

Physiological Effects of an Acute Bout of Shallow Water Sprinting

**Summer B. Cook, Samantha E. Scarneo,
and Richard M. McAvoy**

The purpose of this study was to compare heart rate, blood lactate, flexibility, ratings of perceived exertion (RPE), and delayed onset muscle soreness (DOMS) in males sprinting on land and in shallow water. Twenty recreationally active males participated in sprinting on land and in shallow water. Ten 9.1m sprints were performed during each condition. Heart rate, blood lactate, and range of motion were measured before and after each condition. RPE was evaluated immediately after exercise. DOMS was assessed at 24 h and 48 h postexercise. The results show that heart rate and range of motion increase similarly in both conditions. Blood lactate levels and RPE increase the most during sprinting in the water. Sprinting in shallow water elicits similar heart rate responses and range of motion following sprinting on land and in water. Higher lactate and RPE levels when sprinting in water suggest that the metabolic demands of shallow water sprinting are different than land sprinting of the same distance.

Aquatic exercise can be used for rehabilitation or injury prevention. It can even be used as a supplemental training modality for athletes. When individuals are immersed in water, body weight is unloaded (Piotrowska-Calka & Karbownik-Kopacz, 2007). As a result, weight bearing impact is reduced and could therefore decrease the risk of injury and allow for physical activity to be performed during injury rehabilitation. In addition, the density of water is approximately 800 times higher than the density of air and creates a three-dimensional resistance that the individual must overcome during aquatic exercise (Piotrowska-Calka & Karbownik-Kopacz, 2007). To accomplish exercise in the water, antagonist muscle groups will be recruited in addition to the agonists.

Walking and running are common aerobic exercise modalities and performing these exercises in water reduces loading as a result of the buoyancy effect. Deep water running eliminates about 90% of one's body weight and it has been shown to improve cardiovascular fitness (Piotrowska-Calka, 2010). Shallow water walking and running reduces weight bearing activity by 70–75% of one's body weight but allows contact forces to occur (Hauptenthal, Rushcel, Hubert, de Brito Fontana, & Roesler, 2010). It has been shown that walking in water yields higher VO_2 , heart

Summer Cook and Samantha Scarneo are with the Kinesiology Department at the University of New Hampshire in Durham. Richard McAvoy is with McAvoy Aquatic & Sports Therapy in Wells, ME.

rate, flexibility, and ratings of perceived exertion (RPE) values when compared with similar speeds on land (Hall, Macdonald, Maddison, & O'Hare, 1998; Piotrowska-Calka & Karbownik-Kopacz, 2007).

Exercise in the water has also been shown to result in less muscle damage than exercises performed on land (Pantoja, Alberton, Pilla, Vendrusculo, & Krueel, 2009). Shallow water exercise, particularly shallow water sprinting, is a new, and not yet thoroughly researched, mode of aquatic training and conditioning. The enhanced physiological effects and the functional application of shallow water exercise may be a beneficial alternative form of training for athletes and may serve as a modality of rehabilitation for patients recovering from injuries.

Therefore, the purpose of the current study was to compare heart rate, blood lactate, flexibility, RPE, and delayed onset muscle soreness (DOMS) responses in males performing sprinting on land and in shallow water. It was hypothesized that heart rate, blood lactate, flexibility, and RPE values would be greatest following an acute bout of shallow water sprinting compared with land sprinting. It was hypothesized that DOMS would be lower in the shallow water sprinting condition.

Method

Participants

Twenty healthy, recreationally active males (21 ± 1 years; 180 ± 6 cm; 79.6 ± 10.5 kg) volunteered and gave their written informed consent for participating in the study. The University of New Hampshire Institutional Review Board approved the study design. Each subject completed a health history and aquatic questionnaire. Participants were excluded if they had any lower extremity injuries within the last 3 months, a self-reported inability to swim, or hydrophobia. In addition, participants had to be at least 173 cm tall to participate in the study due to the depth of the pool (137 cm) and the concept of shallow water running. The participants were instructed to not perform any additional exercise during the investigation period.

