Deep Water Running: An Effective Non-Weightbearing Exercise for the Maintenance of Land-Based Running Performance

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Deep water running (DWR) has become a well-recognized form of cardiovascular conditioning for injured athletes and has been used successfully to maintain running performance. DWR provides for decreased stress and weightbearing to injured tissue and joints, allows for maintenance of cardiovascular fitness and a training effect, and offers greater specificity of exercise in relation to running. During a 22-month period, 181 active duty Army soldiers, placed on temporary profiles for injuries that precluded them from their regular weightbearing physical fitness activities, participated in a DWR program. Injuries to the back, knee, and ankle were the most common reasons for referral to the program. This article reviews the physiological characteristics of DWR, specifics of DWR program design, DWR mechanics, and the advantages of DWR over other aerobic forms of exercise to maintain land running performance in military personnel on temporary non-weightbearing profiles.

Introduction

The ability to run effectively is of paramount importance in the lives of most military personnel. Running is an essential part of daily military training and fitness activities. In the Army, running is used to help define the level of a soldier's fitness (a 2-mile land run is part of the Army Physical Fitness Test). The inability to run at an age-specific standardized time can negatively affect a soldier's job performance, promotion in rank, and deployment readiness.

Active duty Army soldiers frequently sustain injuries that require them to temporarily cease land running and weightbearing activities. Such a mandatory hiatus can quickly lead to significant deconditioning.[1-3] Detraining results in decreases in (1) cardiovascular function, (2) aerobic capacity, (3) mitochondrial respiratory enzyme activity, (4) capillary density, (5) preexercise muscle glycogen stores, and (6) utilization of lipids. These changes can occur within 2 to 4 weeks after cessation of activity.[4] Compared with the training break that initially led to deconditioning, reconditioning to the preinjury level of running can take significantly longer.

To deter the consequences of deconditioning, soldiers are frequently placed in alternative exercise programs, such as stationary bicycling or swimming. It is well established in the literature that exercise is very specific and that the best performance at an exercise is achieved by training at the exercise itself.[5-8] Deep water running (DWR) has become a well-recognized form of cardiovascular conditioning for injured athletes across the nation and has been used successfully to maintain running performance.[4,9-15] With DWR, land running is simulated as closely as possible with the exception of weightbearing. DWR, therefore, has potentially greater specificity for maintaining run performance compared with other alternative forms of exercise. DWR provides for decreased stress and weightbearing to injured tissue and joints, allows for maintenance of cardiovascular fitness and a training effect, and offers greater specificity of exercise, thereby potentially serving as a more optimal alternative exercise than biking or swimming.

This article is a review of the senior author's (T.D.L.) experience using a DWR program for injured active duty Army soldiers. The objective of this review is (1) to make military personnel aware of the utility of a DWR program as a form of rehabilitation for injuries that prohibit weightbearing, (2) to provide guidance on how to institute a DWR program, and (3) to provide readers with information about previous experience with a DWR program with injured active duty soldiers.

Description of a DWR Program

From September 1995 to June 1997, 181 individuals participated in a DWR program at Fort Lewis Army Post in Tacoma, Washington. The program was organized and directed by the Physical Medicine and Rehabilitation (PM&R) Department at Madigan Army Medical Center. The base pool was used for all training sessions. Notification and education regarding the benefits of the program were distributed to all of the units at Fort Lewis and to all of the medical units in the hospital and troop medical clinics. Participation was open to any soldier with an injury requiring a non-weightbearing temporary profile as administered to the soldier by his or her health care administrator (forms DA 689 or DA 3349). Attendance in the program was optional. Soldiers were referred to the program by their health care provider or unit authority. Only those soldiers with injuries prohibiting immersion in water (e.g., open or draining wounds, new surgical incisions, or infectious skin lesions) or soldiers not willing to be in deep water with a flotation device were precluded from participation.

Enrollment

Requirements for program enrollment consisted of the following: (1) a temporary profile (forms DA 689 or DA 3349), and (2) written and signed permission by the soldier's unit commander or first sergeant. Both documents were collected at the PM&R Clinic at Madigan Army Medical Center, where soldiers enrolled in the program. All soldiers completed an enrollment questionnaire, which requested information regarding demographic fea-

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The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

This manuscript was received for review in January 2000. The revised manuscript was accepted for publication in May 2000.

tures, nature of the injury, preinjury exercise level, and medical history. Table I summarizes the characteristics of the participants during a 22-month period.

