

2-15-2022

Effect of Water Depth on Heart Rate and Core Temperature During Underwater Treadmill Walking

Carrie E. Bajenski

The University of Alabama in Huntsville, cb0141@uah.edu

Brianna R. Brandon

The University of Alabama in Huntsville, brb0023@uah.edu

Cailey A. Curry

The University of Alabama in Huntsville, cac0041@uah.edu

Leslie Fajardo

The University of Alabama in Huntsville, lf0022@uah.edu

Ryan T. Conners

The University of Alabama in Huntsville, Ryan.Conners@uah.edu
For articles and additional works at: <https://scholarworks.bgsu.edu/ijare>



Part of the Educational Assessment, Evaluation, and Research Commons, Exercise Physiology Commons, Exercise Science Commons, Health and Physical Education Commons, Other Rehabilitation and Therapy Commons, Public Health Commons, Sports Sciences Commons, and the Sports Studies Commons

How does access to this work benefit you? Let us know!

Recommended Citation

Bajenski, Carrie E.; Brandon, Brianna R.; Curry, Cailey A.; Fajardo, Leslie; and Conners, Ryan T. (2022) "Effect of Water Depth on Heart Rate and Core Temperature During Underwater Treadmill Walking,"

International Journal of Aquatic Research and Education: Vol. 13: No. 4, Article 4.

DOI: <https://doi.org/10.25035/ijare.13.04.04>

Available at: <https://scholarworks.bgsu.edu/ijare/vol13/iss4/4>

This Research Article is brought to you for free and open access by the Journals at ScholarWorks@BGSU. It has been accepted for inclusion in International Journal of Aquatic Research and Education by an authorized editor of ScholarWorks@BGSU.

Abstract

Exercising using an underwater treadmill (UTM) has become a popular modality; however, few studies have focused on the physiological demands of UTM walking at varying water depths. Thus, the objective of this study was to investigate changes in heart rate (HR) and core temperature (CT) values in college-aged males and females while exercising at different water immersion depths using an UTM. Twenty participants (age = 21.50 ± 2.19 years; height = 169.04 ± 10.85 cm; weight = 75.56 ± 22.28 kg) walked at water depths of 10cm below the xiphoid process and at the level of the superior iliac crest (I.C.). Each UTM session lasted 15 minutes, consisting of 5-minute bouts at 1, 2, and 3 mph. Polar HR monitors and ingestible thermoregulatory pills were used to measure HR and CT. Results indicated that HR at 1 ($p = .305$) and 2 mph ($p = .864$) were not significantly different between water depths. Heart rate was significantly higher at 3 mph ($p = .003$) at the I.C. water level. No significant differences were found in CT at 1 ($p = .919$), 2 ($p = .392$), or 3 mph ($p = .310$) during either immersion depth. As a result, higher immersion depths resulted in a lower average HR during higher intensity exercise due to the increased buoyancy effects and the reduced gravity environment of the water. Thus, exercising in higher immersion depths allows participants to exercise at a higher intensity with less overall stress placed on the lower extremities.

Keywords: aquatic exercise, water depth, cardiovascular effects, college students, thermoregulation

Introduction

From a biomechanical standpoint, immersing the body in water creates a partial or non-weight bearing environment, depending on the amount of water (Benelli et al., 2013; Dowzer et al., 1998; Harrison et al., 1992), which creates a suitable exercise environment for both healthy individuals (Benelli et al., 2004; Benelli et al., 2013; Cuesta-Vargas et al., 2009;) and those who are sensitive to exercise based upon various clinical conditions (Benelli et al., 2013; Cantarero-Villanueva et al., 2013; Cuesta-Vargas & Adams, 2011; Cuesta-Vargas et al., 2009; Frangolias et al., 1997). Water based fitness activities can vary in the level of intensity and can generate muscular fatiguing physical activity due to the high drag resistance produced by moving the body in water compared to air (Edlich et al., 1987). An attractive modality for aquatic exercise is the use of an underwater treadmill (UTM).

