any data which contains personal information. This should cover agreement to not disclose, retain or copy information.

Prepare your Confidentiality Agreement for persons other than the researcher/participants who have access to project data, based on the format below.

The biomechanics of underwater exercise

CONFIDENTIALITY AGREEMENT

I .... (Full Name - printed)

Agree to keep confidential all information concerning the project

....

....

....

.... (Title of Project).

I will not retain or copy any information involving the project.

Signature: .... **Date:** ....

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Format for Transcriber's Confidentiality Agreement

Researchers must obtain a signed confidentiality agreement from transcribers who will process audio recordings which contain personal information. This should cover agreement to not disclose, retain or copy information.

Prepare your Transcriber's Confidentiality Agreement based on the format below.

The biomechanics of underwater exercise

TRANSCRIBER'S CONFIDENTIALITY AGREEMENT

I .... (Full Name - printed) agree to transcribe the recordings provided to me.

I agree to keep confidential all the information provided to me.

I will not make any copies of the transcripts or keep any record of them, other than those required for the project.

Signature: .... **Date:** ....

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TE KURA HAUORA TANGATA

Appendix C

Health and Activity Recruitment Questionnaire

The biomechanics of underwater exercise

Child name:______________________ **DOB:**________ **Age:**_____
Gender: _____

Parent name:____________________________

Contact phone: (H):________________ (W): _______________
mobile:____________

Email:_________________________________ Fax:_______________________

Address:____**Post code**:_______

What is your child's current **height** (preferably without shoes on)?

What is your child's current **weight** (preferably first thing in the morning with minimal clothing)?

<u>Has your child recently (within the last 6 months) had an acute injury to the lower body that required medical attention?</u> (i.e. fracture, sprain, strain)

Yes **No**

- If yes please provide details: ____

<u>Has your child ever had surgery to correct an orthopaedic or neuromuscular condition?</u>

Yes **No**

- If yes please provide details: ____

<u>Has your child had any exposure to radiation in the last 12 months?</u> (i.e xrays, CT scan, etc.)

Yes **No**

- If yes, please give details of what they had and the date______________________________

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Does your child have any of the following conditions? (If so, please circle whichever apply)

Cerebral palsy	Muscular dystrophy	Autism	
Asthma	Diabetes	Heart murmur	
Dyspraxia	Spina Bifida	Arthritis	Skin allergies/conditions

Other condition (please specify):______________________________

Is your child on any medications or supplements?: ____

- **If yes, what are these for?**

Compared to other people their age, how would you rate your child's physical health at the present?

(please circle one)

Excellent	Very good	Good	Fair	Poor	Don't know
1	2	3	4	5	6

How would you describe your CHILD's present weight? *(please circle one)*

Underweight	Normal Weight	Overweight	Obese

Compared to other people their age, how would you rate your child's physical activity levels at the present? *(please circle one)*

Excellent	Very good	Good	Fair	Poor	Don't know
1	2	3	4	5	6

Have you exercise in the water before?

Yes **No**

- If no, are you comfortable to participate in the water sessions? **Yes** **No**

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Please fill out the following table for each physical activity (e.g. Bike riding; Netball; Swimming) that your child currently does in a typical WEEK.

Physical Activity	Monday-Friday			Saturday-Sunday		
	How many times?	Minutes per session	Total minutes	How many times?	Minutes per session	Total minutes

Please fill out the following table for each leisure activity (e.g. Homework, Watching TV, Playing video games) that your child currently does in a typical WEEK.

Physical Activity	Monday-Friday			Saturday-Sunday		
	How many times?	Minutes per session	Total minutes	How many times?	Minutes per session	Total minutes

Thank you for completing this questionnaire

Please return to:

Mr Mostafa Yaghoubi

School of Sport and Exercise

Massey University

Email: m.yaghoubi@massey.ac.nz

Appendix D

MASSEY UNIVERSITY
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TE KURA HAUORA TANGATA

Is your child interested in aquatic jogging?