Documentation

The soldier was allowed to participate in the program for the duration of his or her temporary profile. After the expiration of the temporary profile, a new profile and permission slip were required if continued participation was recommended or requested. Attendance was taken at each session, and this information was available to all unit commanders. All soldiers unable to participate in a scheduled session were responsible for notifying the PM&R Clinic or the pool staff. A folder was kept for each soldier that included the documents described above, the questionnaire, documentation of attendance and the soldier's progress, and notation of any adverse affects or complications.

TABLE I

PARTICIPANT DEMOGRAPHIC FEATURES AND EXERCISE BACKGROUND

Participants (181)		
Male	123	68.0%
Female	58	32.0%
Average age (years)	29	
Age range (years)	18–62	
DWR program participation		
Average number of sessions	9	
Range	1–73	
Anatomical injury distribution		
Knee	54	29.8%
Back	41	22.7%
Ankle	33	18.2%
Tibia	28	15.5%
Foot	18	9.9%
Hip/pelvis	6	3.3%
Neck	4	2.2%
Femur	3	1.7%
Other	3	1.7%
Fibromyalgia	2	1.1%
Ovarian cyst	1	0.6%
Unknown	3	1.7%
Injury onset		
Average duration (days)	316	
Range of duration (days)	1–4,272	
Median duration (days)	120	
Nature of injury		
New injury	123	68.0%
Recurrent	58	32.0%
Run routine when healthy[a]		
≥ 3 times per week	123	68.0%
< 3 times per week	56	32.0%
Unknown	2	1.1%
Exercise routine at program enrollment[b]		
Aerobic (including running)		
≥3 times per week	85	47.0%
<3 times per week	90	49.7%
Unknown	6	3.3%
Strength training		
≥2 times per week	56	30.9%
<2 times per week	119	65.7%
Unknown	6	3.3%

[a] Average duration of run session ≥ 20 minutes before injury.

[b] Average duration of aerobic exercise ≥ 20 minutes after injury.

Pool Workout

One-hour training sessions were held three times per week during the soldier's normal Army morning physical fitness training. An individual trained in DWR directed each session. Each session started with an approximately 10-minute session of push-ups and sit-ups, allowing each soldier to work within the limits of his or her profile. The remaining 50 minutes were held in the water and consisted of a warm-up and cool-down stretching program and up to 40 minutes of DWR. A flotation belt was used to maintain the head above water and allow the individual to maintain strict adherence to proper form and technique. Program participants used the Aquajogger DWR belt (Excel Sports Science, Eugene, Oregon). Other flotation devices are available, but those made specifically for DWR should be used to maintain proper posture and running form. Care was taken that each individual soldier became proficient in performing a running form that simulated land running as closely as possible and ensured the highest physiological responses possible.

DWR Mechanics

The running form used in deep water should simulate the form on land as closely as possible (Fig. 1). Running should be performed in water deep enough that the participant's feet never contact the bottom of the pool. A flotation belt or vest is used to maintain the head above water. This allows the runner to remain upright and focus on maintaining proper running mechanics. The viscosity of water results in a 30 to 40% lower