An UTM allows walking and running at various water depths, which can range from ankle to chest depth for the participant (Hall et al., 1996; Hall et al., 1998). Compared to a land treadmill (LTM), an UTM provides an individual the opportunity to exercise in a safer environment while also improving balance, stability, and gait with higher drag resistance forces within the water. Exercising in an UTM can create improvements to an individual's gait pattern, due to the reduced

gravity environment (Hall et al., 1998). There are numerous physiological changes that can occur because of varying water depths in the UTM, such as, but not limited to, changes in heart rate and core body temperature.

Though few investigations have been conducted over the past few decades examining the effect of water immersion depths in an UTM on heart rate (HR) and core temperature (CT), it has been found that the rate of perceived exertion was significantly higher during exercise while immersed in water at the superior portion of the iliac crest rather than at the level of the sternum (Barbosa et al, 2007; Barbosa et al., 2009). The discrepancies in perceived exertion can be explained by the noticeable differences in drag forces of the lower body in comparison to the upper body, increased ground force reactions combined with a lower buoyancy, and the differences in activated muscles during underwater exercise (Barbosa et al, 2007; Nakazawa et al. 1994). As perceived exertion is seen to increase, HR has an inverse relationship with higher water immersion depths in an UTM.

The inverse relationship between HR and water immersion depth has been hypothesized to be due to bradycardia rhythms caused by the so-called mammalian diving reflex (Andersson et al., 2004; Barbosa et al, 2007; Holmér, 1974; Shono et al., 2001), greater blood distribution volume (Barbosa et al, 2007; Sheldahl et al., 1987), and increased stroke volume due to the buoyancy and hydrostatic pressure (Barbosa et al, 2007, Holmér, 1974) from the water. Water immersion depths at the sternum leads to a lower energy expenditure and oxygen uptake, in comparison to lower water immersion depths. Thus, at deeper immersion levels, the work of the cardiovascular system declines as the hydrostatic pressure of the water increases. The increased buoyant forces of the water and the reduced neuromuscular activity in the primary muscles responsible for postural control are some of the factors that lead to a decline in cardiovascular function in UTM exercise (Barbosa et al., 2007; Butts et al., 1991). On the other hand, during deeper levels of immersion, the secondary muscles are not receiving the same amount of blood circulation as they would receive on an LTM, which causes decreased circulation and energy expenditure in UTM (Barbosa et al., 2007; Barbosa et al., 2009). This causes heat transfer to become more difficult during increased water immersion (Barbosa et al., 2007; Barbosa, et al., 2009).

Due to the water's thermal conductivity, which is twenty-six times higher than that of air, the body is unable to effectively increase the temperature of the surrounding water (Barbosa et al., 2007; Fink et al., 1975; Wilmore and Costill, 1994). Because of this, the body temperature decreases four times faster in water (Barbosa et al., 2007; Fink et al., 1975; Wilmore & Costill, 1994). Body temperature can also be affected by the exercise intensity during UTM exercise. Elements such as convection, water movement, and duration also have a significant

effect on body temperature (Barbosa et al., 2007, Srámek et al., 2000). Past studies showed that cold water immersion led to an overall decrease in body temperature and an increase in HR; whereas, in neutral water temperatures, body temperature and metabolic rate remained the same, but HR increased. (Barbosa et al., 2007; Srámek et al. 2000).

Previous research has investigated and compared cardiorespiratory responses such as HR and oxygen consumption during water based physical activity in collegiate athletes (Brubaker et al., 2011) to the differences in gait patterns in healthy males (Masumoto et al., 2007). There were insignificant findings in both these studies on the cardiorespiratory and biomechanical responses between UTM exercise and LTM exercise in individuals (Brubaker, et al., 2011; Masumoto et al., 2007). From previous research, it was determined that manipulating variables, such as increasing grade, jet velocity (Benelli et al., 2013), and applying various combinations of water submersion during maximal exercise intensities (Silvers et al., 2007), yielded significantly different results in cardiorespiratory and biomechanical responses during UTM exercise. However, the manipulation of water immersion depths during UTM exercise has not been investigated in healthy, college-aged individuals. Thus, the purpose of this study was to measure how changes in water immersion depths affect CT and HR during UTM exercise in healthy, college-aged individuals. It was hypothesized that a higher water immersion level would cause a decrease in CT and HR across all walking speeds due to the movement of water and its convection properties.

