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The purpose of this study was to analyze whether trained competitive runners could maintain running kinematics, cardiorespiratory performance (VO_{2peak}, ventilatory threshold, running economy) and on-land running performance by replacing 30% of conventional training with water run training during 8 weeks. Eighteen runners were divided in two groups: on-land run (OLR Group) and deep water run (DWR Group). The DWR Group replaced 30% of training volume on land with DWR, and the OLR group trained only on land (both groups undertaken workouts 6–7 $d.wk^{-1}$ for a total of 52 sessions). No significant intra- or intergroup differences were observed for VO_{2peak} in the DWR Group and OLR Group. Similarly, ventilatory threshold second was unaltered in the DWR Group and OLR Group. Regarding running economy (at 14 $km.h^{-1}$) also, no intra- or intergroup differences were found in the DWR Group (pre = 43.4 ± 5.0, post = 42.6 ± 3.85 $ml.kg^{-1}.min^{-1}$) and OLR Group (pre = 43.9 ± 2.5, post = 42.6 ± 2.6 $ml.kg^{-1}.min^{-1}$). Kinematic responses were similar within and between groups. Water running may serve as an effective complementary training over a period of 8 weeks up to 30% of land training volume for competitive runners.

The lower limb injuries are extremely common in runners. Several epidemiological studies estimate that 24–65% of competitive runners present injuries due to overuse, during one year (Hoeberigs, 1992; Van Mechelen, 1992). With this high incidence of lower limb injuries incurred by runners, it seems prudent to pursue training techniques to relieve some running-related trauma but without compromising aerobic conditioning and movement pattern. In particular, a replacement is interesting if it can be made without affecting land running performance.

The deep water running (DWR) is a popular mode of rehabilitation for athletes, mainly in competitive runners with overuse injuries in lowers limbs. In fact, the DWR have shown to be satisfactory as a rehabilitation program (Assis et al., 2006; Frangolias, Taunton, Rhodes, McConkey, & Moon, 1997; Thein & Brody, 1997). Many mechanisms of DWR benefits can be attributed to the hydrostatic

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effect of water and their reduced mechanical load, for example, on the spine (Dowzer, Reilly, & Cable, 1998) and principally in lower limbs. These factors have proportioned an increase on interest in the effects that a DWR program may have as an alternative training mode for maintaining the aerobic responses and performance in healthy athletes (Bushman, Flynn, Andres, Lambert, Taylor, & Braun, 1997; Eyestone, Fellingham, George, & Fisher, 1993; Wilber, Moffat, Scott, Lee, & Cucuzzo, 1996). Both the popular (IAAF, 2004) and the scientific (Reilly, Dowzer, & Cable, 2003) literature propose the DWR for runners recovering from strenuous races and as a training complement.

Although, the effects of chronic DWR training supplement on the maintenance of some cardiorespiratory parameters have been extensively investigated, particularly among recreational runners (Eyestone et al., 1993; Wilber et al., 1996), to our knowledge, the DWR effects on running kinematic and second ventilatory threshold (T_{vent}) has never been measured in competitive runners. Wilber and collaborators (1996) noted that DWR may improve stride biomechanics, resulting in a more efficient stride and thus contributing to the maintenance of running economy; nevertheless, the efficacy of such a strategy in maintaining the running economy in endurance-trained runners remains to be firmly established. Probably, the running simulated movement, in an environment 800 times denser than the air, could favor an increase on muscle strength and, consequently, a greater stride length, due to greater relative utilization of oxidative fibers, which contributes to maintenance of running economy. There were no experimental evidences of this improvement on running biomechanic aspects. Otherwise, some authors (Kaneda et al. 2007; Kruel, Peyré-Tartaruga, Larronda, Loss, & Tartaruga, 2002; Nilsson, Tveit, & Thorstensson, 2001) have stated that the movement pattern of DWR is different from that of land-based running, but there is no empirical data in relation to long-term kinematic effects. Specifically, Nilsson et al. (2001) did not find significant electromyographical activation of the lower limb muscles during stretching phases (no eccentric contraction) on DWR. Taking into consideration this observation and relating this to the effects of fatigue on stretching-shortening cycle (Komi, 2000) and on running kinematics (Hardin, Van den Bogert, & Hamill, 2004; Peyré-Tartaruga, Coertjens, Black, Tartaruga, Ribas, & Kruel, 2003), we would expect differences on running kinematics during fatigue stages of running after inclusion of DWR in a normal training program for runners. Therefore, the purpose of this study was to investigate the effects of the inclusion of DWR as part of an 8-wk training program on running kinematics during economy test and 500 m race on the track and the parameters of cardiorespiratory performance (VO_{2peak}, T_{vent}, running economy) of competitive runners and compare them with those from on-land training only.