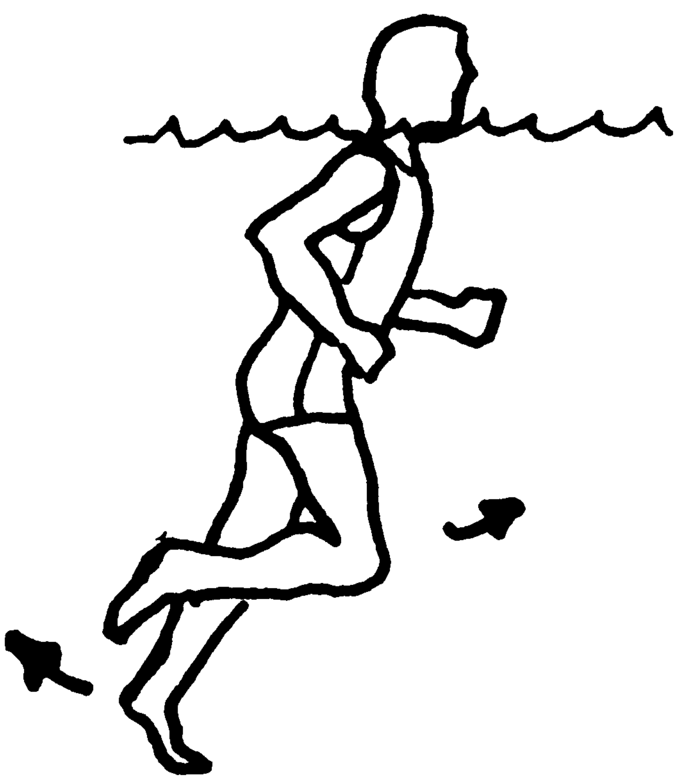

Fig. 1. For DWR, assume a natural running position in deep water. (Reprinted with permission of Publitec Editions from *Deep Water Exercise for Health and Fitness*.[18])

stride frequency with DWR compared with land running.[16] In general, the following biomechanics should be followed[13,17] (Figs. 1 and 2):

- The head is maintained straight ahead with the mouth out of the water, avoiding cervical extension (Fig. 2).
- The trunk is held upright with the spine in neutral. A slight forward lean may occur during the leg push-off stage of the running cycle.
- The elbows are held slightly flexed, the hands are held relaxed or slightly clenched, and the upper extremity pumping motion occurs at the shoulder, identical to that performed on land.
- Initially, the hip and knee are brought forward and flexed with the ankle plantarflexed (toes pointed). When the thigh becomes horizontal, the lower leg is swung forward as the ankle dorsiflexes. The hip and knee are then extended against the water with the ankle dorsiflexed until the hip is at neutral. The hip is then further extended while the knee flexes and the ankle plantarflexes as in push-off in land running and the opposite leg begins to swing forward.
- Each arm swings forward in tandem with the opposite leg.

The following are common errors that should be avoided[13]:

- using the hands to cup the water and propel the individual forward and to keep the head above water;
- moving the arms in a dog-paddle fashion with abduction at the shoulders;
- using uncharacteristic lower trunk mechanics, such as incomplete flexion at the knees and hips or a swim-style kick; and
- performing a cycling motion with the legs.

These errors are usually caused by the exerciser's attempt to keep the head above water. These can be corrected with practice and the use of a flotation device. When proper running technique is achieved, the participant usually finds that it is more difficult to maintain the chin easily above water, and the intensity of the workout is increased significantly.

Maintenance of Workout Intensity

Each workout was based on a defined intensity level. Program structure varied between endurance and interval training programs to reproduce the exercise the soldier would perform in regular Army physical fitness training. Training techniques similar to those described by other authors were used.[9,18,19] The majority of workouts were done with the soldier moving freely in the water. Occasionally (when there were large numbers of participants), workouts were performed by tethering the individual to the side of the pool. All participants were educated in the technique of using heart rate and the 15-point Borg rate of perceived exertion (RPE) scale as an indicator of the intensity of exercise being performed.[20,21] With DWR, a strong correlation (0.89) has been demonstrated between perceived exertion and percentage maximal oxygen uptake (VO_2 max).[22] After each interval of exercise performed at a specific intensity level, the soldiers were instructed to check their heart rate and indicate the result to the instructor. Soldiers not in the expected target heart rate range for the prescribed intensity level were given verbal feedback on whether to increase or decrease their exercise intensity.

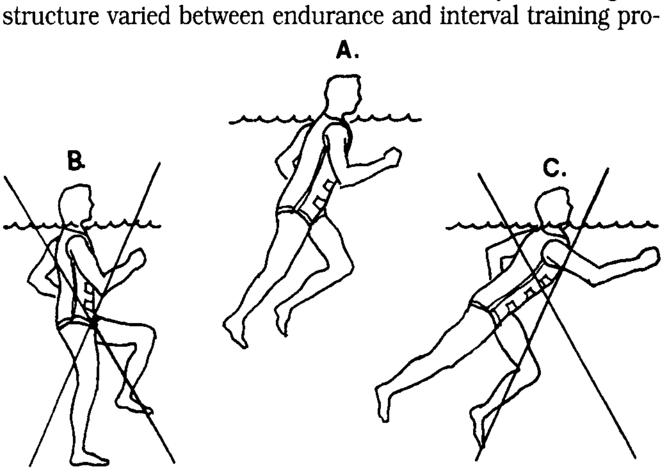

Fig. 2. To perform DWR, lean forward slightly as though running on land (A). Do not attempt to remain stationary (B), and avoid neck extension (C). (Reprinted with permission of Publitec Editions from *Deep Water Exercise for Health and Fitness*.[18])

