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Luiz Fernando Martins Kruel
Federal University of Rio Grande do Sul, kruel@esef.ufrgs.br

Leonardo Alexandre Peyré-Tartaruga
Federal University of Rio Grande do Sul

Cristine Lima Alberton
Federal University of Rio Grande do Sul

Fabiane Graef Müller
Federal University of Rio Grande do Sul

Rosemary Petkowicz
Federal University of Rio Grande do Sul

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Effects of Hydrostatic Weight on Heart Rate During Water Immersion

Luiz Fernando Martins Kruel, Leonardo Alexandre Peyré-Tartaruga, Cristine Lima Alberton, Fabiane Graef Müller, and Rosemary Petkowizc

The aim of this study was to analyze the influence of hydrostatic weight on the changes in heart rate (HR) observed during water immersion (WI). Ten men underwent the following experimental situations: HRR—recumbent position, outside the water; HRS—standing position, outside the water; HRU—standing position, immersed up to the umbilical scar region; HRUW—standing position, immersed up to the umbilical scar region with the addition of weight to equal force weight reached in the situation standing outside the water, and HREND—standing position outside the water again. The HR was measured at the final 15 seconds of each experimental situation. ANOVA for repeated measures with posthoc Tukey tests were used. No statistically significant difference was found between HRU (60.6 ± 7.7 bpm) and HRUW (64.9 ± 7.7 bpm); however, in the comparison of these two situations with HRS (75.7±7.7 bpm), HRU presented a statistically significant difference, while HRUW did not produce a significant bradycardia. Thus, the decrease in hydrostatic weight, during WI, does not influence the behavior of HR.

Humans use water immersion (WI) for relaxation (Oda, Matsumoto, Nagakawa, & Moriya, 1999), physical activity (Alberton, Olkoski, Pinto, Becker, & Kruel, 2007; Silvers, Rutledge, & Dolny, 2007), and as a means for providing medical therapy (Suomi & Collier, 2003; Tovin, Wolf, Greenfield, Crouse, & Woodfin, 1994). Moreover, WI has been used to study human cardiovascular physiology. WI induces various changes in the cardiovascular system including a decrease in heart rate (HR; Andersson, Line´r, Fredsted, & Schagatay, 2004; Epstein, Levinson, & Loutzenhiser, 1976; Jay, Christensen, & White, 2007). The theory that explains this phenomenon states that during WI, central blood volume is increased through the redistribution of venous blood and extracellular fluid from the lower to the upper part of the body in the same way as during face immersion reflex (Campbell, Gooden, & Horowitz, 1969). As a result of the increase in plasmatic volume in the central part of the body, the heart and central circulation are distended, leading to stimulation of volume and pressure receptors of these tissues, which in turn leads to a readaptation of the cardiovascular system,

The authors are with Federal University of Rio Grande do Sul, Laboratory of Research on Exercise, in Porto Alegre, Brazil.

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increasing central venous pressure, cardiac output, and stroke volume, and finally lowering HR (Watenpaugh, Pump, Bie, & Norsk, 2000).

Besides this mechanism, another important factor that explains the reduction in HR during WI is the ability of water to transfer heat more quickly and easily than air does, thus facilitating heat exchange between the body and the environment. As a result, the need to distribute blood from the central region (i.e., chest and abdomen) to the extremities decreases, resulting in the concentration of plasmatic volume in the central region of the body. The increased blood volume becomes another factor that stimulates volume and pressure receptors of the heart and central vascular system (Craig & Dvorak, 1966).

In WI there is also a decrease in the body's hydrostatic weight (HW), which can be defined as the difference between the body weight on land and the buoyant force on that body when submerged in water (Kruel, 1994). This effect is due to one of the best known principles of hydrostatics, Archimedes principle, which briefly states that a body partially or totally immersed in fluid is subject to a force that is equal to the weight of the volume of the fluid displaced by the body mass but in the direction opposite to the gravitational force (Okuno, Caldas, & Chow, 1982). Regardless of age, the percentage of reduction of the hydrostatic weight in the region of the umbilicus found in the literature is 55% (Harrison, Hillman, & Bulstrode, 1992; Kruel, 1994). Based on this information, we hypothesized that, besides thermodynamics and hydrostatic pressure, a factor that may play a major role in the HR reduction response to WI is HW. As mentioned, WI leads to a decrease in HW, thus inhibiting the effects of gravitational force (Archimedes principle). Therefore, it is likely that the muscles involved in the maintenance of an erect standing position experience fewer demands and that less blood is flowing to lower limbs, also helping the concentration of blood in the central region of the body.