Method

Participants

A total of 20 healthy college aged ($21.50 \text{ yrs} \pm 2.19$) participants (5 males, 15 females) were recruited for this study. To be included in the study, participants had to be aerobically active ≥ 60 minutes a day for 3 or more days per week (Howley, 2001) and be free of any illnesses or injuries that could affect full participation in the study. Additionally, individuals were excluded from the study if they were unable to swallow the thermoregulatory pill (CorTemp® Ingestible Core Body Temperature Sensor, Palmetto, FL), taking any medications that affected HR, have any current or previous injuries that prevented participants from walking normally on an UTM, and/or consumed alcohol or caffeine on the day of the study. Height, body mass, resting heart rate (RHR), and resting CT ($^{\circ}\text{F}$) were calculated for each participant to determine their baseline values prior to their exercise session (see Table 1).

Table 1
Participant Characteristics

Variable	$M \pm SD$
Age (years)	21.50 \pm 2.19
Sex (male/female)	5/15
Height (cm)	169.04 \pm 10.85
Weight (kg)	75.56 \pm 22.28
RHR (bpm)	68 \pm 11
Resting CT ($^{\circ}$ F)	98.89 \pm 0.80

Note. $M \pm SD$ = mean \pm standard deviation; RHR = resting heart rate; CT = core temperature.

Protocol

Prior to the exercise session days, all participants completed an informed consent which was approved by the University's Institutional Review Board and a physical activity readiness questionnaire (PAR-Q+). During the informational session, the participant's height (cm) and body mass (kg) (clothed, but without shoes) was measured, as well as their resting heart rate (RHR). To obtain the participants RHR, each participant was asked to remain seated for 5 minutes in a quiet, dark room. After 5 minutes, RHR was measured by counting the number of beats from palpation of the radial pulse in 15 seconds and multiplying that number by four (Allison et al., 2011; Connors et al., 2014). The participant also received an FDA-approved CorTemp[®] thermoregulatory pill during their informational session for their first walking session. The CorTemp[®] thermoregulatory pill was used to accurately measure CT in the exercise sessions. Emphasis was placed on taking the pill 2 hours prior to their set exercise session. When the pill was ingested, a sensor was activated and measured the participants' core body temperature while transmitting the temperature to a CorTemp[®] Data Recorder (CorTemp, Palmetto, FL), which is an external device used for recording purposes only. The sensor is accurate to $\pm 0.1^{\circ}$ C (CorTemp, 2020).

Before the testing session, participants received an email reminder from the research team of their session time, when to take the CorTemp[®] thermoregulatory pill (CorTemp, Palmetto, FL), and to not ingest alcohol or caffeine before the test. Participants met with the research team in the University's aquatic laboratory at their scheduled meeting time to perform their exercise session on the UTM. Each

participant wore a polar HR monitor (Polar, Finland) which was placed around the participant's chest at the level of the xiphoid process (Connors et al., 2014). Heart rate was recorded during the last 10-seconds of every minute using the Polar HR monitor. Core temperature, which was monitored by the ingestible thermoregulatory pill, was recorded within the last 10 seconds of each minute throughout the exercise session using the CorTemp® Data Recorder (CorTemp, Palmetto, FL).

