ABSTRACT
Water has a density 800 times greater than that of air. During water exercise, kinetic and kinematic aspects such as body motion, ground reaction force, joint moment and muscle activity change dramatically compared with the same exercise forms on land mostly due to buoyancy and water drag force. This review of literature mainly focused on walking and running in water exercise. Furthermore, this article discussed future necessary study and practical implications. When walking in water, the motion was slower and joint motion was roughly similar to walking on land. However, some characteristics such as ground reaction force, lower extremity joint moment and muscle activity were much different from walking on land. During running in water, the motion was slower and joint motion was different from running on land. Ground reaction force and muscle activity showed discriminative differences compared with running on land. This review shows that investigation of kinesiology of running and other exercise forms in water were limited especially with regards to determining gender differences, and impact on those people with a disability or injury. Research of this nature would provide a useful suggestion for water exercise instruction to both different genders and populations. Key aspects of exercise in the water environment includes reduced gravity stress and increased safety without fear of injury or fall, which would suit a wide range of people. Future research possibilities were also discussed with practical implication for water exercise.

Keywords: water exercise, kinetics, kinematics, buoyancy, water drag force

INTRODUCTION
Due to the different density, hydro-static pressure, buoyancy, thermal conductivity, and drag force properties found in water, when compared to land, variations in the response to human exercise are expected. The density of water is roughly 800 times greater than air and the specific gravity of water is equal to ‘1’ (Burkett 2010). The specific density of an individual
can vary depending on body composition, with the human body having an overall average specific gravity of 0.974. Body fat’s specific density is less than 1, whilst bone, muscle and organs are just over 1 (Becker 2009).

Hydrostatic pressure is related to both density and depth. When a human is standing in water 1 m deep, pressure is increased by about 73.5 mmHg (Becker 2009), which is similar to normal diastolic pressure. Hydrostatic pressure causes blood to shift from lower extremities to the thoracic region (Arborelius, Ballidin, Lilja, & Lundgren 1972).

Buoyancy acts to oppose gravity on immersed objects because of gradual increase of hydrostatic pressure with depth. The degree of buoyancy force is equal to water weight displaced by the immersed object. When a human is immersed to the umbilicus region approximately 50% of body weight is eliminated by buoyancy, while immersion to the xiphoid process eliminates almost 60% (Becker 2009).

Water drag force consists of surface drag, form drag and wave drag (Burkett 2010). Surface drag is affected by viscosity of water and surface quality. Form drag depends on the shape and size of the object, whilst wave drag directly opposes and object’s movement. Water drag force increases proportionally by the frontal projected area and square of moving velocity (Naemi et al. 2011). Therefore, humans need to exert much greater force to overcome water drag force when moving in water.

Water thermal conductivity is about 25 times larger than air, which indicates versatile usage in rehabilitation for cardiovascular diseases (Becker 2009). In conditions with lower than thermo-neutral water temperature, vasoconstriction and blood shift to the thoracic region occurs as a thermoregulation reaction (Bonde-Petersen et al. 1992).

Among these physical properties of water, buoyancy and water drag force are essential when considering kinesiology of walking and running in water. Therefore, knowledge about kinesiology of walking and running in water is required to appropriately prescribe training programs, this knowledge is extended when treating reduced mobility cases and when rehabilitating from disability.