This hypothesis, if correct, could improve the knowledge about the crucial mechanisms that exert influence on hemodynamic responses, specifically the HR's patterns of response during WI. The aim of the current study was to analyze the effect of HW on the decrease in HR during WI.

Method

Participants

This study, which was approved by the Ethics Committee of the School of Physical Education of the Federal University of Rio Grande do Sul, Brazil, included 10 healthy men (age: 22.6 ± 2.12 years; weight: 75.29 ± 8.32 kg; height: 178.6 ± 8.58 cm). All voluntary study participants provided written consent for their participation after being fully informed about the study.

Procedures

Each participant experienced the following experimental sequence:

Experimental situation 1 (ES1)—ten minutes in recumbent position, outside the water, to determine HR at rest on land (HRR);

Experimental situation 2 (ES2)—one minute in an upright standing position (USP), outside the water, to assess standing HR (HRS) and body weight (BW);

Experimental situation 3 (ES3)—one minute in an USP, immersed in water up to the umbilicus, followed by measurement of HR (HRU) and HW at this point;

Experimental situation 4 (ES4)—one minute in an USP, immersed in water up to the umbilicus with the addition of weight so as to equal the value of BW determined in the USP, outside the water, with HR measured after one minute in this situation (HRUW); and

Experimental situation 5 (ES5)—return to an USP, outside the water, followed by measurement of HR after one minute (HREND).

The experiment's protocol is shown in Figure 1. All measurements of HR were performed using a Polar HR monitor (model Vantage XL), during the final 15 s of each experimental situation. The cardiovascular adjustments resulting from immersion normally occur in the first 15 s (Magel, McArdle, Weiss, Stone, & Newman, 1982). The mean of these final 15 s was used to represent each experimental situation. For the addition of weight, weights were placed in a backpack and ankle weights were placed, respectively, on the subject's back and lower and upper limbs to represent weight relatively uniformly across the body.

Materials

We used a cylindrical immersion tank 1.20 m wide and two meters high, which had a capacity of 2000 L for immersion activities. The water temperature was always measured in the beginning of the collection of the each participant and was maintained at 30.18 ± 1.17 °C.

A rectangular iron frame support apparatus was used to submerge participants so that they did not require physical movement that would alter the heart rate. The vertical movement of the structure was controlled by means of an electrical hoist, geared 20:1 and fixed to an external structure as well as to the support apparatus. A measuring tape was fixed on the side of the iron frame to allow for the control of the immersion of study participants in the water tank.

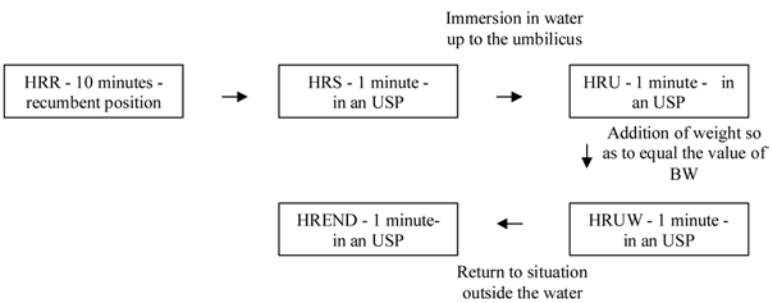

Figure 1 — Experiment's protocol.
Note. HRR, heart rate at rest; HRS, standing heart rate; HRU, immersion in water up to the umbilicus; HRUW, immersion in water up to the umbilicus with weight; HREND, heart rate end; BW, body weight; USP, upright standing position.

