JRRD Guest Editorial

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Underwater treadmill training in adults with incomplete spinal cord injuries

Gravity. We spend our lives fighting it. One day it will win, as it always does. Until then, much of what we call "quality of life" is based on our ability to resist the effects of gravity and to be functionally mobile at home, at school, at work, and in our community. For those with physical disabilities, the challenge is greater and the stakes are higher. To counter the loss of mobility, strength, and endurance that often accompanies a disabling condition, a variety of interventions have been studied to improve physical fitness and reduce the weight-bearing challenges associated with walking. Several of these systems involve supporting a portion of a person's body weight with a harness during overground walking or land-based treadmill exercise [1]. This editorial describes an innovative method to unload body weight that allows a person with a gait impairment to walk on a treadmill submerged in a water tank (see Underwater Treadmill Training Videos 1 and 2).

UNDERWATER TREADMILL

Our interest in this unique therapeutic approach follows earlier studies that examined the evolution of gait in nondisabled youth and documented the influence of growth and maturation on the energy cost of walking. This research effort compared the aerobic demands of walking in nondisabled youth and children with cerebral palsy (CP). Results indicated that locomotor energy use was much higher in youth with CP [2]. Realizing that higher ambulatory energy use could help explain the fatigue often experienced by children with CP during extended walking bouts, training interventions to improve locomotor efficiency in this population were investigated.

One such intervention was the implementation of an aquatics-based treadmill walking program to reduce the energy cost of walking and increase overall fitness and mobility in youth with CP. Because aquatic exercise is less damaging to joint integrity, it can be an effective alternative to land-based exercise programs in persons with lower-limb joint weakness and balance problems. Gait training can also be performed in a very controlled setting with an underwater treadmill because speed, water depth, and water temperature can be easily manipulated and reproduced. Other advantages of underwater treadmill exercise include the similarity of muscle activity and gait patterns used in land walking, minimization of postural distortions, greater weight-bearing support for deconditioned individuals, increased leg strength gained by overcoming water resistance and turbulence, and decreased pain levels. The preliminary findings from this research in ambulatory youth with CP suggest that a number of fitness and mobility variables can be improved following an underwater treadmill training program incorporating the gradual, systematic, and overlapping manipulation of water height, gait speed, and walking duration.

UNDERWATER TREADMILL WITH SPINAL CORD INJURIES

Based on these initial findings, we explored the possibility of applying this therapeutic regimen to individuals experiencing a greater degree of mobility impairment. After much discussion, we decided to document the impact of underwater treadmill training in adults with incomplete spinal cord injuries (SCIs). Because impairments associated with SCI are often considered permanent and irreparable, even slight improvements in physical function are noteworthy. We chose to train adults with SCI to differentiate their responses from those of children with neural impairment, who exhibit nervous systems that are still somewhat plastic and whose ability to recover from injury is more dynamic than adults. In addition, SCIs are stable and do not progressively worsen like diseases such as cancer or multiple sclerosis. Accordingly, factors that could potentially confound the interpretation of study findings are often not present. Because individuals with SCI typically experience some degree of injury resolution during the initial healing period, we enrolled participants whose injuries were more than a year old and unlikely to improve without some type of clinical intervention.

PARTIAL BODY-WEIGHT SUPPORT IN THE WATER

Water promised to be a beneficial environment for the study. More specifically, the underwater treadmill provides partial body-weight support in a unique manner when compared with a typical land-based harness system. In a harness system, the body is suspended but the full weight of the legs remains unchanged. In contrast, unloading in the water provides buoyancy to the legs. Water levels in our underwater treadmill program were adjusted to a point of relative neutral buoyancy. The water level selected was high enough to support full extension of the hips and knees, but low enough to provide some weight-bearing support. On a practical note, wearing a harness can be uncomfortable and detract from the overall training experience. In addition, because many individuals with SCI have diminished sensation, they can be unaware of excessive pressure caused by the harness, which could lead to skin damage.

