Deep Water Running: Applications to Performance and Rehabilitation for Long Distance Runners

Landon Bright

Hardin-Simmons University

Although it is considered a “non-contact sport,” running has been described as a series of collisions with the ground (McMahon & Greene, 1979). Because of these collisions, a serious or even recreational runner has a high probability of obtaining an injury due to his or her training. An estimated 70% of runners encounter symptoms of overuse during any one year (Hreljac, 2004). Several other studies estimate that 24 to 65% of competitive runners have overuse injuries during any one year (Hoeberigs, 1992; Van Mechelen, 1992). These injuries are often caused by repeated exposure to vertical ground reaction forces incurred during foot contact with the ground that can be two to four times the runner’s body weight (Crossley, Bennell, Wrigley, & Oakes, 1999). These types of injuries most often surface in the lower limbs and include tendinitis, plantar fasciitis, patellofemoral syndrome and stress fracture of the foot or tibia (Hreljac, 2004).

Injuries to the lower limbs, as previously stated, can require athletes to cease their training. Unfortunately, periods of inactivity can rapidly reverse physiological adaptations that have been obtained during training. A literature review by Wilber and Moffat (1994) shows that detraining of less than three weeks is associated with maximal oxygen decrements of 6 to 11% and additional weeks of inactivity up to 12 weeks are associated with decreases up to 18%. These percentages are important to note, as many musculoskeletal injuries require 4 to 6 weeks for collagen maturation and tissue healing (Triche, 2003). Taking this amount of time off due to injury can be very detrimental for any training plans an athlete might have. Thus, finding and utilizing functional activities that counter cardiovascular deconditioning are vital to minimize performance decrements during physical rehabilitation (Dale, 2007).

One way to avoid or reduce performance decrements while not being able to on-land run (OLR) is to utilize deep-water running (DWR). DWR is performed at the deep end of a swimming pool as an individual attempts to reproduce the pattern of limb movement used during

OLR. Impact is eliminated as contact with the floor is avoided. This activity contrasts shallow-water running (SWR), in which each foot in turn lands and drives off the bottom of the swimming pool (Reilly, Dowzer, & Cable, 2003). Although the traditional use of DWR has been for rehabilitation, it is now often used as supplementary training to improve performance and avoid injuries altogether. This paper will examine the performance and rehabilitation applications of DWR for endurance athletes by outlining the physiological and kinematic responses of DWR and contrasting DWR with OLR. This paper will also discuss the use and benefits of underwater treadmill running (UTR) and its application to DWR training.

Maximal exercise

It is commonly reported that DWR leads to reductions in VO_2max and maximal heart rate when compared to treadmill or OLR running. In fact, the average heart rate max has been reported to be 10 to 15 beats per minute lower than those found on land (Frangolias & Rhodes, 1996). Although there is no clear consensus on the reason for the reductions during maximal exercise in water, there are several mechanisms that researchers point to as possible culprits. These reasons include the effect of water temperature, an increase in hydrostatic pressure, the short duration of running protocols during DWR, a reliance on participants to increase exercise intensity to a perceived maximum, the shortening of stride length and the possibility of individuals trying to avoid fatigue. Despite the obvious lowered heart rate during maximal exercise, research still points to DWR as a viable alternative to maintain or improve fitness levels in athletes who are injured or healthy.

In one study, (Dowzer, Reilly, Cable, & Nevill, 1999) researchers compared the maximal physiological responses to treadmill running, SWR, and DWR while wearing a buoyancy vest in 15 trained male distance runners. Treadmill running resulted in VO_2max and heart rate values that were significantly higher than the peaks attained in both water tests. The peak oxygen uptake averaged 83.7 and 75.3% of VO_2max for SWR and DWR. Peak heart rates for SWR and DWR were 94.1 and 87.2% of the maximal heart rate reached in the treadmill test. Despite the reductions in maximal values, the study suggested the training stimulus provided by exercise in water was still adequate as a form of supplementary training.