In this study, participants performed two exercise sessions using the UTM (Ferno, Wilmington, OH) with a controlled, neutral water temperature set at 80°F (Burton et al., 2020). The UTM is a self-contained unit which consists of a water reservoir with a built-in water filtration system, a variable-speed motor, and two plexiglass windows that enables participants to be viewed from the outside (Connors et al., 2014) (see Figure 1). For one of the exercise sessions, the water level of the tank was maintained at 10cm below the xiphoid process (10cm B.X.P), measured using a tape measure, and the other exercise session, the water level was placed at the superior portion of the iliac crest (I.C.) which was determined by manual palpation of the anatomical location (Burton et al., 2020). The order at which the participants completed these exercise sessions was selected at random. Participants performed three stages of walking, each lasting 5 minutes. The stages were performed at 1, 2, and 3 mph (McNarry et al., 2017). The participant performed a cool down at a self-selected pace to allow the individual to safely return to baseline values. The overall exercise session including set up, 3 stages of walking at 5 minutes, a cool down, and drying time took approximately 30-40 minutes for each participant to complete. At the end of the first exercise session, the participant was given their final thermoregulatory pill to take 2 hours prior to their final exercise session.

The second walking session took place exactly 48 hours after the first exercise session. This allowed the body to return to resting levels as well as to give time for the first CorTemp ® pill to be excreted. The final testing session was a replica of the first, except for the water depth. The water depth was raised or lowered depending on the participant's first exercise session. Thus, all data collection, exercise testing stage conditions, and water temperature were the same in both sessions. All other factors remained constant in order to receive accurate results and to draw valid and reliable conclusions.

Photograph 1

Underwater treadmill used for all walking bouts



Statistical Analyses

All statistical analyses were calculated using the Statistical Package for Social Science (SPSS) Version 26. The participants' baseline characteristics are presented in Table 1. Two, three-way repeated measures factorial analysis of variances (ANOVAs) were used to compare HR and CT between water depths at 10CM B.X.P and at the I.C. Pairwise comparisons were used to compare the differences obtained in HR and CT during walking speeds of 1 mph, 2 mph, and 3 mph. Effect sizes were calculated using Cohen's *d*. Interpretation of Cohen's *d* was based on the guidelines given by Cohen (1988) stating that an effect size of 0.01 = small, 0.06 = moderate, and anything greater than 0.14 = large effect size. Furthermore, two, three-way ANOVAs were used to compare HR and CT values between male and female participants, to determine if there were sex differences.

A violation of sphericity was noted during the two, three-way repeated ANOVAs between HR and CT in both males and females during both the 10CM B.X.P and I.C. sessions. A Huynh-Feldt correction was used to determine the interaction between males and females and the violations of sphericity noted above.

Results

Heart rate ($F = 121.60, p = p < .001, \eta^2 = .988$) and CT ($F = 1.56, p = .234, \eta^2 = .28$) were found to be significantly different based upon the height of the water

while performing UTM walking at varying speeds. There were no significant differences found for HR at 1 mph ($t = 1.06$, $p = .305$, $d = .24$) and 2 mph ($t = -0.17$, $p = .864$, $d = .04$) when the 10CM B.X.P and I.C. sessions were compared. Heart rate was found to be significantly higher while walking at 3 mph ($t = -3.43$, $p < .003$, $d = .78$) during the I.C. session, when compared to walking at the same speed with water height placed at 10CM B.X.P. There were no significant differences found for CT at 1 mph ($t = -0.10$, $p = .919$, $d = .02$), 2 mph ($t = 0.88$, $p = .392$, $d = .19$), and 3 mph ($t = 1.04$, $p = .310$, $d = .23$) with water placed at 10CM B.X.P and at the I.C. level. All HR and CT values during the different exercise water depths are presented in Table 2.

There were no significant differences between males and females when comparing HR and CT at the varying water levels during walking at speeds of 1 mph, 2 mph, and 3 mph. When HR values were compared, there was no significant difference between males and females at the 10cm B.X.P ($F = 0.155$, $p = 0.750$, $\eta_p^2 = 0.009$) or the I.C. ($F = 0.121$, $p = 0.790$, $\eta_p^2 = 0.007$). Likewise, no significant differences were found when comparing CT in both genders with water placed at 10CM B.X.P ($F = 0.127$, $p = 0.763$, $\eta_p^2 = 0.007$) or at the I.C. ($F = 1.644$, $p = 0.214$, $\eta_p^2 = 0.084$).