Design

The experimental design was a within-subjects protocol in which a group of 20 males completed ten 9.1 m (ten-yard) sprints both in water and on land in a randomized order. Heart rate, blood lactate, flexibility, and range of motion (ROM) were measured before and immediately after each condition. RPE was assessed immediately after exercise and DOMS was assessed at 24 hr and 48 hr postexercise.

Measurements

Each participant completed a familiarization session during which informed consent was obtained, a study questionnaire regarding health and physical activity was completed, and body height and mass were measured. Participants were oriented to the two conditions by performing two 9.1 m sprinting trials in the pool and on an indoor track at a light effort. The participants were randomly assigned to the order of their exercise conditions.

Physiological testing then was done before and immediately after each exercise condition. Resting heart rate was measured in the seated position after 10 min of

quiet rest using a heart monitor strapped flat and snug around the chest with data being transmitted wirelessly to a watch (Polar FS3c Fitness Heart Rate Monitor, Polar Electro, Kempele, Finland). Resting heart rate was assessed in the pool before the bout of shallow water sprinting. Heart rate was recorded after each of the 10 sprints. To assess blood lactate values, 5-uL finger-stick blood samples in duplicate were obtained after resting heart was taken and then taken again 3 min after each bout of exercise was completed. The Lactate Pro LT—1710 test meter (Arkray, Inc, Kyoto, Japan) was used. This device has been shown to be valid and reliable (Pyne, Boston, Martin, & Logan, 2000).

Flexibility of the lower back and hamstrings was evaluated using the sit-and-reach test. The participants removed their shoes and sat facing the flexibility box with the knees extended and feet touching the box. The participants extended the arms over the head with the hands placed on top of each other, inhaled and then exhaled, and reached as far forward as possible along the box, holding for 1–2 s. The most distant point reached was recorded and the average of three trials was used in the analysis. This was performed before and after each bout of sprinting.

Passive and active hip ROM were measured with a standard plastic goniometer (QualCraft Alimed, Inc. Dedham, MA) on both legs as described by Palmer and Epler (1989). For all measurements, the goniometer was placed laterally on the femur approximately superior to the greater trochanter. The stationary arm was placed parallel to the long axis of the trunk in line with the greater trochanter of the femur. The moving arm was placed along the lateral midline of the femur toward the lateral epicondyle. To measure active hip flexion, participants allowed the knee to flex to prevent a stretch on the hamstring muscles while keeping the opposite leg flat on the floor to control posterior pelvic tilt and avoid lumbosacral motion. Participants then lifted one knee to the chest and the rater recorded active hip flexion ROM. Passive hip flexion was assessed when the participant was in a relaxed state. The rater stabilized the opposite hip, applied a gentle passive pressure into hip flexion to the participants' reported tolerance, and recorded passive hip flexion ROM. Active hip hyperextension ROM was measured with the participants in a prone position in which they were instructed to keep the knee extended while extending their hip to tolerance. Passive hip hyperextension ROM was measured with the participants in a prone and relaxed position. The rater stabilized the opposite leg and applied a gentle passive pressure into hip extension and passive hyperextension ROM was recorded. Three measurements were taken for each ROM on each leg and the average ROM was used in the analysis. The rater was consistent among each subject. Reliability and validity of the goniometric measurements have been previously reported (Ekstrand, Wiktorsson, Oberg, & Gillquist, 1982).

Immediately upon completion of each condition, participants were asked to rate their perceived exertion of the entire bout of exercise using the 15-point Borg scale that ranges from 6 (very, very light) to 20 (maximum exertion; Borg, 1998). At 24 hr and 48 hr following each exercise bout, subjects were asked to rate the muscle soreness of their legs using the continuous Visual Analog Scale. Participants indicated their soreness by marking a position along a 10 cm line between two end-points. The visual analog scale has been found to be a valid and reliable indicator of muscle soreness (O'Connor & Cook, 1999).