Materials and Methods

Subjects

Eighteen middle-distance competitive runners (three subjects ran the 800 m, while 15 competed in 800–3000 m track events), 12 male, and 6 female participated in this study, which was approved by the Ethics Committee of UFRGS. All subjects provided written consent for their participation after the experimental procedures and the associated risks and benefits of participation were explained. Subjects were 22.2 ± 3.3 yr of age; weighed 59.1 ± 11.2 kg, 171.8 ± 10.4 cm tall; and had an average running distance per week: 88.7 ± 8.1 km (see Table 1).

Design

Following preliminary screening, subjects were assigned to one of two training groups matched by VO_{2peak}, either on-land run (OLR) or DWR. The subjects were studied in January and February following the preceding competitive season. The subjects were all fully familiar with laboratory exercise testing procedures, having previously participated in other studies.

Both groups were required to follow the same workout schedule, where the OLR group performed the training program just on land, while the DWR group replaced 30% of on-land training volume with in-pool DWR. The choice by 30% is based in a practical proposal for competitive runners. Subjects participated in their respective training programs, which consisted of workouts 6–7 days/wk^{-1} for a total of 52 sessions supervised by the same instructor. The training time was 8 weeks with 6 sessions per week during the first four weeks, and 7 sessions per week during the last four weeks (Table 2). The training adherence was from initially 23 athletes and, at final, 18 runners, all of which obtained more than 95% attendance. All data are from the 18 runners. The Brennan Scale (Wilder & Brennan, 1993), a 5-point perceived exertion scale, was used to set the workout intensity. The scale has verbal descriptors ranging from very light to very hard. Each level is also equated with OLR intensities as follows: level 1 (very light) corresponds to a light jog or recovery run, level 2 (light) to a long steady run, level 3 (somewhat hard) to a 5–10 km road race pace, level 4 (hard) to a 400–800 m track speed, and level 5 (very hard) to sprinting (a 100–200 m track speed). Bushman et al. (1997) and Michaud, Brennan, Wilder, and Sherman (1995) also used this scale to prescribe intensity for DWR exercise in healthy sedentary individuals and recreational runners, respectively.

Preexperimental Procedures

Both pre- and posttraining measures, each runner completed a maximal oxygen uptake (VO_{2peak}) test, a running kinematic and economy test, and a 500 m race on the track, with two days interval between each procedure and an interval of at least

Table 1 Physical and Training Characteristics of Deep Water Running (DWR) Group or On-Land Running (OLR; mean ± *SD*)

	DWR	OLR
Body mass (kg)	61.7 ± 11.5	56.6 ± 11.0
Stature (cm)	172.5 ± 12.3	167.8 ± 12.7
Age (years)	22.9 ± 3.4	21.4 ± 3.2
Training years	4.8 ± 2.5	6.4 ± 5.3
Training distance (km.wk1)	85.0 ± 20.6	92.2 ± 16.4