**KINESIOLOGY OF WATER WALKING**

Due to the drag forces in water, walking speed during water-walking decreases to approximately one-half to one-third land-walking speed, for the same metabolic intensity. The majority of literature shows the water-walking speed was set at one-half of the land-walking or self-selected speed. The self-selected water-walking speed is also reported as being approximately one-half to one-third of land-walking speed (Evans et al. 1978; Barela et al. 2006; Barela & Duarte 2008; Giaquinto et al. 2008; Chevutschi et al. 2009; Kaneda et al. 2009). Stride frequency during water-walking decreases to nearly a half of land-walking (Shono et al. 2007; Masumoto et al. 2008), increasing stride duration time to nearly double that of land-walking (Barela et al. 2006; Kaneda et al. 2009) when water-walking speed is set to one-half of land-walking or self-selected. An increase in water depth also causes a reduction in stride frequency (Pohl & McNaughton 2003). The longer stride duration during water-walking is due to longer time of both swing (Kato et al. 2001; Kaneda et al. 2008b) and stance phases (Kaneda et al. 2008b) when compared with land-walking. Percentage of stance time of stride duration (% stride duration time) also decreases slightly during water-walking compared with land-walking (Barela et al. 2006; Barela & Duarte 2008; Kaneda et al. 2009), and Orseli & Duarte (2011) reported a significant decrease. This might be due to weight reduction by buoyancy as reported in simulated reduced gravity conditions (Ivanenko et al. 2002). Stride length also shorten slightly during water-walking compared with land-walking (Barela et al. 2006; Barela & Duarte 2008; Giaquinto et al. 2008; Orseli & Duarte et al. 2011), with a significant reduction detected by Masumoto et al. (2008). If the walking speed is set to the same between water-walking and land-walk-
ing, the stride length is longer during water-walking than land-walking (Shono et al. 2007). Thus, walking parameters during water-walking change to slower speed, lower stride frequency, and longer stride duration than those of land-walking which indicates the water environment increases stability and control of movement increasing safety and reducing rate of fall accidents during exercise.

Ankle, knee and hip joint angles are roughly similar between water-walking and land-walking (Miyoshi et al. 2003; Miyoshi et al. 2004; Barela et al. 2006; Degani & Danna-dos-Santos 2007; Barela & Duarte 2008). However there is disagreement with respect to the ankle joint, as some literature reported increased dorsi flexion (Miyoshi et al. 2003; Miyoshi et al. 2004; Kaneda et al. 2008b) and other reported decreased dorsi flexion (Barela et al. 2006; Degani & Danna-dos-Santos 2007; Barela & Duarte 2008) during water-walking compared with land-walking. Further, dorsi flexion peak occurred 10% earlier in the stance phase during water-walking when compared with land-walking (Miyoshi et al. 2003; Miyoshi et al. 2004). Some differences in ankle joint range of motion (ROM) have been reported as smaller ROM (Degani & Danna-dos-Santos 2007) or larger ROM (Kaneda et al. 2008b) during water-walking than land-walking, yet most literature showed no significance differences (Kato et al. 2001; Miyoshi et al. 2003; Miyoshi et al. 2004; Barela et al. 2006; Barela & Duarte 2008). These results would suggest that ankle joint motion is still similar between water-walking and land-walking. Knee joint flexion is larger during water-walking than land-walking at heel contact (Miyoshi et al. 2003; Miyoshi et al. 2004; Barela & Duarte 2008; Kaneda et al. 2008b) and normal knee flexion post heel contact seen during land-walking mostly disappears during water-walking (Miyoshi et al. 2003; Miyoshi et al. 2004; Barela et al. 2006; Degani & Danna-dos-Santos 2007). This may be attributed to weight reduction effect of buoyancy requiring less load absorption during water-walking (Miyoshi et al. 2003; Miyoshi et al. 2004). At the end of stance phase, knee joint shows an increased extension position during water-walking compared to land-walking (Miyoshi et al. 2004; Barela & Duarte 2008; Kaneda et al. 2008b), resulting in a smaller knee joint ROM during water than land (Miyoshi et al. 2003; Miyoshi et al. 2004). During swing phase, the knee joint tends to be more flexed during water than land to avoid water drag force of shank (Kato et al. 2001; Shono et al. 2007). In the result, knee joint motion remains similar during water-walking compared with land-walking except when walking speed is matched between both conditions where knee joint ROM is larger during water than land (Kato et al. 2001). Hip joint shows increased flexion throughout stance phase (Miyoshi et al. 2003; Miyoshi et al. 2004) and at heel contact and toe off (Barela & Duarte 2008; Kaneda et al. 2008b) during water-walking compared to land-walking. In addition, maximum hip joint flexion is larger during water than land (Kato et al. 2001; Barela et al. 2006). Larger hip joint ROM during water than land at self-selected faster speed has also been reported (Miyoshi et al. 2004; Kaneda et al. 2009). Kaneda et al. (2009) reported more forward inclination of pelvis and trunk during water than land, and this inclination increased with self-selected speed increment. This phenomenon may occur to compensate for dramatically increased water drag force (Kaneda et al. 2009). This inclination would contribute to increased hip joint ROM during water-walking as buoyancy might allow increased thigh flexion motion during swing phase (Kaneda et al. 2008b).