Discussion

The purpose of this study was to compare how walking in a UTM at different water heights affects HR and CT of college-aged individuals. Additionally, this study investigated if HR and CT values varied, based upon sex differences. It was hypothesized that participants would have significant decreases in HR and CT, while performing exercise at chest level water immersion depths when compared to I.C. immersion depths. Due to the results of the study, the hypotheses were rejected.

During the research study, there were no adverse events throughout the 40 (2 exercise sessions \times 20 participants) completed exercise sessions. The participants ($N = 20$) consisted of active college-aged males and females with no recorded injuries and/or major health conditions. The lack of adverse events was contrary to similar exercise studies that have used an UTM to perform exercise (Barbosa et al., 2007; Hall et al., 1998). The lack adverse events in this study, could be attributed to a younger, healthier population (21.50 ± 2.19) of males and females and not comparing results with a land treadmill.

Table 2
Heart rate and core temperature values based upon water height

Variable	10CM B.X.P.	I.C.	<i>P</i> -value	<i>d</i>	Effect Size
HR @ 1 mph	82 ± 12	81 ± 10	0.305	0.24	S
HR @ 2 mph	94 ± 11	94 ± 11	0.864	0.04	T
HR @ 3 mph	120 ± 16	128 ± 16	0.003*	0.78	M
CT @ 1 mph	99.26 ± .81	99.28 ± .56	0.919	0.02	T
CT@ 2 mph	99.50 ± .68	99.37 ± .52	0.392	0.19	T
CT@ 3 mph	99.52 ± .60	99.30 ± .88	0.310	0.23	S

Note. All 10CM B.X.P and I.C. values are presented as mean ± standard deviation; HR = heart rate; CT = core temperature; 10CM B.X.P. = 10cm below xiphoid process; *d* = Cohen's *d*; * = significant difference ($p < 0.05$); T = trivial ($d < 0.2$); S = small ($0.2 > 0.49$); M = moderate ($0.5 > 0.79$); L = large ($d > 0.79$).

Heart Rate

There were no significant differences in HR seen during walking at either water depth at both 1 mph ($p = 0.305$) and 2 mph ($p = 0.864$). There was a significant difference observed in HR at the I.C. depth, in comparison to water immersion at 10 CM B.X.P, at 3 mph ($p = 0.003$). Mean HR at 3mph at the 10 CM B.X.P. water immersion depth was 128 bpm (\pm S.D. = 16 bpm), whereas the mean HR at 3mph at the I.C. depth was 120bpm (\pm S.D. = 16 bpm). On average, HR was 8bpm lower while exercising at 3mph with water immersion at the I.C. versus 10 CM B.X.P. According to the study completed by Barbosa et al. (2007), the Borg Rating of Perceived Exertion (RPE) was higher in aquatic exercises, specifically when immersed to the level of the hip, when comparing land exercise at the same level of intensity (2007). The procedures used in these previous studies proved that exercising in water at chest level was shown to have a reduction in HR, when compared to exercising on dry land or at water immersion to the hip. Our findings are comparable to the study by Barbosa et al. (2007) which determined that cardiovascular responses when exercising with water immersion at the hip are higher when compared to exercising at water immersion at the xiphoid process.

Similarly, the results of a study by Brubaker et al. (2011) indicated that HR increased exponentially while participants exercised at a lower immersion depth in an UTM. The potential reasoning for the higher HR during lower immersion water exercise, was due to a decrease in the amount of hydrostatic pressure. The decrease in hydrostatic pressure experienced on an individual leads to a decrease in venous return (Yoo, 2014). As a result, the cardiovascular system sees a decrease in stroke volume at lower immersion heights which causes the heart to work at a higher rate (Brubaker et al., 2011). Exercising in lower water immersion heights at a higher intensity results in more stress placed on the lower body due to the greater amount of body mass that needs to be supported while exercising. The increased stress and decrease in venous return explained why the mean HR at 3mph was higher at the lower immersion depth at the I.C. compared to the higher immersion depth at 10 CM B.X.P.