Table 2 Training Workouts

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
First	2 × 3 × 600m @ RPE 4 3km @ RPE 1	2 × 8 × 200m @ RPE 5 5km @ RPE 2	DWR 15 × 1 min. @ RPE 4 15 min. @ RPE 1	2 × 8 × 200m @ RPE 5 5 km @ RPE 2	DWR 40 min. @ RPE 2	running technique 15 × 150m @ RPE 5 (uphill) 3 km @ RPE 1	REST
			OLR 15 × 1 min. @ RPE 4 15 min. @ RPE 1		OLR 40 min. @ RPE 2		
Second	8 × 500m @ RPE 4 3km @ RPE 1	2 × 8 × 200m @ RPE 5 5km @ RPE 2	DWR 12 x 2 min. @ RPE 4 15 min. @ RPE 1	2 × 8 × 200m @ RPE 5 5 km @ RPE 2	DWR 50 min. @ RPE 2	running technique 15 × 150 m @ RPE 5 (uphill) 3 km @ RPE 1	REST
			OLR 12 × 2 min. @ RPE 4 15 min. @ RPE 1		OLR 50 min. @ RPE 2		
Third	2 × 5 × 400m @ RPE 4 3km @ RPE 1	2 × 8 × 200m @ RPE 5 5 km @ RPE 2	DWR 20 × 30 s @ RPE 5 15 min. @ RPE 1	2 ×x 8 × 200m @ RPE 5 5 km @ RPE 2	DWR 60 min. @ RPE 2	running technique 15 × 150m @ RPE 5 (uphill) 3 km @ RPE 1	REST
			OLR 20 × 30 s @ RPE 5 15 min. @ RPE 1		OLR 60 min. @ RPE 2		

(continued)

Table 2 *(continued)*

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Fourth	2 × 3 × 600m @ RPE 4 3 km @ RPE 1	2 × 8 × 200 @ RPE 5 5 km @ RPE 2	DWR 15 × 1 min. @ RPE 4 15 min. @ RPE 1 OLR 15 × 1 min. @ RPE 4 15 min. @ RPE 1	2 × 8 × 200m @ RPE 5 5 km @ RPE 2	DWR 40 min. @ RPE 2 OLR 40 min. @ RPE 2	running technique 15 × 150m @ RPE 5 (uphill) 3 km @ RPE 1	REST
Fifth	2 x 4 x 400m @ RPE 4	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 10 × 2 min. @ RPE 4 15 min. @ RPE 1 OLR 10 × 2 min. @ RPE 4 15 min. @ RPE 1	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 50 min. @ RPE 2 OLR 50 min. @ RPE 2	15 × 150m @ RPE 5 (uphill)	40 min. @ RPE 2
Sixth	2 × 3 × 500m @ RPE 4	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 12 × 1 min. @ RPE 4–5 15 min. @ RPE 1 OLR 12 × 30s @ RPE 4–5 15 min. @ RPE 1	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 45 min. @ RPE 2 OLR 45 min. @ RPE 2	10 × 200m @ RPE 5 (uphill)	40 min. @ RPE 2

(continued)

Table 2 *(continued)*

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Seventh	3 × 2 × 600m @ RPE 4	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 15 × 30s @ RPE 5 15 min. @ RPE 1 OLR 15 × 30s @ RPE 5 15 min. @ RPE 1	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 50 min. @ RPE 2 OLR 50 min. @ RPE 2	12 × 200m @ RPE 5 (uphill)	50 min. @ RPE 2
Eighth	2 x 4 x 400m @ RPE 4	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 10 × 2 min. @ RPE 4 15 min. @ RPE 1 OLR 10 × 2 min. @ RPE 4 15 min. @ RPE 1	running technique 6 × 50m @ RPE 5 strength training 10 × 120 @ RPE 5 (strides) 4 km @ RPE 1	DWR 40 min. @ RPE 2 OLR 40 min. @ RPE 2	10 × 150m @ RPE 5 (uphill)	40 min. @ RPE 2

Note. All workouts also included a 10-min warm-up and 5-min cool-down. RPE, Ratings of perceived exertion. Workouts are written in the following form: number of × distance of repetition (on days of DWR, duration of repetition was used) @ exertion level (1–5 scale).

two days before beginning the training program. Subjects were instructed to perform only a light workout one day before all tests to allow the maximal effort in testing.