We employed a load cell fastened between the support apparatus and the electrical hoist to measure the vertical forces. The load cell (Alfa, model S-200) was connected to a signal conditioner, which in turn was connected to a 14 bit A/D converter, both manufactured by Computer Board and connected to a microcomputer Pentium II 200 MHz.

The data related to BW and partial weight were obtained from the load cell connected to the structure and processed by a computer using software SAD32 version 2.59b. After the collection of the data related to BW, a signal treatment was performed by means of the calculation of the average value of the signal during the final 15 s of the second experimental situation (ES2).

Statistical Analysis

The data obtained were presented as descriptive means and standard deviations (*SD*). We have verified the normality using Shapiro-Wilks' test. To compare HR under the different experimental situations, we used repeated-measures ANOVA, followed by posthoc Tukey tests. SPSS version 13.0 was used to compute all statistical comparisons. The level of statistical significance was set at $\alpha < .05$, with a statistical power of 80%.

Results

The test of normality demonstrated that the sample was not significantly different from a normal distribution, allowing us to use parametric tests on these data. Figure 2 shows the pattern of the HR under the different experimental situations through the means and standard deviations of each testing situations, in their order in the experiment. The figure also shows in which pairs of values statistically significant differences were found.

The HR in the situations HRR and HRU, with values of 61.4 ± 5.89 and 60.6 ± 7.68 bpm, respectively, was significantly lower ($\alpha < .05$) than in the situations HRS (75.7 ± 7.72 bpm) and HREND (73.2 ± 11.51 bpm). In the situation HRUW, mean HR was 64.9 ± 7.71 bpm. No statistically significant difference was found between HR in the situation HRUW ($\alpha > .05$) and the remaining experimental situations.

Discussion

Study participants presented a HR 18.9% lower in the situation HRR when compared with the situation HRS; these results are similar to the results found in previous studies (Costill, Cahill, & Eddy, 1967; Nishiyasu, Nagashima, Nadel, & Mack, 1998). The lower HR observed during recumbent position is due to the facilitation of the venous return to the body's central region. This decrease occurs when the person is standing because the vascular system has to overcome gravitational forces to return blood from the lower limbs to the heart. In a recumbent position, gravitational forces do not provide significant resistance to the venous blood flow return to the heart, because the column of blood that dominates the flow of intravascular fluid in the standing position disappears,

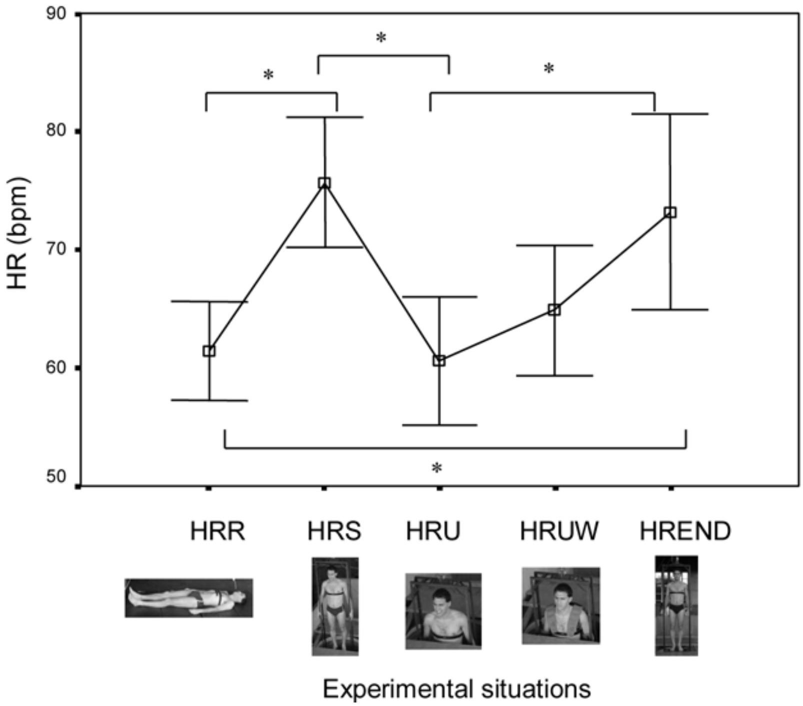

Figure 2 — Heart rate in the different experimental situations: heart rate at rest (HRR), standing heart rate (HRS), immersion in water up to the umbilicus (HRU), immersion in water up to the umbilicus with weight (HRUW), and heart rate end (HREND). * Indicates differences with $\alpha < .05$.