Elderly and young adults lower extremity joint motion is similar during water-walking compared with land-walking. However differences seen by comparison between elderly and young adults during water-walking show that elderly subjects produce more ankle joint dorsi flexion at toe off, knee joint flexion at heel contact, and hip joint flexion at toe off than young adults (Barela & Duarte 2008). Age may also influence movement in water, with shorter stride duration reported in...
the elderly than young during water-walking (Barela & Duarte 2008) and similar changes were also seen between walking parameter from land to water for both groups. However, this is not consistent in the literature as Giaquinto et al. (2008) reported no age difference in any walking parameter and Masumoto et al. (2007a) showed higher stride frequency in elderly than young with treadmill water-walking. These characteristics might be affected by decrease of muscle power by aging, and lower propulsive force increasing stride frequency during water-walking (Masumoto et al. 2007a). Evidence also suggests there is no gender effect in any walking parameter during water-walking (Chevutschi et al. 2009). Further research is required to consolidate the effect of aging on water-walking.

Vertical GRF ($\gamma$GRF) during water-walking decreases with depth increment or weight load decrement (Nakazawa et al. 1994b; Miyoshi et al. 2006; Roesler et al. 2006). The two $\gamma$GRF peaks identified during land-walking disappear gradually during water-walking as water depth increases (Nakazawa et al. 1994b). This appears to be due to the reduction of impact force and weight load effect of buoyancy, creating a valley curve of $\gamma$GRF during water-walking (Barela et al. 2006; Roesler et al. 2006; Barela & Duarte 2008; Orselli & Duarte et al. 2011). $\gamma$GRF increases as walking speed increases, which relates to propulsive force generation against water drag force (Miyoshi et al. 2004; Miyoshi et al. 2006; Roesler et al. 2006). Anterior-posterior GRF ($a$GRF) also shows dramatic change from negative (posterior) direction seen during land-walking after heel contact to positive (anterior) direction during water-walking (Barela et al. 2006; Roesler et al. 2006; Degani & Danna-dos-Santos 2007; Barela & Duarte 2008; Orselli & Duarte et al. 2011), and increases as speed increments (Roesler et al. 2006). This suggests during water-walking the body always generates propulsive force to deal with increased water drag force (Barela et al. 2006; Roesler et al. 2006; Barela & Duarte 2008). Continuously positive $a$GRF during water-walking would affect motion changes presented before and after heel contact (Barela et al. 2006; Barela & Duarte 2008). Thus, $\gamma$GRF is affected by immersion level or weight load and walking speed, while $a$GRF is mostly affected by walking speed during water-walking (Roesler et al. 2006). It is considered that vertical and anterior forces would fluctuate less in lower extremities during water-walking.