Core Temperature

Results from our study indicated that there were no differences in CT when walking in an UTM at 1 mph ($p = .919$), 2 mph ($p = .392$), and 3 mph ($p = .310$). Previous studies have shown that cold water immersion leads to an overall decrease in body temperature with an increase in HR. This is due to water's thermal conductivity properties and the body loses heat four times faster in colder water. While exercising in a neutral water temperature, CT and metabolic rate remained the same, but HR increased (Barbosa et al., 2007, Srámek et al. 2000). It was hypothesized that participants would have a significant decrease in CT while

performing exercise at higher water immersion depths in thermoneutral temperature while using an UTM due to the conductive properties of water.

Our findings were similar to a study performed by Srámek et al. (2000) which indicated that exercising in a thermoneutral water temperature did not alter CT. Throughout this study, vasomotor changes occurred within the first 2 minutes of water immersion and then CT became stabilized throughout the remainder of the participants exercise session. Exercising in an UTM can be a beneficial exercise medium for an individual, as CT remains the same or slightly decreases while exercising in a thermoneutral temperature water. This can allow an individual to exercise at higher intensities and for longer durations without large fluctuations in CT. Our findings also were similar to those of a study conducted by Nielsen and Davies (1976). While using healthy subjects, this study concluded that exercising in 80°F water helped regulate CT due to the increased convective and conductive properties of water. These water properties were shown to reduce heat storage and limit the amount of heat transfer from the skin, which helped regulate overall CT in participants (Nielsen & Davies, 1976). Due to water's conductive properties, exercising in an UTM helps regulate CT and makes it a suitable modality to use for cardiovascular exercise.

Limitations and Future Research

Limitations of this study included the number of participants as well as participant characteristics. Performance variables could have been more significant if more male and female participants would have volunteered to participate in the study and if the ratio of male to female participants were equal. Also, while the purpose of this paper was to identify the differences in HR and CT in college-aged individuals while exercising on an UTM at varying water depths, the study would be expected to have different results if individuals with special exercise considerations were included. It is suggested that further research be conducted to determine the differences in HR and CT in special populations, such as older adults, children, and people with acute and chronic physical disabilities; for rehabilitation purposes as well as to improve fitness levels in sedentary populations.

A final limitation of this study would be the temperature of the water. Although the temperature of the water was set to 80°F for this study, there are limitations to controlling the water temperature. Core body temperature is affected by the water temperature due to the water's highly conductive properties. Thus, by controlling the water temperature to increase reliability, there is a lack of understanding of how varying water temperatures affect the body in aquatic settings. Therefore, further testing should be done to compare the differences caused by changing the water temperature on a participant's HR and CT while exercising at different water depths.

Conclusion

The results of this study showed no significant changes in HR and CT between either the 10CM B.X.P and I.C. water levels at 1 mph or 2 mph. Findings did show a significant increase in the HR at 3 mph with a water immersion level at the I.C. These results suggested that, at higher immersion depths, HR was less affected by higher intensity than lower immersion depths. The increased buoyancy effect and reduced gravity environment, in higher immersion depths, allowed participants to exercise at a higher intensity level with less exertion, with little effect on CT due to the thermal conductivity of water. Thus, exercising at high immersion depths allowed for higher intensity and longer duration with less physiological change, lower average HR and consistent CT.