Studies have also examined and compared underwater treadmill running (UTR) to OLR in terms of maximal rates. One study (Silvers, Rutledge, & Dolney, 2007) that focused on college-age runners determined that oxygen consumption (VO_2), heart rate, and ratings of perceived exertion (RPE) at maximal exertion were similar for UTR and land treadmill running. The study concluded that even though there were slight differences in pulmonary measures between UTR and land treadmill running, the similarity in VO_2max between the two modalities suggest either one can be used successfully to enhance cardiorespiratory conditioning of college runners.

The previous two studies are supported by anecdotal evidence as prescribed by the coach of the gold and silver medalists in the 10,000 meters at the 2012 London Olympics, Alberto Salazar. Salazar, a former New York City Marathon and Boston Marathon winner utilizes UTR for difficult workouts despite the lowered maximal values. He recently wrote about the benefits his athletes have seen using UTR (Salazar, 2012):

> Our world-class athletes log up to 25 to 33% of their weekly mileage in the pool. In a year's time, that's equated to many of them missing zero days of training. Even if they couldn't run on land, they were able to run in the water. They've stayed on-track and motivated, even if they weren't at 100%. In short, it's been a coach's dream come true from the perspective of not having to wait to continue training. (p. 46)

Submaximal exercise

In terms of submaximal exercise, cardiorespiratory responses have been shown to vary (Azevedo, Lambert, Zogaib, & Neto, 2010). This may be due in part to the various methods of comparison, such as some studies using RPE, while others use step frequency, absolute VO_2max values, or VO_2 at the ventilatory threshold. Much like maximal exercise, at a given perceived exertion, VO_2 and heart rate have been reported to be lower during DWR than during submaximal treadmill running (Svedenhag & Seger, 1992). Brown, Chitwood, Beason, and McLemore (1996) found higher ratings of RPE during DWR than during OLR at equal stride frequencies. But, during DWR, stride frequencies are lower compared with OLR due to water resistance, which slows down movements made in the water (Reilly, 2003).

It is important to note that familiarity may play a role in determining physiological responses during DWR as compared with OLR. Gehring, Keller, and Brehm (1997) reported that competitive runners were able to elicit very similar responses in terms of VO_2 values in land and water, while non-competitive runners did not. These findings are supported by a study (Yamaji, Greenley, Northey, & Highson, 1990) that observed lower heart rates for a given VO_2 for those who were more experienced in DWR, while less skilled participants had higher heart rates for similar VO_2 values during DWR. These studies indicate that heart rate responses at a given VO_2 during DWR compared with OLR may be largely influenced by the ability of the athlete in the water.

Injury prevention and recovery

Trying to prevent lower limbs from injury is always a top priority for athletes and coaches, but that goal can sometimes be thwarted by a multitude of problems. OLR can place repetitive stress on the lower limbs and lower back. This compressive loading is inevitable during regular running as the feet will make contact with the ground 600 to 1200 times per kilometer, which, as previously mentioned, causes ground reaction forces of two to three times body mass (Lees, 1988). The linear relation between OLR training load and stress-related injuries leads many running coaches to substitute part of the low-intensity running on hard surfaces for DWR (Reilly, et al., 2003). Salazar (2012) supports the use of DWR in order to lower the risk of injury:

> The health of the runners is at the core of any running program, thus, it should be at the top of coaches' concerns at all times. Over the years, I've found that water offers more miles, less risk and great rewards. (p. 47)

The evidence that DWR reduces injuries is mostly based on empirical wisdom, there is, however, experimental evidence to show that DWR reduces spinal loading and the likelihood of lower back problems in runners. Dowzer, Reilly, and Cable (1998) compared spinal shrinkage in response to DWR, SWR and normal treadmill running in 14 athletes. The study involved each runner completing 30 minute runs on separate days in deep water, shallow water and on a treadmill. The participants were asked to exercise at 80% of peak oxygen consumption. Running in deep water caused significantly lower shrinkage than the other trials, with zero difference between SWR and treadmill running. This finding provides support for the use of DWR to decrease the compressive load on the spine.