Water has other positive values as an exercise medium. For example, water provides external pressure that enhances cardiovascular function. Normally, the heart responds to skeletal muscle activity by routing more blood to active muscles. When nerve pathways are interrupted, as they are in SCI, upper- and lower-body muscles may not receive adequate blood, and blood in the lower limbs is not pumped back to the heart efficiently, which leads to blood pooling as gravity pulls it to the lowest point [3]. The hydrostatic pressure provided by the water in the tank helps direct blood back to the heart, increasing venous return and in turn increasing preload and cardiac output. Another benefit of partial water immersion is the sensory stimulation of nerve receptors in the skin. As water moves across the skin during water walking, the force and the temperature of the water provide stimulation. Even if sensation is not "felt" by the individual, the closed-loop nature of nerve transmission is activated, increasing motor output.

Partial immersion in water also allows participants to work on improving dynamic balance. Land-based harness systems do not require effort to maintain balance, since falling is not an option. In water, however, falling is always a possibility but rarely a danger in well-monitored programs. A fall in water does not occur as quickly as it does on land, and efforts to stay upright while walking in water provide the necessary retraining for individuals who have not spent much time out of a wheelchair following their injury.

CENTRAL PATTERN GENERATORS

In addition to promoting ambulation by facilitating control of gait by upper brain centers, central pattern generators may contribute to improving walking performance in persons with SCI who undergo underwater treadmill training. An example of how central pattern generators initiate movement is the commonly observed phenomenon of a how a newborn baby takes reflexive steps if she is held upright and her feet touch the floor. In theory, these steps are subcortical, occurring before a baby's brain is cognitively aware of walking or volitionally controls her limbs. While the presence of central pattern generators in humans is by no means settled science, the concept is nonetheless intriguing. If the movement of the treadmill belt facilitates reflexive stepping, this might help establish a patterned gait response. The resultant gait activity would be autonomic in nature, originating from a complex neural network located in the spinal cord and not from signals descending from upper-brain areas [4]. In our study, most participants were able to generate a stepping pattern prior to the study. Hence, we speculate that gains in motor function produced by underwater treadmill training may arise from neural networks in the spinal cord as well as from upper motor command of locomotor activity.

As a final point, the gait pattern that emerges from each participant who trains on a water treadmill is their own and not produced by external assistance. Conversely, in land-based harness programs, gait is often facilitated by therapists or robotic devices that move the limbs. Evidence shows that a self-developed gait, even in impaired populations, can be a metabolically efficient way to move. Along these lines, research has shown that children with CP tend to select preferred walking speeds and step length/step frequency combinations that require the least amount of energy per unit of body mass [5].

UNDERWATER TREADMILL AMBULATION STUDY

In recruiting participants, we decided to restrict our study to individuals with incomplete SCI, primarily because we hypothesized that individuals with some physical function below the level of the spinal injury might improve greatly in mobility compared with individuals with more severe injury. Before training started, walking speed and endurance, leg strength, balance, and free-living step activity were assessed. Once pretesting was completed, an 8-week, 3-day-a-week training phase was initiated. Water temperature was tailored to maximize comfort and help control spasticity. Water height was established following a "friendly negotiation" between the clinician and each participant that helped support ample body weight and possibly fully extend the hips and knees, while allowing for a normal gait pattern to emerge. During a typical training session, participants completed three walking trials, with rest breaks interspersed between trials. At the beginning of the training program, each walking bout lasted 5 minutes, resulting in a total walking time of 15 minutes. As training progressed, the duration of each walking trial increased from 5 to 9 minutes, so that participants accumulated 27 minutes of walking time per session by the end of the program. Walking speed was also increased gradually during the training period. The water resistance becomes more challenging as speed increases. Once the training program was finished, participants were retested to document changes in mobility and fitness.

DISCUSSION

While the training process is currently ongoing, each participant who has finished the program has meaningfully improved motor function, from greater stability during transfers to eliminating the need for an assistive device during walking. Participants have also reported an improved sense of self-confidence and personal well-being, as well as restored hope for the continuation of gains in mobility and physical performance. All participants have stated that they would continue training if this option was available.

One of our participants, a middle-aged gentleman with incomplete tetraplegia, used crutches regularly. As he progressed through the training program, he depended less on his crutches for transfers and when walking short distances. On a particularly busy day in our laboratory, we had completed his treatment and had moved on to other tasks when the telephone rang. Our participant was calling us from the parking lot, asking if he had left his crutches in the training room.

Was he cured? Far from it. Did he gain a small victory that day over gravity? Absolutely.

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