reducing hydrostatic pressure in local blood vessels of the lower limbs (Bevegard, Holmgren, & Jonsson, 1960; Hagan, Diaz, & Horvath, 1978). This is such that the more distal the muscle is located in this region, the smaller is the local blood volume (Conley, Foley, Ploutz-Snyder, Meyer, & Dudley, 1996). As a result, there is an increase in circulating blood in the central (i.e., thoracic) region of the body. The greater volume of circulating blood also results in more blood reaching the heart, and, with this increased pressure in the cardiac chambers, the power of each cardiac contraction will be greater; consequently, stroke volume will be higher (Frank-Starling's Law). To balance cardiac output, a reduction in HR takes place (Costill et al., 1967; Epstein et al., 1976; Watenpaugh et al., 2000).

When changing from the situations HRS to HRU, we observed a significant reduction ($\alpha < .05$) of 15.1 bpm in the HR. The literature confirmed these same values (e.g., Costill et al., 1967; Craig & Dvorak, 1966). Immersion in water exposes the body to a increased hydrostatic pressure (Agostoni, 1966; Ertl, Bernauer, & Hom, 1991; Gauer & Henry, 1976), which favors the stimulation of peripheral baroreceptors. Stimulation of the peripheral baroreceptors redistribute blood from the region of the lower limbs to the central region (Taylor, Jordan, & Coote, 1999). Moreover, the change in thermal conditions offered by the water also seems to induce part of the reduction in HR, once the heat exchange between the body and the environment is facilitated during WI (Costill et al., 1967; Johansen, Jensen, Pump, & Norsk, 1997; Keatinge & Evans, 1961; McArdle, Magel, Lesmes, & Pechar, 1976; Srámek, Simecková, Janský, Savlíková, & Vybíral, 2000).

Similar to the situation in the recumbent position, during WI, blood plasma volume is increased in the central region, resulting in more blood arriving to the heart, thus increasing cardiac dimensions (Kinney, Cortada, & Ventura, 1987; Risch, Koubenec, & Beckmann, 1978; Risch, Koubenec, Gauer, & Lange, 1978) and concomitantly the stroke volume. The HR decreases to compensate for the increase in stroke volume to maintain the cardiac output (McArdle et al., 1976, Risch, Koubenec, & Beckmann, 1978; Risch, Koubenec, Gauer et al., 1978). The translocation of blood from the peripheral extremities to the central region is more significant during WI (700 ml) than in a change in position from vertical to recumbent (400 ml; Bevegard et al., 1960).

According to the theory we presented in the previous paragraph, if the weight addition did not exert influence in the HR responses in immersion, it would be expected that with the addition of weight to the body equal to the value of weight force found outside the water, the HR would still be lower during immersion, showing no change from HRU to HRUW. There were no significant differences found between HRU and HRUW; therefore, the added weight as an explanation was not supported. In other words, ruling out the hypothetical effect of HW during immersion, HR was not significantly modified when compared with the HR in the situation outside the water.

According to our study, hydrostatic pressure and thermodynamic changes were the only factors that accounted for the changes in HR during WI. The decrease in HW during WI did not influence HR reduction. And, in case of immersion up to the umbilicus, this reduction is by around 55% (Harrison et al., 1992; Kruel, 1994). That is to say that, especially in the lower limbs and postural muscles, smaller muscular recruitment is required to keep a standing position, reducing the need for blood in this region, and, consequently, resulting in decrease in HR as well.