Another aspect of training that is an important function of success is the need for recovery. Runners often perform difficult workouts that exhaust the legs and may lead to feelings of fatigue for several days. DWR running has been recommended for athletes to accelerate the recovery process between competitions (Cable, 2000). One study (Reilly, Cable, & Dowzer, 2001) examined the effects of DWR on the prevention and recovery from an exercise plan designed to induce delayed-onset muscle soreness (DOMS) by way of stretch-shortening exercises. Although the study did not use runners in particular, stretch-shortening exercises are often used in conjunction during a runner's total workout and could thus provide support for the use of DWR to enhance the process of recovery. The study took 15 males and 15 females and divided them into five different groups based on the type of recovery exercise to be preformed after the workout. Although DWR running failed to prevent DOMS it sped up the process of recovery for leg strength and perceived soreness. Leg strength after the workouts was reduced on average by 20% after 48 hours, but the DWR group only experienced reductions of 7%. Likewise, soreness in the legs for the DWR group was reduced by 40% and was reduced threefold for abdominal soreness. The authors concluded that compared with treadmill running, DWR is effective in temporarily relieving soreness, while enhancing the process of recovery.

Biomechanical comparison

As previously stated, it seems practical to pursue training techniques to avoid lower limb injuries and running-related trauma. But these techniques would only seem prudent if they did not compromise aerobic conditioning and the movement pattern of OLR. As mentioned, the effects of DWR as a training supplement on the maintenance of cardiorespiratory parameters has been extensively studied, but the biomechanical comparisons between OLR and DWR are limited. Regardless, Reilly, et al. (2003) state that fundamental laws of physics may be applied to any exercise performed in water:

> Whereas gravity is a prominent factor during performance on land, buoyancy can assist a body moving toward the surface and resist a body moving away from the water surface. This may result in mechanical variations during the two running modes. In addition, the

> water resistance imposed on the body during the aquatic locomotion is much greater than that on land, as water is about 800 times more dense than air. (p. 965)

Some studies have brought into question the extent to which DWR can simulate treadmill running. Moening, Scheidt, Shepardson, and Davies (1993) found large differences in the range of motion at the hip, knee and ankle. Glass (1987) undertook extensive biomechanical and cinematographical analysis of treadmill running and DWR and found range of motion at the hip increased with an increase in running speed, while an increase in intensity for DWR decreased the range of motion in the hip. When comparing the kinematics of between DWR and OLR, Kruel, Peyre-Tartaruga, Larronda, Loss, and Tartaruga (2002) found that stride frequency and length are shorter for DWR than in OLR. It has also been found that the activity of the soleus and gastrocnemius is lower during DWR than in OLR (Kaneda, Wakabayashi, Sato, & Nomura, 2007). According to Kilding, Scott, and Mullineaux (2007), the muscle recruitment patterns hinder the transferability of DWR to OLR. They state, "The lack of the stretch-shortening cycle during DWR is a significant factor and is highly likely to alter the coordination and hence, the muscle recruitment patterns typically experienced during on-ground running" (p. 479).