The 15-point Borg RPE scale was chosen for its simplicity in determining the approximate desirable heart rate for a specific exercise intensity level. The 15-point Borg scale values range from 6 to 20 (Table II). For healthy individuals, the heart rate during land exercise should be about 10 times the RPE value (simply adding a zero to the end of the intensity level number represents the target heart rate).[20] The heart rate achieved with water exercise varies with the temperature of the water. In cooler water, the target heart rate may be up to 15% less than with exercise of the same intensity on land.[23] In warmer water, the target heart rate achieved may not differ from that achieved with land exercise of the same intensity. Because the pool available for our use was kept at a very warm temperature (80–90°F), heart rate responses achieved were similar to heart rate responses expected for land exercise.

In addition to the 15-point Borg scale, other methods are available for monitoring exercise intensity. Brennan and Wilder designed a 5-point scale using verbal descriptors ranging from very light to very hard, with each descriptor corresponding to a

TABLE II

THE BORG RATE OF PERCEIVED EXERTION SCALE[a]

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Reprinted with permission of G. Borg from Borg G: Perceived Exertion and Pain Scales, Figure 5.3, p 31. Champaign, IL, Human Kinetics, 1998.

[a] The Borg RPE scale must not be used without correct instruction and administration.

descriptor of a land run distance (Table III).[24] This scale was designed to be easily understood by individuals who do a great deal of land running. Participants were also instructed in the use of the Brennan scale for exercise intensity. Soldiers who chose to use the Brennan scale could do so because each workout was designed using both the Borg and the Brennan scales. The use of cadence has also been described as an effective method of monitoring exercise intensity.[9,25] Table IV shows an example of a DWR workout using the Borg and Brennan RPE scales.

Adverse Affects

In general, participation in the program was well tolerated. There were only two adverse effects during the period reported here. Soldier 1 had an asthma attack while in the pool and was taken to the emergency room for treatment and did well. Soldier 2 had avascular necrosis of the hip and found that the resistive hip flexion action achieved with the exercise exacerbated his hip discomfort. Soldier 2's program was modified to allow him to do deep water exercises with less hip flexion and to decrease the total duration of the program. Although soldier 2 was not able to achieve a strict simulated running form, he was still able to perform exercises that allowed him to reach a cardiovascular training effect and, therefore, remain active. He tolerated these modifications well and continued in the program.

Discussion

In this paper, we describe our experience with a military-based DWR program. During a 22-month period, 181 soldiers participated in the program. Participants had a variety of injuries that restricted participation in traditional military weight-bearing activities. All participants demonstrated good tolerance for the DWR program. A DWR program such as the one described here is a more specific form of alternative exercise, which is useful in a variety of military settings and situations. Other advantages of DWR include a possible impact on injury healing itself. The hydrostatic pressure of water makes it an ideal medium for reducing edema, and the increased blood flow to muscles allows for the elimination of metabolic waste products and inflammatory mediators.[23]

Inactivity associated with a non-weightbearing profile can rapidly lead to deconditioning. A 6-week layoff in training can decrease VO_2 max by 14 to 16%.[2,3] The resultant deconditioning can prolong a return to preinjury performance levels and full active duty. Even the substitution of other forms of exercise does not necessarily protect against a decrease in land running performance. It is well established in the medical literature that exercise is very specific and that the best performance in a given

TABLE III

BRENNAN SCALE OF PERCEIVED EXERTION

1	Very light (light jog or recovery run)
2	Light (long, steady run)
3	Somewhat hard (5- to 10-km road race pace)
4	Hard (400- to 800-m track speed)
5	Very hard (sprinting: 100- to 200-m track pace)

Reprinted with permission of D.K. Brennan from *Aquarunning: An Instructors Manual*.[24]

TABLE IV

LADDER WORKOUT

Time	Borg Rate of Perceived Exertion Scale	Target Heart Rate[a]	Brennan Scale
5 minutes	10	80–100	1
5 minutes	14	120–140	2
4 minutes	10	80–100	1
4 minutes	15	130–150	3
3 minutes	10	80–100	1
3 minutes	16	140–160	3–4
2 minutes	10	80–100	1
2 minutes	17	150–170	4
1 minute	10	80–100	1
30 seconds to 1 minute	19	170–190	5
1 minute	10	80–100	1

Modified from *Deep Water Exercise for Health and Fitness*.[18]

[a] The achieved heart rate varies with the temperature of the water. In cooler water temperatures, the target heart rate may be up to 15% less than with the same intensity exercise on land. In warm water temperatures, the target heart rate achieved may not differ from that achieved with land exercise at the same intensity.[18]

exercise is achieved with training using the specific exercise.[5–8,26,27] Training produces specific adaptations at the peripheral and central levels that are specific to the mode and manner of exercise. This principle of specificity is particularly important to military personnel on a non-weightbearing profile.