Before each protocol, participants performed standardized dynamic warm ups on land or in the water. The warm-up included 30-s bouts of straight leg raising walks, heel to buttocks kicks, lunges with arms overhead, side lunge windmills and

hip rotations. The land sprints were completed on an indoor track and participants wore their own athletic shoes. The temperature of the indoor track facility was typically 24–27 °C. The sprinting distance was marked on the track with tape and the location on the track was the same for all subjects. The aquatic sprints were performed in an indoor pool in the shallow end which measured 1.37 m deep. Water temperature was maintained at 26–28 °C. The stature of all participants was over 1.73 m, which allowed them to complete the sprints at a water level between their nipple line and navel. Each participant wore AQx aquatic training shoes (McMinville, OR) to assist with grip during shallow water running. The participants ran the 9.1 m distance marked along the length of the pool. For both conditions, participants were instructed to “give 100% maximum effort on all sprints” and verbal encouragement was provided from the investigators. Participants performed 10 sprints and each was timed by an external observer using a stopwatch. Thirty seconds of rest was provided between sprints.

Statistical Analysis

Data are presented as means \pm *SD*. Data were analyzed using a factorial repeated measures analysis of variance (ANOVA) with condition (land vs. aquatic) and time (pre- and postexercise) as the within-subjects factors. Significant differences were followed with dependent *t* tests with Bonferroni corrections. Partial eta-squared values (η^2), indicating the ratio of the variance due to the condition and the total variance (Vincent, 2005) are also presented. Sample size for this study was based on previous research using shallow water running in which sample sizes were 9–22 subjects (Conti, Rosponi, Dapretto, Magini, & Felici, 2008; Hauptenthal et al., 2010; Town & Bradley, 1991). Presumably 20 participants offered sufficient statistical power to detect meaningful outcomes to the inferential analyses although we did not specifically determine statistical power.

Results

Heart rate increased significantly following each condition ($p < .001$; $\eta^2 = 0.97$) but there was not a significant time \times group interaction (Table 1; $p = 1.0$; $\eta^2 = 0.00$). A significant time \times group interaction was evident for blood lactate ($p < .001$; $\eta^2 = 0.99$) and post hoc analysis demonstrated a significant twofold increase following the land condition ($p < .01$) and a fourfold increase following the water condition ($p < .01$; Table 1).

Scores on the sit-and-reach test improved by ~5% following both conditions ($p = .001$; $\eta^2 = 0.44$), but no significant time \times group interaction was detected (Table 1; $p = .95$; $\eta^2 = 0.05$). Active and passive hip flexion and hyperextension on the left leg did not change following either condition. Significant time main effects in range of motion in the right leg were evident only in active hip flexion (2.5%; $p = .01$; $\eta^2 = 0.30$), active hyperextension (14.3%; $p = .01$; $\eta^2 = 0.30$) and passive hip extension (9.5%; $p = .01$; $\eta^2 = 0.32$; Table 2).

Participants reported significantly higher RPE in the water condition than in the land condition ($p < .001$; $\eta^2 = 0.69$). DOMS ratings were statistically higher in the land condition than the water condition at 24 hr post exercise ($p = .02$; $\eta^2 = 0.06$) but not at 48 hr post ($p = .06$; $\eta^2 = 0.00$; Table 3).