Miyoshi et al. (2003; 2004; 2005) and Orselli & Duarte et al. (2011) calculated lower extremity joint moment during stance phase. Ankle joint shows a planter flexion moment during both water and land, and similar movement pattern between both conditions (Miyoshi et al. 2003; Miyoshi et al. 2004; Miyoshi et al. 2005). However, the moment is much smaller during water-walking than land-walking because of weight load reduction (Miyoshi et al. 2003; Miyoshi et al. 2004; Miyoshi et al. 2005). Both weight load and walking speed increment apparently enhance the planter flexion moment during water-walking (Miyoshi et al. 2005). At knee joint, land-walking shows two extension moment peaks in early and late stance phase, while water-walking has only one peak in late stance phase and shows flexion moment in the rest because propulsive force generation is needed instead of absorbing impact force (Miyoshi et al. 2003; Miyoshi et al. 2004; Miyoshi et al. 2005). When walking speed increased, an extension peak at knee joint in early phase emerges slightly during water-walking (Miyoshi et al. 2005). Hip joint moment dominates total moment during water rather than land (Miyoshi et al. 2003). During water-walking, an extension moment is always shown at hip joint though the moment changes extension to flexion during land-walking (Miyoshi et al. 2003; Miyoshi et al. 2004; Miyoshi et al. 2005). The extension moment during water-walking increases with walking speed increment (Miyoshi et al. 2005). Miyoshi et al. (2005) reported the effect of walking speed on hip joint moment was clearly different.
between water and land. They go on to suggest attention should be given to changes in hip moment in the late stance phase to reduce stress to the hip joint. Orselli & Duarte et al. (2011) computed power for each joint taking into account the water drag force concluding that exercise in water environment is effective for patients suffering joint problems as power for every joint was reduced greatly during water-walking compared with land-walking.

Research is not in agreement regarding muscle activation with some reporting. Tibialis Anterior activates more during water-walking than land-walking at self-selected speed in stance (Nakazawa et al. 1994a; Barela & Duarte 2008; Kaneda et al. 2008b) and swing phase (Barela et al. 2006; Barela & Duarte 2008; Kotani et al. 2009), while other studies reported no significant differences (Miyoshi et al. 2004; Kaneda et al. 2007). Nakazawa et al. (1994a) revealed intra and inter subject variability in Tibialis Anterior activity during water-walking. It would be concluded that Tibialis Anterior activity during water-walking depends on subject and instruction. Activation of Soleus was related to weight load and walking speed while Gastrocnemius was related only with walking speed (Nakazawa et al. 1994a; Miyoshi et al. 2006). Furthermore, changes in walking speed showed a much higher sensitivity in Gastrocnemius than Soleus (Nakazawa 1994a). Additionally, some studies reported lower Soleus activity (Chevutschi et al. 2007; Kaneda et al. 2008b; Kotani et al. 2009) during water than land, no significance in Gastrocnemius activity (Nakazawa et al. 1994a; Barela et al. 2006; Barela & Duarte 2008; Kaneda et al. 2008b; Kotani et al. 2009), and increased activity in Gastrocnemius with increased speed during water-walking at self-selected speed (Nakazawa et al. 1994a; Miyoshi et al. 2004; Kaneda et al. 2007; Kaneda et al. 2008b; Kotani et al. 2009). Similarly for the thigh muscles, Rectus Femoris activity is larger during water-walking than land-walking in swing phase at self-selected speed because of swinging whole lower extremity against water drag force (Chevutschi et al. 2007; Kaneda et al. 2008b). Vastus Lateralis tends to be higher during water-walking than land-walking in middle of stance phase with similar difference seen in Biceps Femoris activity (Barela et al. 2006; Barela & Duarte 2008). Higher Biceps Femoris activity during water-walking than land-walking at self-selected speed was also found in the literature (Nakazawa et al. 1994a; Nakazawa et al. 1994b; Miyoshi et al. 2004; Kaneda et al. 2007; Kaneda et al. 2008b). This phenomenon would indicate the necessity of constant muscle activation during water-walking to propelling body forward by overcoming water drag force (Miyoshi et al. 2005; Barela & Duarte 2008; Giaquinto et al. 2008). Gluteus Maximus is also higher during water than land because of the increased propulsion required in water-walking (Nakazawa et al. 1994a). However, the Biceps Femoris activity increased as walking speed increased but the Gluteus Maximus activity did not (Miyoshi et al. 2005). For torso muscles, Erector Spine activity is higher during water-walking than land-walking (Chevutschi et al. 2007; Kaneda et al. 2009), and the activity increased dramatically during water-walking when walking speed increased (Kaneda et al. 2009). Barela et al. (2006) and Barela & Duarte (2008) reported the higher Erector Spine activity in latter part of stance phase to swing phase and higher Rectus Abdominis activity during water-walking than land-walking at heel contact. These results show that water-walking stimulates both lower extremity and torso muscles.

