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Underwater Basics: The Physiology of Immersion
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The effects of water immersion on the human body never cease to amaze me. It has been a fascination with researchers going back to the 1920s. As we develop more sophisticated ways to measure physiological parameters, the information collected about the effects of human immersion continues to accumulate and astound.

Aquatic fitness professionals need to keep in mind the range of physiological effects of immersion as it affects how people exercise, why people exercise, and the outcomes of exercise in the water. Important things happen when the body enters the water, remains at rest in the water, exercises in the water, recovers from exercise in the water, and then exits the water.

Immersion affects almost every system in the body, the muscle equation for movement, how the body responds to exercise, and the basic components of exercise. The physiology of immersion can be complicated, but it is important to continue to increase your understanding of these essential concepts so you can guide and provide your clients to get the most from, and properly cope with, their aquatic exercise experience.

I came across a great article by one of my favorite aquatic researchers, Dr. David Pendergast. He has been studying the physiology of immersion for decades and continues to provide information to govern the variables of water exercise including water temperature, water depth and intensity. His new article printed online in September of 2015 reviews what he and his fellow researchers have found about the human body in the aquatic environment.

Humans can be immersed in the water with the head out (vertical aquatic exercise), immersed with the head in (swimming), or immersed underwater at various depths (diving). There is also a difference between the effects of immersion when comparing the head-out vertical position to the head-out supine position. The information provided is based on responses of erect/vertical position, head-out water immersion in various (thermoneutral, warm and cold) water temperatures. Keep in mind that all of the responses described are dependent on the individual, the depth of immersion, water density (salt vs. fresh water), water temperature, and other individual and environmental factors.

Circulatory Responses and Fluid Shifts

- Hydrostatic pressure causes blood to translocate from the extremities to the thoracic region of the body. This happens because hydrostatic pressure compresses the veins in the extremities, enhancing venous return to the heart and decreasing venous blood pooling.
- This creates increased right atrial pressure from venous blood returning to the heart; as a result, cardiac output increases.

- Fluid does not move as readily into the blood stream from the capillaries due to the increased pressure. This creates three major fluid shifts in the body: across the capillary, across the cell wall, and across the kidney.
- Initially blood goes to the cardiac and respiratory muscles (it is harder to breathe in the water due to the hydrostatic pressure) and there is reduced blood flow to the skeletal muscles. Over immersion time, blood flow is reestablished to skeletal muscles.
- The fluid shifts in the body experienced during vertical head out immersion include the following responses: increased blood flow and oxygen uptake, increased cardiac output, increased stroke volume, increased aortic pulse pressure, kidney responses with increased urine output, increased cardiac volume, potassium and amino acid shifts, and blood shift from the legs to the abdomen to the chest.
- The circulatory responses to immersion combined with the subsequent adjustments made by the heart cause a lower heart rate during water exercise compared to the same oxygen consumption on land.

Immersion causes a chain reaction of complicated responses due to fluid shifts in the body caused by hydrostatic pressure. This reminds aquatic professionals to consider the following factors when training in the aquatic environment.

- Acclimation to the water is a very important part of the warm-up process and is even more critical for individuals with heart, respiratory and kidney issues, as well as other chronic diseases. Participants should be encouraged to spend time allowing body systems to acclimate to the water before starting strenuous exercise.
- Educate your participants about increased urine output as a response to immersion. Discourage participants from limiting water intake before, during, and after class; bathroom breaks are a natural part of exercise in the water.
- Prescribing and monitoring intensity require an understanding of recommended procedures to determine the aquatic-adjusted target heart rate or target zone. This is especially critical to new exercisers, those with chronic disease and cardiac patients who must be closely monitored for exercise safety. Proper intensity is the foundation of effective exercise programming; monitoring intensity in the water is complicated due to the lowered heart rate response caused by immersion.

Pulmonary Adjustments

- The hydrostatic pressure of the water causes compression on the chest wall, which causes negative pressure breathing, placing more load on the inspiratory muscles.
- Hydrostatic pressure makes it more difficult to breathe in, and a little easier to breathe out. Elastic loading results due to increased mechanical load of the respiratory muscles. Elastic loading can be visualized as a rubber band: the rubber band is stretched to breathe in (pressure resisted) and released to breathe out (pressure assisted) in the water.

- Exercising in the water can help to strengthen the respiratory (inspiratory) muscles. The additional load to the respiratory muscles does not overtly affect most individuals; however, potential affects increase with age and the presence of pulmonary disease.

Exiting the Water
When exiting the water, the fluid shifts experienced during immersion are reversed. There hasn't been a lot of research performed on this topic. However, existing research indicates that the body is capable of recovering from immersion and regain function quickly on land. Keep in mind that many of the effects of immersion do persist for minutes or hours after exiting the water.