Table 1 Heart Rate, Blood Lactate and Flexibility Values Before and After Land and Shallow Water Sprinting

	Land		Water		Time Main Effect	Condition Main Effect	Time x Condition Interaction
	Pre	Post	Pre	Post			
Heart Rate (bpm ⁻¹)	77 ± 12	148 ± 20*	80 ± 14	152 ± 18*	< 0.001	0.11	1.00
Blood Lactate (mmol)	1.91 ± 0.65	4.13 ± 2.0*	1.91 ± 0.73	8.08 ± 2.0*†	< 0.001	0.001	< 0.001
Sit and Reach Score (cm)	42 ± 11	44 ± 10*	42 ± 11	44 ± 10*	0.001	0.99	0.95

* denotes significantly different from pre

† denotes significantly different from Land condition

Table 2 Hip Range of Motion Values Before and After Land and Shallow Water Sprinting

	Land			Water			Time x Condition Interaction
	Pre	Post	Pre	Post	Pre	Post	
Left Leg							
Active Hip Flexion (°)	121 ± 10	120 ± 10	122 ± 8	123 ± 11	1.00	0.32	0.32
Active Hip hyperextension (°)	29 ± 7	29 ± 9	26 ± 8	28 ± 6	0.12	0.34	0.20
Passive Hip Flexion (°)	133 ± 8	133 ± 8	135 ± 8	136 ± 7	0.72	0.05	0.64
Passive Hip Hyperextension(°)	35 ± 10	35 ± 8	35 ± 7	37 ± 7	0.30	0.51	0.55
Right Leg							
Active Hip Flexion (°)	119 ± 13	122 ± 11*	122 ± 12	125 ± 9*	0.01	0.11	0.72
Active Hip Hyperextension (°)	26 ± 7	29 ± 9*	23 ± 6	27 ± 6*	0.01	0.11	1.00
Passive Hip Flexion (°)	136 ± 10	136 ± 9	140 ± 9	139 ± 8	1.00	0.03	0.38
Passive Hip Extension (°)	32 ± 8	34 ± 6*	30 ± 7	34 ± 8*	0.01	0.71	0.21

* denotes significantly from pre

Table 3 Ratings of Perceived Exertion and Delayed Onset Muscle Soreness Scores Following Land and Shallow Water Sprinting

	Land	Water	P
RPE	11 ± 2	15 ± 2†	< 0.001
DOMS 24 h	11 ± 10	8 ± 15†	0.02
DOMS 48 h	8 ± 9	8 ± 19	0.06

RPE: ratings of perceived exertion, DOMS: delayed onset muscle soreness

† denotes significantly different from Land condition

Discussion

Repetitive 9.1 m sprints on land and in shallow water resulted in similar increases in heart rate and flexibility. Blood lactate levels and RPE, however, were highest following shallow water sprinting. This suggests that shallow water sprinting does not elicit the same metabolic responses as sprinting on land when the distance, but not duration, of exercise is matched.

The duration of exercise varied between the land and water conditions as the land trial took ~1.8 s to perform each 9.1 m sprint, whereas the 9.1 m sprints in the water took ~15 s per sprint. This variation in time spent exercising may have led to differences in the metabolic energy systems used during exercise. For example, it has been estimated that during maximal intensity activity, intramuscular adenosine triphosphate (ATP) and phosphocreatine (PC) stores are significantly depleted within 4 s (Kraemer, Fleck, & Deschenes, 2012). As a result, maximal intensity exercise lasting longer than a few seconds must also rely on glycolysis as a means of energy production. The twofold and fourfold increases in blood lactate following land and water sprinting, respectively, suggest that repeated sprints result in some depletion of ATP and PC stores, and the production of ATP during the exercise must occur through glycolysis. The reliance on glycolysis appears to be more pronounced following sprinting in the water as predicted by the time length of the sprint. This study was purposely designed to match the distance of the exercise as both sprinting protocols have been used by athletes. This is an important finding when shallow water sprint training protocol is used as a supplemental training modality because it likely influences the training adaptations.