When water-walking speed is set to one-half of land-walking by using treadmill, most muscle activity decreased during water compared with land (Masumoto et al. 2004; Masumoto et al. 2008). In addition, muscle activity during treadmill water-walking without water flow further decreased muscle activity than with flow set to the same speed to the walking speed (Masumoto et al. 2004). These results, which are different from water-walking without a treadmill, may be due to the treadmill moving the leg backward.
automatically without force generation. Elderly shows higher activity at thigh muscles and lower activity at shank muscles than young adults. Although muscle activity pattern in elderly is similar with young adults (Barela et al. 2006), force generation may shift from shank to thigh muscles, to compensate for decreased muscle power in the lower extremity.

Several studies have investigated the form of knee or hip arthroplasty patients during water-walking (Giaquinto et al. 2007b) showing the water-walking speed of these patients was much slower than that of healthy patients. A hydrotherapy intervention performed 6-days per week for 3 weeks improved mean speed by 50%. The stride length in patients was shown to be almost half that of healthy patients and this also slightly increased after hydrotherapy. Knee arthroplasty patients showed improved balance on both operated and non-operated side during water-walking when focused on stance and swing time, and stance-swing ratio between both sides became closer following hydrotherapy (Giaquinto et al. 2007a). Further, hip arthroplasty patients showed differences in kinetics of shorter stance and longer swing time on the operated side compared to the non-operated side (Giaquinto et al. 2007b). However, the stance–swing ratio tended to be similar between both sides following a hydrotherapy program. Jung et al. (2010) reported treadmill movements during water-walking of post-stroke patients with chronic hemiparesis using additional weight to knee or ankle. Results showed that additional weight prolonged %SDst and restricted hip joint over flexion indicated improved stability during the stance phase.

KINESIOLOGY OF WATER RUNNING

Running in shallow-water and deep-water are common activities in a range of exercise settings. When in shallow-water-running speed is a-half to a-third of running on land for the same metabolic intensity as seen in water-walking (Evans et al. 1978). Shallow-water-running speed is naturally slower when the water depth is much deeper because of increased water drag force (Haupenthal et al. 2010). Stride frequency is lower during shallow-water-running than land-running with the same speed, and much lower in deeper water (Kato et al. 2001; Pohl & McNaughton 2003). Stance time does not change with any condition (Kato et al. 2001; Killgore et al. 2006) but the swing phase is prolonged (Kato et al. 2001) during shallow-water-running compared with land-running. Namely, shallow-water-running tended to be a jumping motion with buoyancy assistance. During deep-water-running, which has no stance phase and minimal forward travelling, there is a lower stride frequency than land-running (Killgore et al. 2006; Masumoto et al. 2009a) and stride duration is shorter than water-walking but longer than land-walking (Kaneda et al. 2008b; Kaneda et al. 2009). Incidentally, % stride duration time is approximately 50% during deep-water-running (Kaneda et al. 2008b). Thus, running motion in water is slower than on land due to water resistance.

During shallow-water-running there is increased planter flexion of ankle joint and flexion of hip joint, and increased ROM of knee joint when compared with land-running at the same running speed on treadmill (Kato et al. 2001). Further, research has shown deep- and shallow-water-running have increased hip joint flexion and knee joint ROM compared with land-running (Kilding et al. 2007). The difference between shallow- and deep-water-running seems to be related to knee joint flexion during shallow-water-running but extension during deep-water-running when compared with land-running (Kato et al. 2001; Kilding et al. 2007). In addition, hip joint ROM is greater during deep-water-running than during land-running (Kilding et al. 2007). This may be due to lack of a stance phase during deep-water-running generating less ground propulsive force causing free extension motion at knee and hip joint, making it easier to flex hip joint with buoyancy assistance.
Greater joint ROM during deep-water-running is also reported in comparison with land-walking and water-walking at ankle, knee and hip (Kaneda et al. 2007; Kaneda et al. 2008b). Moreover, deep-water-running produced a greater trunk inclination than land-walking and water-walking (Kaneda et al. 2009). Therefore, running in water produces a different running motion compared to land-running and land-walking. However, deep-water-running with cross-country style (DWRCC) could simulate land-running though slower stride frequency than deep-water-running and land-running (Killgore et al. 2006).