The VO_{2peak} test consisted of a 30 s run at 10 $km.h^{-1}$ and 1% elevation followed by an increase of 0.5 $km.h^{-1}$ every 30 s until physiological or volitional fatigue. The VO_{2peak} was considered to be the average of the two highest VO_2 values in the series of 15 s VO_2 values. T_{vent} was determined by plotting the ventilatory equivalents ($VE.VO_2^{-1}$, $VE.VCO_2^{-1}$), using a computational algorithm (Matlab, The Mathworks Inc., Natick, USA) and was defined as an increase in $VE.VO_2^{-1}$ and $VE.VCO_2^{-1}$ with a coincident reduction on CO_2 pressure. Two independent evaluators who were provided with the data double-blind analyzed the T_{vent} data. Running economy was determined from the relative oxygen cost ($ml.kg^{-1}.min^{-1}$) of running at one submaximal workload (6-min workload at 14 $km.h^{-1}$, 1% grade). The fixed velocity corresponded to 83% pretest VO_{2peak}. The VO_2 and the others ventilatory parameters were collected from MGC (Medical Graphics Corporation, St. Paul, USA). The heart rate was monitored continuously via heart rate telemetry. The kinematic variables were obtained from the running economy test and 500 m test. The kinematic variables from the running economy test were stride length (SLeco), relative stride length (stride length divided by lower limbs length—RSLeco), support time (STeco), nonsupport time (NSTeco), and stride frequency (SFeco). In the 500 m test, the kinematic variables were relative stride length (RSL500), stride length (SL500), support time (ST500), nonsupport time (NST500), stride frequency (SF500), knee angle at heel-strike (KAHS500), knee angle at take-off (KATO500), 500m time, and horizontal velocity (HV500). The choice of these variables is related to (a) large influence of these variables on running performance and (b) more sensitive to fatigue effects during 500m test (Peyré-Tartaruga et al., 2003) of these variables between fatigue and nonfatigue stages. The effects of DWR on OLR performance were examined through a 500 m test performance one individual at a time. Although the runners were, in general, from longer distance athletes than 500 m, we used this distance because it was sensitive to kinematic variables and it was possible to analyze the fatigue effects on running kinematics with only 1 cam (the methods are described in detail by Peyré-Tartaruga et al., 2003; see supplementary material). A Punix digital video camera with shutter time of 1.1000^{-1} s and 120 Hz sampling rate filmed each runner at the 50 m and 450 m marks of the race. These two stages were selected because of the need to film the runners through a continuum of running patterns from nonfatigued to possibly fatigued states while also sampling when the influence of race tactics was minimal. The camera, secured on a tripod, was positioned so that the focal axis was at left side to the plane of motion of the runners. One complete running cycle (two steps) were recorded for each runner at each of the two stages filmed. A calibrator of known length (to convert film measurements to real-life size) was filmed before the race in the line of motion of the runners. We used a Peak Performance system (Peak Performance Technologies, Englewood, USA) to follow markers that were specifically placed on the subjects. Retroreflective markers were positioned on the following anatomic landmarks: greater trochanter, the lateral epicondyle of the femur, lateral malleolus fifth metatarsophalangeal joint, and the acromion scapulae. Video images were selected and digitized and *x*-*y* coordinates of different joint markers were obtained at 120 fields.

The data for marker position were low-pass filtered by using a fourth-order zero-lag Butterworth filter with a cutoff frequency of 5 Hz. The cutoff frequency was determined by using residual analysis (Winter, 2005). Marker-position data were used to calculate linear velocities and accelerations of the segments as well as joint angles, segment angles, and segment angular accelerations. Each joint angle was defined by using the marker on that joint and the two adjacent markers.

In addition, on pre- and posttests, subjects were measured for body composition. Skinfold thicknesses were measured to the 0.5 mm at five sites (thigh, triceps, abdomen, suprailiac, subscapula) on the right side of the body by using standard techniques (Heyward & Wagner 2004) and Lange calipers (Cambridge Scientific Industries, Cambridge, USA). Body circumference measurements were taken at the arm (midway between the acromion and the olecranon process), midthigh (midway between the inguinal crease and the distal border of the patella), and upper thigh (third-superior between the inguinal crease and the distal border of the patella). The sum of the five skinfold thicknesses and of the three body circumferences are provided in Table 3. All pre- and postexperimental measurements of body composition were made by the same investigator. The DWR training took place in a swimming pool measuring 25 × 16 m, and 2 m in depth, in which the subjects used a float belt, and the water temperature ranged between 28.5 °C and 29.5 °C.