The properties of water obviously influence the prolonged time to complete the shallow water sprinting protocol. The viscosity and density of water compared with air offers an accommodating resistance, which increases as a squared value when the velocity of movement in the water increases (DeMaere, 1997; Haralson, 1985; Killgore, Wilcox, Caster, & Wood, 2006). Drag forces also increase resistance with velocity and surface area in the water, which results in a greater drive phase during shallow water sprinting when compared with land sprinting. The buoyancy of water can be assistive, supportive, or resistive depending upon body and limb position and motion. All of these forces when combined can add to altered running position and mechanics (Haralson, 1985).

The participants in this study performed shallow water sprinting in a pool with a fixed depth of 1.37 m, which submerged them approximately to chest level. This caused all of the participants to perform the sprinting pattern with their forearms under the water, a factor that created a greater demand on the relatively lesser-trained arm muscles. Studies have shown that this type of altered running technique causes an increase in anaerobic metabolism and energy expenditure (Glass, Wilson, Blessing, & Miller, 1995; Rutledge, Silvers, Browder, & Dolny, 2007). These varieties of muscle recruitment patterns from traditional lower extremity running musculature to muscle groups of the upper and lower body secondary to hydrostatic pressure occur during the entire running cycle (Glass et al., 1995; Michaud, Brennan, Wilder, & Sherman, 1995). Thus, altered running could possibly influence training adaptations and should be further investigated.

Participants in this study were not athletes familiar with water training, and they only performed one familiarization session before data collection. The unfamiliarity

with efficient and effective shallow water sprinting technique could have contributed to the increased blood lactate and RPE levels as well. One study found steeper blood lactate levels in untrained versus trained swimmers. The participants' unaccustomed use of smaller muscle groups for heavy work could have been a factor affecting these results (Holmér, 1972). Because RPE can be a somewhat subjective rating, it may have been influenced by the novelty of the work, as the participants may have been anxious and perceived the task harder than land sprinting (Glass et al., 1995).

Participants rated DOMS significantly lower at 24 hr post water sprinting than land sprinting. While this correlates with current aquatic research studies (Robinson, Devor, Merrick, & Buckworth, 2004; Stemm & Jacobson, 2007), the variability among participants and the low effect size in the current study should be considered. Sprinting in shallow water is a closed kinetic chain movement with a slight support phase in the stride cycle. With the higher water levels, buoyancy increases and reduces ground reaction forces during the landing phase of running (Harrison, Hillman, & Bulstrode, 1992). Eccentric muscle contractions are a large influencing factor for DOMS, but in the water, there likely are reductions in the eccentric contractions, particularly in the landing phase of the running stride (Pantoja et al., 2009).

The present study demonstrated that range of motion increased following acute bouts of land and water sprinting, but the magnitude was not different between the conditions. Current aquatic studies in flexibility are sparse but have shown increased flexibility after several weeks of training (Hoeger, Hopkins, Barber, & Gibson, 1992). Our participants performed a dynamic flexibility warm up in the pool identical to the land-based warm up and then performed ten 9.1 m sprints on land and water in a randomized order. Similar improvements in hamstrings and back flexibility were apparent from the sit and reach test. Active hip flexion and extension and passive hip hyperextension on the right were significantly greater following land and water sprinting.

The physiological explanations for the improved range of motion are likely related to the increased muscle temperature and greater connective tissue elasticity that allowed the muscles to stretch to a greater length along with the activation of the inverse myotatic reflex that may have caused muscle relaxation and resulted in a longer muscle length (Stewart & Sleivert, 1998). The reason for the changes in hip range of motion only in the right leg are unknown, but it can be speculated that the increased intensity of the sprinting performed in both trials may have caused the participants to elicit a greater effort with their dominant leg. It is also important to consider the variability and clinical significance in the hip range of motion data. High variability in hip range of motion has been reported to be related to initial levels of flexibility and the amount of muscle mass limiting motion (Stewart & Sleivert, 1998). The effect sizes were low, suggesting that the improvements in range of motion may not be substantial. Overall, sprinting in shallow water did not favor an increase in flexibility despite the increased duration of the sprints and the altered sprinting mechanics that likely occurred.