Only Haupenthal et al. (2010) investigated GRF during shallow-water-running. Similar to water-walking, $vGRF$ was dramatically reduced with almost no impact force for heel contact, and $aGRF$ was almost anterior direction. In hip deep water for shallow-water-running, $vGRF$ reached a peak of 100% of body weight, and reduced to 80% in chest deep water. This suggests shallow-water-running in hip or deeper water would provide a safer protocol for aquatic rehabilitation. Future study into joint moment calculation during water-walking (Miyoshi et al. 2003; Miyoshi et al. 2004; Miyoshi et al. 2005; Orselli & Duarte et al. 2011) is required to clarify actual joint loads.

During stationary shallow-water-running, thigh muscle activity has been shown to be lower than stationary land-running (Alberton et al. 2011). There is a lack of the EMG research for shallow-water-running as a locomotive exercise. Masumoto et al. (2009a) investigated muscle activity during deep-water-running and compared this with treadmill land-running. They reported no significant differences in thigh muscle activity and both increased with intensity increments, while shank muscles showed lower muscle activity during deep-water-running than land-running with effect due to intensity changes. However, the Biceps Femoris activity pattern during deep-water-running was completely different from that of land-running. Kaneda et al. (2007; 2008b) reported lower muscle activity levels of shank muscles and higher muscle activity levels of thigh muscles during deep-water-running than water-walking and land-walking. Furthermore, thigh, hip and trunk muscles activity were higher during deep-water-running than water-walking and/or land-walking (Kaneda et al. 2009). Therefore, muscle activity during deep-water-running seems to be dominated by thigh and trunk muscles due to the lack of a stance phase in deep-water-running and the activity pattern is largely different. Deep-water-running is a motion of hip flexion and extension, and needs upper body stability. Research into the balance ability of elderly persons showed an improvement following a deep-water-running intervention (Kaneda et al. 2008a).

Deep-water-running is often used as a fitness and rehabilitation activity for Fibromyalgia patients because deep-water-running is a safer modality of aerobic conditioning and no impact (Gowans et al. 2004; Assis et al. 2006; Munguía-Izquierdo & Legaz-Arrese 2007). Studies using deep-water-running showed an improvement of quality of life, muscle pain and walking performance (Gowans et al. 2004; Assis et al. 2006; Munguía-Izquierdo & Legaz-Arrese 2007). Interestingly, one paper reported less stature change in deep-water-running than shallow-water-running and land-running. Dowzer et al. (1998) conducted 30 min exercise training with deep-, shallow-, and land-running, and measured the subjects’ stature before and after training. The results showed that the reduction of stature was smallest in deep-water-running than shallow-water-running and land-running. This may be due to the reduced impact of deep-water-running.

**KINESIOLOGY OF OTHER LOCOMOTION EXERCISES**

There are a limited number of articles published on backward water-walking and side water-walking. Chevutschi et al. (2009) found the walking speed was similar between each walking style for both
gender in water with self-selected and maximal speed. The walking speed was reduced in water compared to on land by approximately 69% in water-walking, 66% in backward water-walking, and 51% in side water-walking (Chevutschi et al. 2009). These results indicated that side water-walking produces less water drag force because the frontal projected area is smaller than that of water-walking and backward water-walking (Chevutschi et al. 2009). Starting from side water-walking might be recommended for people who have a weakness of their muscles or unfamiliar for water exercise to adjust to water environment with less propulsive power generation. Characteristics of stride frequency and stride length during backward water-walking with a treadmill were investigated by Masumoto et al. (2005; 2007b; 2009b). They reported that the stride frequency was higher and the stride length was shorter during backward water-walking than water-walking at the same walking speed (Masumoto et al. 2009b). Further, the activity of trunk muscles, Vastus Medialis and Tibialis Anterior were higher during backward water-walking than water-walking (Masumoto et al. 2007b). However, all muscles except erector spine show lower activity in water than on land in a similar manner to the treadmill water-walking (Masumoto et al. 2004; Masumoto et al. 2005; Masumoto et al. 2008). In addition, increasing walking speed during backward water-walking with water flow set to the same speed as the walking speed enhanced muscle activity compared to without flow as a result of increased water drag force (Masumoto et al. 2005). Therefore, backward water-walking could stimulate most muscles to a greater extent than water-walking with the exception of the cuff muscles, which generate propulsive force during water-walking, when stride frequency is increased. This might expand the application of water exercise as rehabilitation training.