The data are expressed as means ± *SD* (*SD*). Statistical analysis was carried out using a two-way (group × time) analysis of covariance (ANCOVA) with repeated measures in the Statistical Package for Social Sciences General Linear Models procedure (version 11.0). The variables were divided into kinematic and physiological variable groups for multivariated analysis. Univariate analysis also was done. Sex and age were included as covariables/ covariates in all analyses. A *P* value of < 0.05 was considered to indicate a significant difference.

Results

Selected physical and training characteristics of the subjects are shown in Table 1. Repeated measures GLM-ANOVA identified a nonsignificant interaction between the training groups (DWR and OLR) and time (pre and post). Both kinematical (SFeco, STeco, NSTeco, SLeco, RSLeco, SF500, ST500, NST500, SL500, RSL500, KATO500, KAHS500, 500 m time, and VH500) and physiological

Table 3 Anthropometric Parameters, Following 8 Weeks for Deep Water Running (DWR) Group or On-Land Running (OLR) Group (mean ± *SD*)

	Pre		Post	
	DWR	**OLR**	**DWR**	**OLR**
SBC (cm)	156.6 ± 11.5	149.7 ± 15.8	156.8 ± 12.1	147.0 ± 13.1
SST (mm)	57.6 ± 18.8	52.0 ± 10.3	57.5 ± 18.4	51.7 ± 10.5

Note. SBC: sum of body circumference; SST: sum of skinfold thickness.

(VO_{2peak}, T_{vent} and running economy) variables attained *P*s greater than 0.05, indicating that kinematical and physiological behavior responded similarly in the DWR and OLR groups. There were no significant intra- or intergroup differences ($p > .05$) in VO_{2peak} (Table 4) following 8 weeks of workouts. Preexperimental treadmill VO_{2peak} was 49.3 ± 8.3 and 54.0 ± 6.2 ml.kg^{-1}.min^{-1} for the DWR and OLR groups, respectively. Postexperimental treadmill VO_{2peak} was 49.6 ± 8.7 and 53.4 ± 8.8 ml.kg^{-1}.min^{-1} for the DWR and OLR groups, respectively. No significant changes were observed in maximal running velocity, maximal heart rate, and maximal minute ventilation (VE_{peak}), within or between groups following 8 weeks of workouts (Table 4). Similarly, T_{vent} was unaltered for the DWR group (pre = 44.4 ± 6.9, post = 45.0 ± 8.6 ml.kg^{-1}.min^{-1}) and the OLR group (pre = 48.2 ± 6.0, post = 46.7 ± 8.0 ml.kg^{-1}.min^{-1}), nor were there any changes in VO_2 at 14 km.h^{-1}, i.e., running economy in the DWR group (pre = 43.4 ± 5.0, post = 42.6 ± 3.8 ml.kg^{-1}.min^{-1} at 14 km.h^{-1}), and the OLR group (pre = 43.9 ± 2.5, post = 42.6 ± 2.6 ml.kg^{-1}.min^{-1} at 14 km.h^{-1}).

Kinematic variables from the running economy test are shown in Figure 1, and the 500 m test are shown in Table 5. In both kinematic tests (economy running and 500m test), no significant differences identified between the DWR and OLR groups in all kinematic variables. Furthermore, the present data suggest a crossover effect from DWR to land based running on kinematic variables: DWR training for eight weeks did not modified the kinematic profile on land, even in the fatigue stage (450 m of the 500 m test). This is confirmed by the absence of general effects and interactions ($p > .05$). Furthermore, there were no differences between the groups in terms of body composition parameters (Table 3); however, the support time on running at 14 km.h^{-1} (running economy test) after training period decreased 35.6 ms for OLR *versus* 58.9 ms for DWR. Although not statistically significant, this modification is 65% greater for DWR. In the same way, the percent decrement on the horizontal velocity from 50 m (nonfatigued) to 450 m (fatigued), or *fatigue index*, presented an increase between pre and post test equal

Table 4 Physiological Responses Following 8 Weeks for Deep Water Running (DWR) Group or On-Land Running (OLR) Group (mean ± *SD*)