An interesting finding in this study was the lack of reduction of heart rate in the aquatic setting. Numerous studies have demonstrated that because of the waters' hydrostatic forces, there is an alteration in cardiovascular dynamics (Denning, Bressel, Dolny, Bressel, & Seeley, 2012). Increases in central venous pressure, stroke volume and cardiac output lead to decreased heart rate (Nakanishi, Kimura,

& Yokoo, 1999). The range of reduction of heart rates while exercising in the water ranges from 7 to 20 beats per minute and can be influenced considerably by water temperature, depth of water, and intensity of the workout (Graef & Krueel, 2006; Rutledge et al., 2007). When a person is submerged in colder water, the dispersion of heat from the human body is 26 times greater than on land of the same temperature. As a result, heart rate can be significantly lower in colder temperatures (Killgore, 2012). In our study, participants were allowed to stand in the pool for approximately 3–5 min and then perform a dynamic warm up before the water sprinting trials. The resting heart rate diminished approximately five beats per minute compared with when the participants were on the deck of the pool, but this was not a significant reduction. After the aquatic sprinting trials were performed, there was a similar increase in heart rate compared with that of the land-based trials. This little change in maximum heart rate does not coincide with most of the shallow water running research studies (Dowzer, Reilly, Cable, & Nevill, 1999; Svedenhag & Seger, 1992; Town & Bradley, 1991). It is possible that a high heart rate in the water could have been a result of the altered muscle recruitment patterns, more upper body involvement, water temperature, the level of intensity, and time performed during the functional aquatic sprinting component. Because the sprinting distance for both water and land was only 9.1 m the participants when performing land sprinting may not have had enough time for the heart rates to maximize as much as the aquatic sprinting.

We acknowledge that there are limitations to our study. First, the distance of the sprints was limiting because of the significant time differences it took for the water versus the land sprinting. It would have been possible to match sprinting sessions for time versus distance; however, we would have lost the ability to randomize the conditions of the study. The study would not be representative of typical shallow water training and land training currently being performed by athletes. Second, because of the depth of the pool used in this study, the results are generalizable only to males who are 1.73 m and taller. To gain additional knowledge, females should be studied as well as varying water depths, perhaps with an underwater treadmill would need to be used. Finally, the use of the aquatic training shoes may have influenced the physiological responses that were evident in the study. These shoes are designed with strategically-placed hydrodynamic fins on each side that add resistance to many aquatic exercises. It has been shown that wearing aquatic training shoes during deep-water running significantly increases energy expenditure and oxygen consumption during submaximal exercise (Killgore et al., 2010). Because of the enhanced high-knee and piston-like leg action, the ground contact during shallow water sprinting, and the maximal efforts put forth by the participants, the extent to which the aquatic training shoes may have influenced the physiological responses is unknown.

Sprinting in shallow water is a new, and not yet thoroughly researched, mode of aquatic training and conditioning. When matched for distance, shallow water sprinting results in greater duration and blood lactate responses and higher RPE values than sprinting on land. Future studies should evaluate shallow water sprint training protocols and compare blood lactate, heart rate, RPE, flexibility, and DOMS when the duration of exercise is matched to land-based sprinting. In addition, training adaptations from shallow water sprinting still need to be evaluated.

Acknowledgments

This study was supported by an Undergraduate Research Award from the University of New Hampshire to Samantha E. Scarneo. The authors would like to thank the student researchers, Caitlin Colitti, Nadya Vorotnikova, and Kyle Pomerantz, for their assistance in testing the subjects. We would like to thank AQx Sports for loaning us the aqua shoes used in the study.