A piece of data found in the literature that supports the line of thinking put forward in the current study is the modification of cardiovascular responses during immersion due to the position adopted (Ertl et al., 1991). In studies that compared the HR outside the water and in water immersion in an upright seating position, the change in HR was smaller than the change found in studies in which experimental situations were in a standing position (Ertl et al., 1991). Therefore, based on the assumption mentioned above (hydrostatic pressure as the single variable responsible for HR reduction), when study participants underwent immersion in an upright seating position, HR reduction should have been similar to that observed in a standing position, a fact that was not observed.

Other possible factor that could to explain the present results is related to protocol adopted, more specifically, the load position. While during ES2 situation the subjects undergo the gravitational force distributed in proportion to mass of their part constituents, in the ES4 situation the subjects bear loads on shoulders (backpack) and lower and upper limbs (see methods). Although the obvious differences on force distribution between ES2 and ES4, there are no differences on heart rate between different load positions during standing (Devroey, Jonkers, Becker, Lenaerts, & Spaeden, 2007). Therefore, it is unlikely that the protocol used may have influenced the heart rate's responses leading to confusing results.

Conclusion

The change in HR observed during WI does seem to be explainable, mainly by the increased hydrostatic pressure and possibly over time by the thermodynamic effect of cooler water. The influence exerted by HW as a mechanism of HR reduction was not demonstrated by these data.

References

Agostoni, E. (1966). Respiratory mechanics during submersion and negative-pressure breathing. *Journal of Applied Physiology, 21,* 251–258.

Alberton, C.L., Olkoski, M.M., Pinto, S.S., Becker, M.E., & Kruel, L.F.M. (2007). Cardiorespiratory responses of postmenopausal women to different water exercises. *International Journal of Aquatic Research and Education, 1,* 363–372.

Andersson, J.P.A., Line'r, M.H., Fredsted, A., & Schagatay, E.K.A. (2004). Cardiovascular and respiratory responses to apneas with and without face immersion in exercising humans. *Journal of Applied Physiology, 96,* 1005–1010.

Bevegard, S., Holmgren, A., & Jonsson, B. (1960). The effect of body position on circulation at rest and during exercise, with special reference to the influence on the stroke volume. *Acta Physiologica Scandinavica, 49,* 279–298.

Campbell, L.B., Gooden, B.A., & Horowitz, J.D. (1969). Cardiovascular responses to partial and total immersion in man. *The Journal of Physiology, 202,* 239–250.

Conley, M.S., Foley, J.M., Ploutz-Snyder, L.L., Meyer, R.A., & Dudley, G.A. (1996). Effect of acute head-down tilt on skeletal muscle cross-sectional area and proton transverse relaxation time. *Journal of Applied Physiology, 81,* 1572–1577.

Costill, D.L., Cahill, P.J., & Eddy, D. (1967). Metabolic responses to submaximal exercise in three water temperatures. *Journal of Applied Physiology, 22,* 628–632.

Craig, A.B., & Dvorak, M. (1966). Thermal regulation during water immersion. *Journal of Applied Physiology, 21,* 1577–1585.

Devroey, C., Jonkers, I., Becker, A.D., Lenaerts, G., & Spaeden, A. (2007). Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures. *Ergonomics, 50*(5), 728–742.

Epstein, M., Levinson, R., & Loutzenhiser, R. (1976). Effects of water immersion on renal hemodynamics in normal man. *Journal of Applied Physiology, 41,* 230–233.

Ertl, A.C., Bernauer, E.M., & Hom, C.A. (1991). Plasma volume shifts with immersion at rest and two exercise intensities. *Medicine and Science in Sports and Exercise, 23,* 450–457.

Gauer, O.H., & Henry, J.P. (1976). Neurohormonal control of plasma volume. *International Review of Physiology, 9,* 145–190.

Hagan, R.D., Diaz, F.J., & Horvath, S.M. (1978). Plasma volume changes with movement to supine and standing positions. *Journal of Applied Physiology, 45,* 414–418.

Harrison, R.A., Hillman, M., & Bulstrode, S. (1992). Loading of the lower limb when walking partially immersed: Implications for clinical practice. *Physiotherapy, 78,* 164–166.