	Pre		Post	
	DWR	**OLR**	**DWR**	**OLR**
VO2peak (ml.kg˜1.min˜1)	49.3 ± 8.3	54.0 ± 6.2	49.6 ± 8.7	53.4 ± 8.8
Velocity at VO2peak (m.s˜1)	5.1 ± 0.6	5.3 ± 0.5	5.2 ± 0.6	5.4 ± 0.5
HRpeak (beats.min˜1)	187.4 ± 12.7	189.1 ± 17.2	186.2 ± 7.3	193.8 ± 15.5
VEpeak (L.min˜1)	119.5 ± 38.2	114.6 ± 29.2	130.9 ± 35.1	121.0 ± 35.1
Tvent (ml.kg˜1.min˜1)	44.4 ± 6.9	45.0 ± 8.6	48.2 ± 6.0	46.7 ± 8
Velocity at Tvent (m.s˜1)	4.3 ± 0.6	4.5 ± 0.6	4.2 ± 0.3	4.5 ± 0.4
Running economy (ml.kg˜1.min˜1)	43.4 ± 5.0	43.9 ± 2.5	42.6 ± 3.8	42.6 ± 2.6

Note. VO_{2peak}: maximal oxygen uptake; HR_{peak}: maximal heart rate; VE_{peak}: maximal ventilation; T_{vent}: ventilatory threshold.

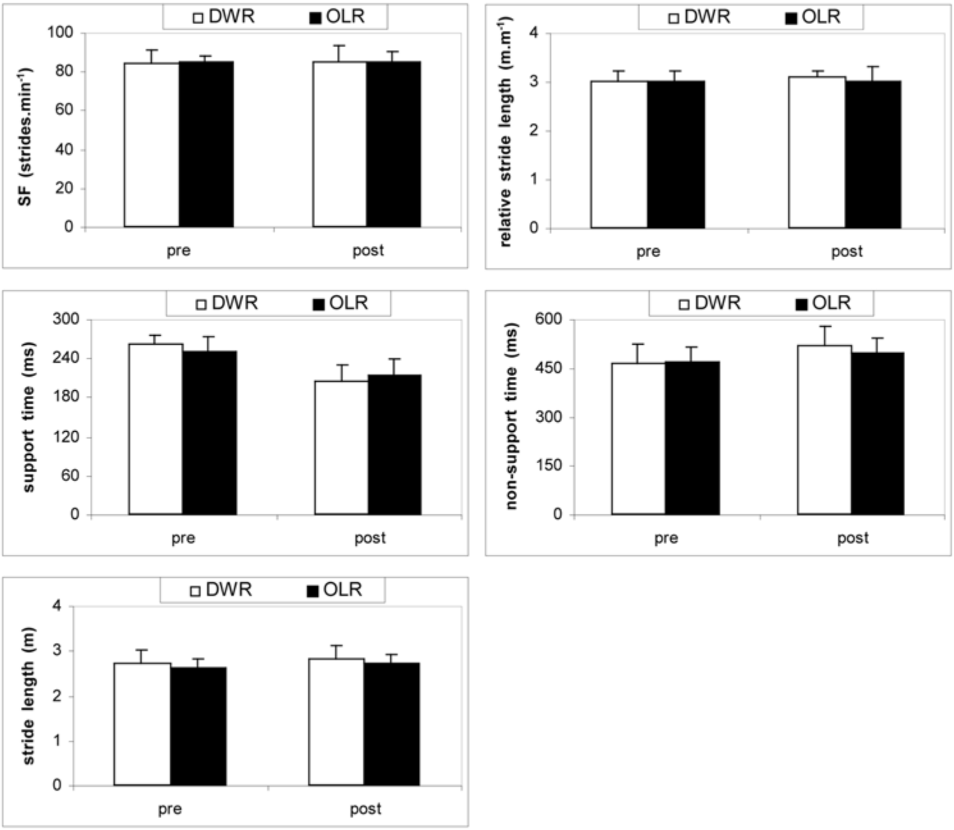

Figure 1 — Kinematical responses from economy running test, following 8 weeks for deep water running (DWR) group or on-land running (OLR) group (mean ± *SD*).

to 3.0% for OLR group, while for DWR was only 0.7% (Figure 2). Others decrements or increments for kinematical variables can be found in supplementary material.