Substitution of run training with activities such as swimming or cycling would be expected to be less effective at maintaining or improving run performance than a training activity with mechanics more similar to running. Swimming uses primarily the upper body for propulsive force.[27] Several studies have failed to demonstrate a transfer of training effect from swimming to running.[28,29] Cycling uses the quadriceps extensively, whereas the plantar flexors are preferentially recruited in running.[27] Studies examining the impact of cycle training versus run training on run performance, using parameters such as work capacity, VO_2 max, and anaerobic threshold, have showed lower aerobic run performance when cycling is substituted for run training.[8,26,30–32] It is because of the principle of specificity that DWR holds such promise as a training method to maintain running performance in the individual restricted to non-weightbearing activities.

DWR is a form of aerobic exercise that is felt to mimic the mechanics of land running closer than other forms of non-weightbearing exercise. Several studies have compared land-based running and DWR at similar levels of exertion. Maximal heart rate (HRmax) ranged from 86 to 95% of land-based running, and VO_2 max ranged from 74 to 91% of land-based running.[1,7,9,11,33–40] HRmax and VO_2 max tended to be slightly higher in studies using individuals with previous running experience and possibly better mechanics. Other variables that could have contributed to the range of values for HRmax and VO_2 max in previous studies include failure to use flotation vests, resulting in poor running form, less than maximal exertion with DWR, and water temperature. Evidence suggests that an aerobic training effect takes place at a lower heart rate with DWR than with land running. With submaximal exercise at the same rate of oxygen uptake, heart rate is lower with DWR than with land running.[41-43] Possible explanations for a lower heart rate at the same level of exercise include an increase in stroke volume secondary to increased central blood volume induced by hydrostatic pressure and peripheral vasoconstriction[43-45] and lower peak ventilation occurring in water temperatures of less than 30 to 34°C.[44] The American College of Sports Medicine recommends exercising at an intensity of 60 to 90% of HRmax or 50 to 85% of VO_2 max for 20 to 60 minutes using large muscle groups at a frequency of three to five times per week to achieve a training effect.[46] These parameters are easily met by DWR.

Regarding maintenance of land running performance, 4- to 8-week DWR training intervals have maintained VO_2 max, anaerobic threshold, land running economy, leg strength, and 2-mile land run performance.[9,10,15,47,48] Eyestone et al. demonstrated that 2-mile land run time can be maintained, and even improved slightly, after 6 weeks of water running only.[15] Michaud and colleagues found gains in VO_2 max of 10.6% for treadmill running and 20.1% for DWR after 8 weeks of DWR training in sedentary adults.[49,50] Using well-conditioned runners, Wilber et al. found no differences in VO_2 max, anaerobic threshold, or running economy after a 6-week training program in water versus on land.[10,48] Hertler and colleagues found no significant difference in maintenance of VO_2 max and leg strength in individuals training with DWR compared with those training with land running.[47]

DWR is an ideal exercise alternative to swimming or cycling for the injured soldier on a non-weightbearing profile because of the similar mechanics to land-based running. Unlike swimming or cycling, there is evidence that run performance can be maintained or improved with DWR. DWR also offers a good alternative form of exercise to prevent injuries occurring from excessive land weightbearing exercise.

Conclusion

DWR is an ideal exercise for maintaining conditioning and land running performance in military personnel who are on a temporary non-weightbearing profile. It is a safe and well-tolerated form of exercise that is more specific for land running than alternative forms of exercise. Although previous reports support the notion that DWR participants will be able to return to full active duty at a comparable level of performance, prospective studies performed on a military population are needed to objectively measure preinjury and postinjury run times as well as the impact on recovery time required for a return to full active duty.

Acknowledgments

The authors thank Juliana Larson and Bruce Becker, MD, for their expertise and recommendations in establishing a DWR program.

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