Jay, O., Christensen, J.P.H., & White, M.D. (2007). Human face-only immersion in cold water reduces maximal apnoeic times and stimulates ventilation. *Experimental Physiology, 92,* 197–206.

Johansen, L.B., Jensen, T.U.S., Pump, B., & Norsk, P. (1997). Contribution of abdomen and legs to central blood volume expansion in humans during immersion. *Journal of Applied Physiology, 83,* 695–699.

Keatinge, W.R., & Evans, M. (1961). The respiratory and cardiovascular response to immersion in cold and warm water. *The Quarterly Journal of Physiology, 46,* 83–94.

Kinney, W.L., Cortada, X., & Ventura, R. (1987). Cardiac size and motion during water immersion: Implications for volume homeostasis. *American Heart Journal, 113,* 345–349.

Kruel, L.F.M. (1994). *Peso hidrostático e freqüência cardíaca em pessoas submetidas a diferentes profundidades de água* [Hydrostatic weight and heart rate in subjects immersed at different water depths]. Unpublished master dissertation, Federal University of Santa Maria, Santa Maria, Brazil.

Magel, J.R., McArdle, W.D., Weiss, N.L., Stone, S., & Newman, A. (1982). Heart rate response to apnea and face immersion. *The Journal of Sports Medicine, 22,* 135–146.

McArdle, W.D., Magel, J.R., Lesmes, G.R., & Pechar, G.S. (1976). Metabolic and cardiovascular adjustment to work in air and water at 18, 25 and 33°C. *Journal of Applied Physiology, 40,* 85–90.

Nishiyasu, T., Nagashima, K., Nadel, E.R., & Mack, G.W. (1998). Effects of posture on cardiovascular responses to lower body positive pressure at rest and during dynamic exercise. *Journal of Applied Physiology, 85,* 160–167.

Oda, S., Matsumoto, T., Nagakawa, K., & Moriya, K. (1999). Relaxation effects in humans of underwater exercise of moderate intensity. *European Journal of Applied Physiology, 80,* 253–259.

Okuno, E., Caldas, I.L., & Chow, C. (1982). *Física para Ciências Biológicas e Médicas* [Physics for biological and medical sciences]. São Paulo: Editora Harbra.

Risch, W.D., Koubenec, H.J., & Beckmann, U. (1978). The effect of graded immersion on heart volume, central venous pressure, pulmonary blood distribution, and heart rate in man. *Pflügers Archiv*. *European Journal of Phycology, 374,* 115–118.

Risch, W.D., Koubenec, H.F., Gauer, O.H., & Lange, S. (1978). Time course of cardiac distension with rapid immersion in a thermo-neutral bath. *Pflügers Archives. European Journal of Physiology, 374,* 119–120.

Silvers, W.M., Rutledge, E.R., & Dolny, D.G. (2007). Peak cardiorespiratory responses during aquatic and land treadmill exercise. *Medicine and Science in Sports and Exercise, 39,* 969–975.

Srámek, P., Simecková, M., Janský, L., Savlíková, J., & Vybíral, S. (2000). Human physiological responses to immersion into water of different temperatures. *European Journal of Applied Physiology, 81,* 436–442.

Suomi, R., & Collier, D. (2003). Effects of arthritis exercise programs on functional fitness and perceived activities of daily living measures in older adults with arthritis. *Archives of Physical Medicine and Rehabilitation, 84,* 1589–1594.

Taylor, E.W., Jordan, D., & Coote, J.H. (1999). Central control of the cardiovascular and respiratory systems and their interactions in vertebrates. *Physiological Reviews, 79*(3), 855–916.

Tovin, B.J., Wolf, S.L., Greenfield, B.H., Crouse, J., & Woodfin, B.A. (1994). Comparison of the effects of exercise in water and on land on the rehabilitation of patients with intra-articular anterior cruciate ligament reconstructions. *Physical Therapy, 74*(8), 710–719.

Watenpaugh, D.E., Pump, B., Bie, P., & Norsk, P. (2000). Does gender influence human cardiovascular and renal responses to water immersion? *Journal of Applied Physiology, 89,* 621–628.