However, some studies point to a negligible difference in biomechanical movement between the two running modes when DWR is substituted in moderation. Peyre-Tartaruga et al. (2009) found that in competitive runners, there was no modification of running economy when DWR was utilized as complimentary training over an 8-week period. During this 8-week study, competitive runners were asked to substitute 30% of their training volume with aquatic exercise. This study can be seen as a realistic situation where a competitive runner is not completely replacing OLR for DWR due to injury, but supplementing it in order to reap aerobic and anaerobic benefits without risking further injury. The authors of the study concluded that any differences between OLR and DWR do not influence the effectiveness of using DWR as a cross-training modality (Peyre-Tartaruga et al., 2009):

> Despite the cardiorespitory, neuromuscular, and mechanical differences between the activities, the general kinematic pattern of OLR was not modified with the inclusion of DWR as a training supplement. Therefore, it may be stated that such acute differences between exercise modes seems not to significantly affect the transferability of DWR training benefits to OLR performance. (p. 147)

Killgore, Wilcox, Caster, and Wood (2006) maintain that to mimic OLR during DWR in terms of lower extremity movement depends on the type of DWR style that is employed. In their study, the authors took 20 intercollegiate distance runners and videotaped them during DWR and treadmill running at 55 to 60% of their VO_2max using two different DWR styles: high-knee (HK), which mimics stair-stepping, and cross country (CC) which is more like TR. In terms of biomechanics, the authors did find significant differences between DWR and treadmill running in horizontal and vertical displacement of the knee and ankle as well as stride rate. However, the CC style of DWR appeared to better satisfy the specificity of training principle with respect to a closer simulation of land-based, lower-extremity running. The authors concluded that although stride rate will be slower at a comparable percentage of VO_2max, the CC style is recommended to best mimic distance running training and the HK style is best used to increase stride rate (Killgore, et al., 2006):

> If the desired effect of DWR is to best mimic treadmill running relative to linear range-of-motion movement specificity and to thus possibly satisfy the specificity-of-training principle, the CC style is recommended. However, if the desired effect is to provide a

> physiological stimulus by emphasizing stride rate cycle irrespective of linear range of motion, the HK style is a closer approximation of TR. (pg. 926)

Conclusion

As discussed, the purposes of DWR are diverse. They include rehabilitation, recovery from ROMS, complementary training, aerobic training, and strength training. In addition to benefitting athletes, DWR also promotes movement for the physically debilitated and aerobic training for those overweight. For endurance runners, DWR has historically been used for rehabilitation, but has recently been incorporated by coaches as complementary training. Elite runners are always looking for advantages over their competition, but opportunities for advantage often come with risk. With high incidence of lower limb injuries among elite runners, adding more miles to a training program can increase the odds of obtaining an injury. Most competitive runners train for two hours per day (Peyre-Tartaruga, et al., 2009), which theoretically means that runners could improve if they can add some form of training that is different from actual running so it does not result in overtraining or injuries. In this regard, the inclusion of DWR can be a strategy for increasing the training time and increasing the physiological load on the mechanical overload on lower limb joints, without risking injury. Tartaruga et al. (2009) provides two possible practical implications of including DWR training for competitive runners:

> (a) Although there are mechanic differences between the modes of exercise (DWR and OLR), DWR helps to maintain or even to improve the OLR performance and mechanics in both non fatigued and fatigued situations on competitive runners; (b) the replacement of land-based training by DWR (=30%) is an approach and a possibility to

> coaches for decreasing the mechanical load in lower limbs and, consequently, for reducing the risks of overuse on competitive runners. (p.149)

One aspect of DWR that cannot be ignored when utilizing for either rehabilitation or supplementary training is form and technique. As previously mentioned, the “cross country” or open gait style is the most appropriate for runners as it best mimics OLR. Killgore (2011) lists several best practices for form and technique for DWR that include: the water being at shoulder level, the body leaning slightly forward, arm-carriage identical to OLR, hands in clenched-fist position, and hip reach position at 60 to 80 degrees.

Much like any form of cross training, the ability to utilize the pool as part of an overall plan for success in running is reliant in large part on accessibility, availability, commitment by the team and coach staff and the development of a great working relationship with an aquatics administrator (Kilgore, 2011). But if an individual or team is able to put these pieces together, they will find that DWR provides an environment that not only aides in rehabilitation, but just as importantly provides a training option which has the potential to enhance the quality and quantity of training needed to be successful.

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