References

- Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.
- Conti, A., Rosponi, A., Dapretto, L., Magini, V., & Felici, F. (2008). Cardiac and metabolic demands of in place shallow water running in trained and untrained men. *The Journal of Sports Medicine and Physical Fitness*, *48*(2), 183–189. [PubMed](#)
- DeMaere, J.M. (1997). Effects of deep water and treadmill running on oxygen uptake and energy expenditure in seasonally trained cross country runners. *The Journal of Sports Medicine and Physical Fitness*, *37*, 175–181. [PubMed](#)
- Denning, W.M., Bressel, E., Dolny, D., Bressel, M., & Seeley, M.K. (2012). A review of biophysical differences between aquatic and land-based exercise. *International Journal of Aquatic Research and Education*, *6*, 46–67.
- Dowzer, C.N., Reilly, T., Cable, N.T., & Nevill, A. (1999). Maximal physiological responses to deep and shallow water running. *Ergonomics*, *42*(2), 275–281. [PubMed](#) doi:10.1080/001401399185649
- Ekstrand, J., Wiktorsson, M., Oberg, B., & Gillquist, J. (1982). Lower extremity goniometric measurements: A study to determine their reliability. *Archives of Physical Medicine and Rehabilitation*, *63*(4), 171–175. [PubMed](#)
- Glass, B., Wilson, D., Blessing, D., & Miller, E. (1995). A physiological comparison of suspended deep water running to hard surface running. *Journal of Strength & Conditioning*, *9*(1), 17–21.
- Graef, F., & Kruehl, L. (2006). Heart rate and perceived exertion at aquatic environment: Differences in relation to land environment and applications for exercise-prescription-A review. *Revista Brasileira De Medicina do Esporte*, *12*(4), 198–204. doi:10.1590/S1517-86922006000400011
- Hall, J., Macdonald, I.A., Maddison, P.J., & O'Hare, J.P. (1998). Cardiorespiratory responses to underwater treadmill walking in healthy females. *European Journal of Applied Physiology and Occupational Physiology*, *77*, 278–284. [PubMed](#) doi:10.1007/s004210050333
- Haralson, K.M. (1985). Therapeutic pool programs. *Clinical Management in Physical Therapy*, *5*(2), 10–13.
- Harrison, R.A., Hillman, M., & Bulstrode, S. (1992). Loading of the lower limb when walking partially immersed: Implications for clinical practice. *Physiotherapy*, *78*(3), 164–166. doi:10.1016/S0031-9406(10)61377-6
- Hauptenthal, A., Rushcel, C., Hubert, M., de Brito Fontana, H., & Roesler, H. (2010). Loading forces in shallow water running at two levels of immersion. *Journal of Rehabilitation Medicine*, *42*, 664–669. [PubMed](#) doi:10.2340/16501977-0587
- Hoeger, W., Hopkins, D.R., Barber, D.J., & Gibson, T.A. (1992). A comparison of maximal exercise responses between treadmill running and water aerobics. *Medicine and Science in Sports and Exercise*, *24*(5, Supplement) S96. doi:10.1249/00005768-199205001-00572
- Holmér, I. (1972). Oxygen uptake during swimming in man. *Journal of Applied Physiology*, *33*(4), 502–509. [PubMed](#)
- Killgore, G.L. (2012). Deep-water running: A practical review of the literature with an emphasis on biomechanics. *The Physician and Sportsmedicine*, *40*(1), 116–126. [PubMed](#) doi:10.3810/psm.2012.02.1958