Statistical power was calculated for all kinematic and physiological variables. All dependent variables were seen to have powers greater than 0.75. Therefore, we may state that the experiment provided adequate power to test the null hypothesis.

Discussion

This study is the first to investigate competitive runners in terms of their kinematical adaptations to the inclusion of DWR within a normal training program. The running kinematics was not changed after the 8 week training program. Our kinematical results refutes the following idea proposed by Wilber et al. (1996): “It is possible that hydrostatic resistance encountered during water run exercise

Table 5 Kinematical Responses During 500 m Test, Following 8 Weeks for Deep Water Running (DWR) Group or On-Land Running (OLR) Group (mean ± *SD*)

	Pre		Post	
	DWR	**OLR**	**DWR**	**OLR**
SF500 (strides.min^{-1}) at 50m	104.0 ± 7.7	97.9 ± 4.8	105.5 ± 6.8	102.8 ± 4.4
SF500 (strides.min^{-1}) at 450m	94.6 ± 5.2	91.2 ± 3.7	92.5 ± 4.5	92.1 ± 2.9
ST500 (ms) at 50m	121.1 ± 32.6	137.8 ± 36.0	121.1 ± 26.7	120.0 ± 29.6
ST500 (ms) at 450m	154.4 ± 47.5	154.4 ± 40.0	153.3 ± 20.6	151.1 ± 34.1
NST500 (ms) at 50m	580.0 ± 45.5	476.7 ± 37.1	571.1 ± 37.9	464.4 ± 39.7
NST500 (ms) at 450m	635.6 ± 33.2	505.6 ± 47.2	650.0 ± 30.8	496.7 ± 36.4
SL500 (m) at 50m	4.2 ± 0.4	4.1 ± 0.4	4.3 ± 0.4	4.1 ± 0.3
SL500 (m) at 450m	3.7 ± 0.4	3.7 ± 0.3	3.9 ± 0.4	3.8 ± 0.3
RSL500 at 50m (m.m^{-1})	4.7 ± 0.4	4.7 ± 0.5	4.8 ± 0.4	4.7 ± 0.5
RSL500 at 450m (m.m^{-1})	4.1 ± 0.4	4.3 ± 0.4	4.9 ± 0.7	5.0 ± 0.7
KATO500 at 50m (degrees)	148.5 ± 9.9	156.2 ± 7.2	145.9 ± 9.0	151.1 ± 13.0
KATO500 at 450m (degrees)	151.1 ± 8.3	158.5 ± 8.4	150.5 ± 11.1	153.0 ± 9.0
KAHS500 at 50m (degrees)	151.0 ± 5.6	156.0 ± 3.9	155.1 ± 7.0	155.6 ± 4.3
KAHS500 at 450m (degrees)	147.4 ± 7.5	155.7 ± 4.6	153.5 ± 6.7	152.5 ± 3.8
HV500 at 50m (m.s^{-1})	7.3 ± 0.9	6.7 ± 0.8	7.5 ± 0.9	7.1 ± 0.7
HV500 at 450m (m.s^{-1})	5.8 ± 0.7	5.7 ± 0.6	5.9 ± 0.6	5.8 ± 0.5
500m time (s)	83.6 ± 12.3	80.6 ± 8.0	81.4 ± 12.0	78.6 ± 6.4

Note. SF500: stride frequency; ST500: support time; NST: non-support time; SL500: stride length; RSL500: relative stride length; KATO500: knee angle at take-off; KAHS500: knee angle at heel-strike; HV500: horizontal velocity; 500m: T500 performance.