References

- Alkurdi, W., Paul, D. R., Sadowski, K., & Dolny, D. G. (2010). The effect of water depth on energy expenditure and perception of effort in female subjects while walking. *International Journal of Aquatic Research and Education*, 4(1), Art. 7. <https://doi.org/10.25035/ijare.04.01.07>
- Allison M., Manson J., Aragaki A. (2004). Resting heart rate and coronary artery calcium in postmenopausal women. *Journal of Women's Health*, 20(5), 661–669
- Andersson, J., Linér, M., Fredsted, A., & Schagatay, E. (2004). Cardiovascular and respiratory responses to apneas with and without face immersion in exercising humans. *Journal of Applied Physiology*, 96(3), 1005-1010.
- Barbosa, T. M., Garrido, M. F., and Bragada, J. A. (2007). Physiological adaptations to head out aquatic exercises with different levels of body immersion. *Journal of Strength and Conditioning Research*, 21(4), 1255-1259.
- Barbosa, T.M., Marinho, D. A., Reis, V. M., Silva, A. J., & Bragada, J. A. (2009). Physiological assessment of head-out aquatic exercises in healthy subjects: A qualitative review. *Journal of Sports Science and Medicine*, 8(1), 179-189.
- Benelli, P., Colasanti, F., Ditroilo, M., Cuesta-Vargas, A., Gatta, G., Giacomini, F., & Lucertini, F. (2013). Physiological and biomechanical responses to walking underwater on a non-motorised treadmill: Effects of different exercise intensities and depths in middle-aged healthy women. *Journal of Sports Sciences*, 32(3), 268–277.
- Benelli, P., Ditroilo, M., & De Vito, G. (2004). Physiological responses to fitness activities: A comparison between land based and water aerobics exercise. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, 18(4), 719–722.

- Brubaker, P., Ozemek, C., Gonzalez, A., Wiley, S., & Collins, G. (2011). Cardiorespiratory responses during underwater and land treadmill exercise in college athletes. *Journal of Sport Rehabilitation*, 20(3), 345-354.
- Burton, J., Duffey, S., Hammonds, A., LeDuc, A., Shumate, R., Coons, J., & Conners, R. (2020) Cardiovascular and Stride Frequency Differences During Land and Aquatic Treadmill Walking. *International Journal of Aquatic Research and Education*, 12(4), 1-16 (Art. 13). <https://doi.org/10.25035/ijare.12.04.13>
- Butts, N., Tucker, M., & Smith, R. (1991). Maximal responses to treadmill and deep-water running in high school female cross-country runners. *Research Quarterly for Exercise and Sport*, 62(2), 236-239.
- Cantarero-Villanueva, I., Fernández-Lao, C., Cuesta-Vargas, A. I., Del Moral-Avila, R., Fernández-de-las-Peñas, C., & Arroyo- Morales, M. (2013). The effectiveness of a deep-water aquatic exercise program in cancer-related fatigue in breast cancer survivors: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, 94(2), 221–230
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Lawrence Earlbaum Associates.
- Conners, R., Morgan, D., Fuller, D., & Caputo, J. (2014). Underwater treadmill training, glycemic control, and health-related fitness in adults with type 2 diabetes. *International Journal of Aquatic Research and Education*, 8(4), 382-396 (Art. 8). <https://doi.org/10.25035/ijare.08.04.08>
- CorTemp Sensor. (n.d.). <https://hqinc.net/home/cortemp/cortemp-products/cortemp-sensor/>
- Craig, A. (1983) *Temperature regulation and immersion in biomechanics and medicine in swimming* (pp. 263-274). Human Kinetics.
- Cuesta-Vargas, A., & Adams, N. (2011). A pragmatic community-based intervention of multimodal physiotherapy plus deep water running (DWR) for fibromyalgia syndrome: A pilot study. *Clinical Rheumatology*, 30(11), 1455–1462.
- Cuesta-Vargas, A. I., Adams, N., Salazar, J. A., Belles, A., Hazañas, S., & Arroyo-Morales, M. (2012). Deep water running and general practice in primary care for non-specific low back pain versus general practice alone: Randomized controlled trial. *Clinical Rheumatology*, 31(7), 1073–1078.
- Cuesta-Vargas, A., Garcia-Romero, J. C., & Kuisma, R. (2009). Maximum and resting heart rate in treadmill and deep-water running in male international volleyball players. *International Journal of Aquatic Research & Education*, 3(4), 398– 405 (Art. 7). <https://doi.org/10.25035/ijare.03.04.07>