Exercise in Head-Out Water Immersion
Immersed movement in the water is altered from land due to the water's density. The density of the water affects your ability to move and float.

- The total mechanical power is the sum of the power required to move the limbs with the respect to the center of mass (internal power) and the power required to compensate for external forces (external power). This general equation is the same on land and in the water.
- But, for aquatic movement, the external power is different than on land. Propelling efficiency is one's capability of moving or not moving. Starting (accelerating) and stopping (decelerating) movement is different in the aquatic environment. This affects ones ability to move his/her body (e.g. walking) or move an object (e.g. exercise paddle) through the water.
- Water creates different musculoskeletal and nervous system results. Efficient movement is learned over time with practice.
- Kinesthetic responses are also affected. Immersion increases activity in the sensory and motor areas of the cortex of the brain. This influences the processing of sensations, including pressure, pain or warmth.
- Buoyancy affects total body and limb movement, sensory input and impact forces. Buoyancy is influenced by individual factors and level of immersion.
- Deep-water or suspended exercise creates yet a different set of musculoskeletal, neurological and physiological responses that are not discussed in this article. *(Sorry deep-water enthusiasts.)*

Movement in the water is not natural. Aquatic fitness professionals must teach efficient movement in the water. Not only for locomotor skills such as walking and jogging, but for coordinated exercise movements as well. Cue for proper form and technique, while recognizing individual physiological responses. When aquatic equipment is added, additional knowledge is required for proper application of muscle actions to achieve desired results.

Head-Out Cold and Warm Water Immersion
The physiological responses in cold or warm water are dependent on water temperature, length of immersion, level of activity, body composition, age, physical activity tolerance, environmental acclimation and other factors. As water gets cooler or

warmer, the effects on the body become more profound. The research emphasized the individuality of responses to cold or warm water. It is important to watch individual participants closely for signs of overheating or chilling as not everyone will respond the same to the same exercise at a given water temperature. Although some people may tolerate working at higher intensities in warmer water, others will not, just as some people can tolerate exercise comfortably in cooler water. The AEA Standards & Guidelines for Aquatic Fitness* list water temperature recommendations for various class formats. Based upon sound research, these recommendations give you a safe range for various types of activities and populations providing acceptable parameters for most people. *(*Available as a free PDF download at the AEA website under Education.)*

The body's response to cold-water immersion is the reduction of heat loss through vasoconstriction of the skin and subcutaneous fat layer to increase tissue insulation. Body temperature starts to drop leading to reductions in blood flow, maximal cardiac output, VO_2max and exercise performance. Eventually shivering starts to occur, which increases VO2 and heat production in an attempt to mediate heat loss.

Drowning is also more likely to occur. Sudden immersion in cold water can result in increased heart rate, hyperventilation and a reduction in brain blood flow velocity, leading to increased risk of drowning without hypothermia. Prolonged immersion in cold water can lead to poor decision-making and muscle failure of the arms and legs. Monitor participants for signs of hypothermia and realize that each person's tolerance is individual, and may vary from day to day. It is clear that the positive effects of exercise in cold water are impaired by the body's physiological responses to the cold and is not recommended as safe or effective.

Although cold-water immersion has been well researched, warm-water immersion has not. Immersion in warm water, when combined with exercise, results in an uncompensated heat load that cannot be balanced by heat loss. "Moreover, the reverse thermal gradient (water to body) may lead to hyperthermia and even death." (Pendergast) Because the water surrounds the body, sweating and evaporation cannot occur to cool the body. The inability to evaporate sweat causes a fast and high elevation in body temperature, in addition to the heat produced by exercise.

Even without evaporation, "sweating continues and eventually would result in lowered blood plasma volume and, when added to the increased blood flow to the skin, leads to lower cardiac output and skeletal muscle blood flow, resulting in reduced exercise capacity and hyperthermia. Although not documented, based on data for subjects acclimatized to air, persons in water could be at greater risk of hyperthermia as this may potentiate sweating and vasodilatation, risking reduced plasma volume, and blood flow to working muscles and brain." (Pendergast) This area of research needs further study, but it is clear that there is risk of hyperthermia and unwanted physiological outcomes that impair exercise due to the body's physiological response to immersion in warm water.

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Summary
Although basic, human water immersion has profound effects on the human body. Look to the Aquatic Exercise Association's Standards and Guidelines for Aquatic Fitness, which are based on sound science and research to guide you in safe aquatic exercise practice. Challenge yourself to reinforce knowledge gained from your experience as an aquatic professional with sound, scientific explanation. Knowledge and understanding of the physiology of exercise and immersion allows you to better assist your participants to adjust, minimize, maximize, or accommodate exercise responses in the water for personal needs and goals.

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