VOLUNTEERS WANTED FOR RESEARCH

The School of Sport and Exercise, Massey University is currently conducting an Aquatic exercise study to compare the differences in joint motion and muscle activity between similar water-based and land-based exercises in children.

We're looking for 10-13 years olds. The study will be carried out on the Wellington campus (Maori Health Centre). It involves 2 testing sessions. These sessions will focus on aquatic and over-ground stationary exercises.

Participants will receive a voucher after testing for their time.

For more information, or if you and your child are interested in taking part, please contact:
Mostafa Yaghoubi
Email: m.yaghoubi@massey.ac.nz
And ask about the 'AquatSport' study.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 14/08. if you have any concerns about the conduct of this research, please contact Massey University Human Ethics Committee: Southern A, telephone 04080105799 x 63487, email humanethicsoutha@massey.ac.nz

Appendix E

Human Ethics approval letters

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA

6 November 2014

Mostafa Yaghoubi
[redacted]

Dear Mostafa

Re: HEC: Southern A Application – 14/76
Aquatic exercise: An option for motor development and weight management

Thank you for your letter dated 6 November 2014.

On behalf of the Massey University Human Ethics Committee: Southern A I am pleased to advise you that the ethics of your application are now approved. Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Dr Brian Finch, Chair
Massey University Human Ethics Committee: Southern A

cc Dr Sarah Shultz
School of Sport & Exercise
WELLINGTON

Dr Philip Fink
School of Sport & Exercise
PN621

A/Prof Wyatt Page
IFNHH
WELLINGTON

Prof Stephen Stannard, HoS
School of Sport & Exercise
PN621

A/Prof Rachel Page, HoI
IFNHH
WELLINGTON

Massey University Human Ethics Committee
Accredited by the Health Research Council
Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11222, Palmerston North 4442, New Zealand T 06 3505573; 06 3505575 F 06 350 5622
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz www.massey.ac.nz

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA

25 March 2014

Mostafa Yaghoubi
[redacted]

Dear Mostafa

Re: HEC: Southern A Application – 14/08
The biomechanics of aquatic exercise

Thank you for your letter dated 20 March 2014.

On behalf of the Massey University Human Ethics Committee: Southern A I am pleased to advise you that the ethics of your application are now approved. Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

J. O'Neill

Dr Brian Finch, Chair
Massey University Human Ethics Committee: Southern A

cc Dr Sarah Shultz
School of Sport & Exercise
WELLINGTON

Dr Philip Fink
School of Sport & Exercise
PN621

A/Prof Wyatt Page
IFNHH
WELLINGTON

Prof Stephen Stannard, HoS
School of Sport & Exercise
PN621

Appendix F

Massey University
Te Kunenga ki Pūrehuroa

SCREENING QUESTIONNAIRE
TO DETERMINE THE APPROVAL PROCEDURE

(Part A and Part B of this questionnaire must both be completed)

Name: Mostafa Yaghoubi
Project Title: The biomechanics of underwater exercises

This questionnaire should be completed following, or as part of, the discussion of ethical issues.

Part A

The statements below are being used to determine the risk of your project causing physical or psychological harm to participants and whether the nature of the harm is minimal and no more than is normally encountered in daily life. The degree of risk will then be used to determine the appropriate approval procedure.

If you are in any doubt you are encouraged to submit an application to one of the University's ethics committees.