- Dowzer, C. N., Reilly, T., & Cable, N. T. (1998). Effects of deep and shallow water running on spinal shrinkage. *British Journal of Sports Medicine*, 32(1), 44–48.
- Edlich, R. F., Towler, M. A., Goitz, R. J., Wilder, R. P., Buschbacher, L. P., Morgan, R. F., & Thacker, J. G. (1987). Bioengineering principles of hydrotherapy. *The Journal of Burn Care & Rehabilitation*, 8(6), 580–584.
- Fink, W., Costill, D., van Handel, P. & Getchell, L. (1975). Leg muscle metabolism during exercise in the heat and cold. *European Journal of Applied Physiology*, 34(3), 183-190.
- Frangolias, D. D., Taunton, J. E., Rhodes, E. C., McConkey, J. P., & Moon, M. (1997). Maintenance of aerobic capacity during recovery from right foot Jones fracture: A case report. *Clinical Journal of Sport Medicine*, 7(1), 54–58.
- 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(3), 278-284.
- Hall J., Skevington S. M., Maddison P. J., & Chapman, K. (1996). A randomized and controlled trial of hydrotherapy in rheumatoid arthritis. *Arthritis Care Research*, 9(3), 206-215.
- 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.
- Holmér, I. (1974). Physiology of swimming man. *Acta Physiologica Scandinavica*, 407(1), 1-55.
- Howley, E. T. (2001). Type of activity: resistance, aerobic and leisure versus occupational physical activity. *Medicine and Science in Sports and Exercise*, 33(1). <https://doi.org/10.1097/00005768-200106001-00005>
- Masumoto, K., Takasugi, S., Hotta, N., Fujishima, K., & Iwamoto, Y. (2007). A comparison of muscle activity and heart rate response during backward and forward walking on an underwater treadmill. *Gait & Posture*, 25(2), 222–228.
- McNarry, M., Wilson, R., Holton, M., Griffiths, I., MacKintosh, K., & Ardigò, L. (2017). Investigating the relationship between energy expenditure, walking speed and angle of turning in humans. *PLoS ONE*, 12(8), 1-12.
- Nakazawa, Kimitaka & Yano, H. & Miyashita, M. (2015). Ground reaction forces during walking in water. *Medicine and Science in Aquatic Sports*, 39, 28-34.
- Nielsen, B., Davies, C. (1976). Temperature regulation during exercise in water and air. *Acta Physiologica Scandinavica*, 98(4), 500-508.

- Sheldahl, L., Tristani, F., Cliffors, P., Highes, C., Sobocinki, K. & Morris, R. (1987) Effect of head-out water immersion on cardio-respiratory response to dynamic exercise. *Journal of the American College of Cardiology*, 10(6), 1254-1258.
- Shono, T., Fujishima, K., Hotta, N., Ogaki, T., & Masumoto, Kenji. (2001). Cardiorespiratory response to low-intensity walking in water and on land in elderly women. *Journal of Physiological Anthropology and Applied Human Science*, 20, 269-74.
- Silvers, W. M., Rutledge, E. R., & Dolny, D. G. (2007). Peak cardiorespiratory responses during aquatic and land treadmill exercise. *Medicine & Science in Sports & Exercise*, 39(6), 969-975.
- Srámek, P., Simecková, M., Janský, L., Savlíková, J., & Vybíral, Stanislav. (2000). Human Physiological responses to immersion into water of different temperatures. *European Journal of Applied Physiology*, 81(5), 436-42.
- Wilmore, J. H., Costill, D. L., & Kenney, W. L. (1994). *Physiology of Sport and Exercise* (Vol. 524). Human kinetics.
- Yoo, J., Lim, K. B., Lee, H. J., & Kwon, Y. G. (2014). Cardiovascular response during submaximal underwater treadmill exercise in stroke patients. *Annals of Rehabilitation Medicine*, 38(5), 628.