- Killgore, G.L., Coste, S.C., O'Meara, S.E., & Konnecke, C.J. (2010). A comparison of the physiological exercise intensity difference between shod and barefoot submaximal deep-water running at the same cadence. *Journal of Strength and Conditioning Research*, 24(12), 3302–3312. [PubMed doi:10.1519/JSC.0b013e3181ddaf4a](#)
- Killgore, G.L., Wilcox, A.R., Caster, B.L., & Wood, T.M. (2006). A lower-extremities kinematic comparison of deep-water running styles and treadmill running. *Journal of Strength and Conditioning Research*, 20(4), 919–927. [PubMed](#)
- Kraemer, W.J., Fleck, S.J., & Deschenes, M.R. (2012). *Bioenergetics and meeting the metabolic demand for energy. Exercise physiology: Integrating theory and application* (pp. 32–38). Philadelphia, PA: Lippincott Williams & Wilkins.
- Michaud, T.J., Brennan, D.K., Wilder, R.P., & Sherman, N.W. (1995). Aqua running and gains in cardiorespiratory fitness. *Journal of Strength and Conditioning Research*, 9(2), 78–84.
- Nakanishi, Y., Kimura, T., & Yokoo, Y. (1999). Physiological responses to maximal treadmill and deep water running in the young and the middle aged males. *Applied Human Science: Journal of Physiological Anthropology*, 18(3), 81–86. [PubMed doi:10.2114/jpa.18.81](#)
- O'Connor, P.J., & Cook, D.B. (1999). Exercise and pain: The neurobiology, measurement, and laboratory study of pain in relation to exercise in humans. *Exercise and Sport Sciences Reviews*, 27, 119–166. [PubMed](#)
- Palmer, L., & Epler, M. (1989). *Clinical assessment procedures in physical therapy. Clinical assessment procedures in physical therapy* (pp. 246–247). Philadelphia, PA: Lippincott Williams & Wilkins.
- Pantoja, P.D., Alberton, C.L., Pilla, C., Vendrusculo, A.P., & Krueel, L.F.M. (2009). Effect of resistive exercise on muscle damage in water and on land. *Journal of Strength and Conditioning Research*, 23(3), 1051–1054. [PubMed doi:10.1519/JSC.0b013e3181a00c45](#)
- Piotrowska-Calka, E. (2010). Effects of a 24-week deep water aerobic training program on cardiovascular fitness. *Biology of Sport*, 27, 95–98.
- Piotrowska-Calka, E., & Karbownik-Kopacz, J. (2007). The influence of shallow and deep water exercise on the specific morphophysiological indicators and level of physical fitness. *Medicina Sportiva*, 11(1), 11–16. [doi:10.2478/v10036-007-0003-5](#)
- Pyne, D.B., Boston, T., Martin, D.T., & Logan, A. (2000). Evaluation of the lactate pro blood lactate analyser. *European Journal of Applied Physiology*, 82(1-2), 112–116. [PubMed doi:10.1007/s004210050659](#)
- Robinson, L.E., Devor, S.T., Merrick, M.A., & Buckworth, J. (2004). The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. *Journal of Strength and Conditioning Research*, 18(1), 84–91. [PubMed](#)
- Rutledge, E., Silvers, W.M., Browder, K., & Dolny, D. (2007). Metabolic-cost comparison of submaximal land and aquatic treadmill exercise. *International Journal of Aquatic Research and Education*, 1(2), 118–133.
- Stemm, J.D., & Jacobson, B.H. (2007). Comparison of land- and aquatic-based plyometric training on vertical jump performance. *Journal of Strength and Conditioning Research*, 21(2), 568–571. [PubMed](#)
- Stewart, I.B., & Sleivert, G.G. (1998). The effect of warm-up intensity on range of motion and anaerobic performance. *The Journal of Orthopaedic and Sports Physical Therapy*, 27(2), 154–161. [PubMed](#)
- Svedenhag, J., & Seger, J. (1992). Running on land and in water: Comparative exercise physiology. *Medicine and Science in Sports and Exercise*, 24(10), 1155–1160. [PubMed doi:10.1249/00005768-199210000-00014](#)
- Town, G.P., & Bradley, S.S. (1991). Maximal metabolic responses of deep and shallow water running in trained runners. *Medicine and Science in Sports and Exercise*, 23(2), 238–241. [PubMed doi:10.1249/00005768-199102000-00015](#)
- Vincent, W.J. (2005). *Statistics in Kinesiology*. Champaign, IL: Human Kinetics.