**FUTURE POSSIBILITY**

There are an enormous number of investigations reporting the effect of water exercise intervention for a wide range of people (Gowans et al. 2004; Devereux et al. 2005; Assis et al. 2006; Munguía-Izquierdo & Legaz-Arrese 2007; Sato et al. 2007; Kaneda et al. 2008a; Becker 2009; Sato et al. 2009). However, gender and aging effect on kinematics and kinetics during water exercise is lacking. Investigations about changes due to aging would provide guideline information and potential benefits or issues with water exercise to assist with maintenance of an active life. Similar changes with young adults were seen during water-walking compared to land-walking but this is yet to be determined in the aged (Masumoto et al. 2007a; Barela & Duarte 2008; Giaquinto et al. 2008).

Kinetic and kinematic research with disabled populations is also limited and has many practical benefits to exercise in water without fear of fall or injury during such exercise (Devereux et al. 2005; Sato et al. 2007; Sato et al. 2009). Some studies reported the effectiveness of water exercise intervention for frail elderly training and improving their ability of activity of daily living (Sato et al. 2007; Sato et al. 2009). However, the kinetic or kinematic relationship between in water and on land has not been clearly established. Further investigation would consolidate effectiveness of the training of targeted motion in water. Moreover, when allowing for adjustment between on land and in water, immersion level should be taken into account in training prescription for both aged and disabled populations. The gravity stress and body area receiving water drag-force change by immersion level, which vary kinetic and kinematic parameters little by little (Nakazawa et al. 1994a; Pohl & McNaughton 2003; Kotani et al. 2009). Further investigation regarding the effect of immersion level should be necessary for both populations.

Current research lacks kinesiological data during water exercise including; net force estimation derived by water drag force, the effect of assistance provided by tools, investigation for many exercise
forms other than walking and running, and so on. There is a wide range of exercise forms in water and it is impossible to investigate all of those forms. However, new technologies allow research to monitor many activities during a period of time on land environment by using inertial sensor (Tanaka et al. 2007; Lee et al. 2010; Crouter et al. 2011). Inertial sensors are a light, small and unobtrusive device providing convenient attachment on body with no need for formal laboratory systems (Lee et al. 2010). Although there is no definitive exercise monitoring system for water exercise, the investigation using inertial sensor devices should be considered in future to provide an expanded exercise prescription.

**SUMMARY**

This literature reviewed previous research investigating kinesiology during water exercise. Kinetics and kinematic variables during exercise in water changed in comparison with the same exercise form on land due to physical properties of water such as increased buoyancy and water drag force. The movement in water slowed, joint motion was roughly similar, and ground reaction force, joint moment and muscle activity showed discriminative differences in water compared to on land. Exercise in water would provide reduced gravity stress and a safer environment without fear of falling and injury for a wide range of ages and physical conditions. Nevertheless, caution should be paid for dramatic changes in speed as this increases muscle and joint stress significantly. However, the literature on running and other water exercise forms with respect to gender and aging populations is limited and requires further study. Further investigation would provide helpful suggestions for water exercise prescription for a range of populations and allow for differences with respect to gender. Future research expanding the utility of water exercise may include; the relationship between in water and on land in particular targeted motion as activity of daily living, the effect of immersion level for adjusting to on land environment from in water, and the development of a monitoring system for water environment using inertial sensor devices.

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