Does your Project involve any of the following?
(Please answer all questions. Please circle either YES or NO for each question)

Risk of Harm

1.	Situations in which the researcher may be at risk of harm.	YES	NO
2	Use of questionnaire or interview, whether or not it is anonymous which might reasonably be expected to cause discomfort, embarrassment, or psychological or spiritual harm to the participants.	YES	NO
3.	Processes that are potentially disadvantageous to a person or group, such as the collection of information which may expose the person/group to discrimination.	YES	NO
4.	Collection of information of illegal behaviour(s) gained during the research which could place the participants at risk of criminal or civil liability or be damaging to their financial standing, employability, professional or personal relationships.	YES	NO
5.	Collection of blood, body fluid, tissue samples, or other samples.	YES	NO
6.	Any form of exercise regime, physical examination, deprivation (e.g. sleep, dietary).	YES	NO
7.	The administration of any form of drug, medicine (other than in the course of standard medical procedure), placebo.	YES	NO
8.	Physical pain, beyond mild discomfort.	YES	NO
9.	Any Massey University teaching which involves the participation of Massey University students for the demonstration of procedures or phenomena which have a potential for harm.	YES	NO

Informed and Voluntary Consent

10. Participants whose identity is known to the researcher giving oral consent rather than written consent (if participants are anonymous you may answer No).	YES	NO
11. Participants who are unable to give informed consent.	YES	NO
12. Research on your own students/pupils.	YES	NO
13. The participation of children (seven (7) years old or younger).	YES	NO
14. The participation of children under sixteen (16) years old where active parental consent is not being sought.	YES	NO
15. Participants who are in a dependent situation, such as those who are under custodial care, or residents of a hospital, nursing home or prison or patients highly dependent on medical care.	YES	NO
16. Participants who are vulnerable.	YES	NO
17. The use of previously collected identifiable personal information or research data for which there was no explicit consent for this research.	YES	NO
18. The use of previously collected biological samples for which there was no explicit consent for this research.	YES	NO

Privacy/Confidentiality Issue

19. Any evaluation of organisational services or practices where information of a personal nature may be collected and where participants or the organisation may be identified.	YES	NO

Deception

20. Deception of the participants, including concealment and covert observations.	YES	NO

Conflict of Interest

21. Conflict of interest situation for the researcher (e.g. is the researcher also the lecturer/teacher/treatment-provider/colleague or employer of the research participants or is there any other power relationship between the researcher and research participants?)	YES	NO

Compensation to Participants

22. Payments or other financial inducements (other than reasonable reimbursement of travel expenses or time) to participants.	YES	NO

Procedural

23. A requirement by an outside organisation (e.g. a funding organisation or a journal in which you wish to publish) for Massey University Human Ethics Committee approval.	YES	NO

Part B

FOR PROPOSED HEALTH AND DISABILITY RESEARCH ONLY

Not all health and disability research requires review by a Health and Disability Ethics Committee (HDEC).

Your study is likely to require HDEC review if it involves:

- **human participants recruited in their capacity as:**
  - **consumers of health or disability support services; or**
  - **relatives or caregivers of such consumers; or**
  - **volunteers in clinical trials; or**
- **human tissue; or**
- **health information.**

In order to establish whether or not HDEC review is required: (i) read the Massey University Digest of the HDEC Scope of Review standard operating procedure; (ii) work through the 'Does your study require HDEC review?' flowchart; and (iii) answer Question 24 below.

If you are still unsure whether your project requires HDEC approval, please email the Ministry of Health for advice (hdecs@moh.govt.nz) and keep a copy of the response for your records.

24. Is HDEC review required for this study?	YES NO

Select the appropriate procedure to be used (choose one option):

If you answer **YES** to any of the questions 1 to 23 (Part A) and **NO** to Q24 in Part B	If you answer **YES** to question **24** (Part B)	If you answer **NO** to all of the questions in Parts A and B*
↓	↓	↓
Prepare an application using the MUHEC Application Pack	**Prepare an application using the Health & Disability Ethics Committee Application Form**	**Prepare a Low Risk Notification** ** Note- researchers who are new to the University, new to research with human participants or for whom Committee approval is desirable are welcome to send in a full MUHEC application, even if the Screening Questionnaire questions have all been answered "no".*

↓ ↓

GO BACK TO APPROVAL PROCEDURES, STEP 4, AND DOWNLOAD THE INFORMATION REQUIRED.

http://www.massey.ac.nz/massey/research/research-ethics/human-ethics/forms-and-procedures.cfm