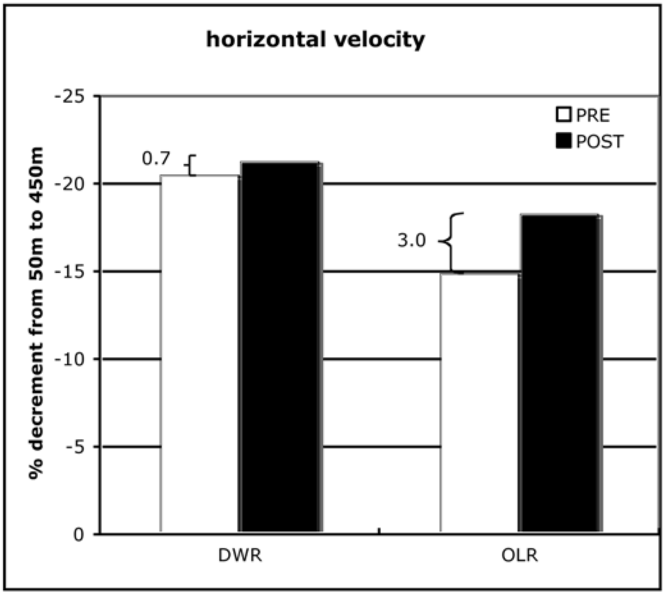

Figure 2 — Percent decrements of the horizontal velocity from 50 m to 450 m conditions during the 500 m tests for the DWR and OLR groups.

favorably modified the water runners' stride mechanics, resulting in a more efficient stride (e.g., reduced overstriding). In turn, improvements in stride biomechanics may have contributed to the maintenance of running economy among water runners. . . ". A satisfactory answer is still lacking in relation to the running economy's improvement mechanisms.

As expected, the physiologic results collectively indicate that DWR and OLR groups exhibit largely similar responses. The physiological responses to DWR and OLR training in this study are in accordance with those from previous studies (Bushman et al., 1997; Eyestone et al., 1993; Morrow, 1995; Wilber et al., 1996). Bushman and coworkers (1997) reported that trained runners attained the following VO_{2peak}: 63.4 and 62.2 $ml.kg^{-1}.min^{-1}$ before and after 4 weeks of DWR, respectively. In that study, the runners substituted 100% of training volume on land; therefore, the maintenance of physiologic profile in the current study, in which 30% of training volume on land was substituted by aquatic exercise, was expected. Both studies reported similar running economy and ventilatory threshold before and after the inclusion of DWR in the training. Eyestone et al. (1993) analyzed trained runners ($VO_{2peak} = 57.4 \pm 1.7$ $ml.kg^{-1}.min^{-1}$) and stated that VO_{2peak} on treadmill was not different between the DWR group (100% DWR) and OLR group; however, both decreased the VO_{2peak} by about 4% during training. The data from Morrow (1995) indicate the DWR and OLR groups attained similar changes in VO_{2peak}. The VO_{2peak} increased 5.6% in the DWR group and 7% in the OLR group. With a similar experimental design, Wilber and coworkers (1996) found a decrease of about 2% in VO_{2peak} after 21 days of training for both groups, with an increase of 3% at the 42nd day; however, these nonsignificant differences probably reflect a normal daily variation of maximal aerobic capacity (Katch, Sady, & Freedson, 1982). On the other hand, Quinn and colleagues (Quinn, Sedory, & Fisher, 1994) reported that DWR training (4 days/wk^{-1} and 30 min/day^{-1}) after OLR for 10 wks was ineffective in maintaining the VO_{2peak} of sedentary female students (VO_{2peak}= 39.9 ± 3.6 ml.kg^{-1}.min^{-1}). To be effective, however, cross-training should consist of an equivalent training pattern in terms of load intensity and volume. Quinn and coworkers (1994) also stated that the intensity used during the DWR training was not sufficient to maintain the VO_{2peak}.

The T_{vent} is considered a strong predictor of middle and long distance running performance (Farrel, Wilmore, Coyle, Billings, & Costill, 1979; Powers, Dodd, Deason, Byrd, & McKnight, 1983). In the current study, both experimental groups obtained high T_{vent}. In the DWR group the T_{vent}, expressed in terms of velocity, was 15.6 and 15.1 km.h^{-1} in the pre and post period, respectively, while in the OLR group it was 16.2 and 16.3 km.h^{-1}. The T_{vent}s expressed as a percentage of VO_{2peak} were in the range of 87–90% VO_{2peak}. These results demonstrate that the athletes are aerobically well trained.

As with VO_{2peak} and T_{vent}, running economy has an important role as a predictor of middle and long distance running performance (Basset & Howley, 2000; Conley & Krahenbuhl, 1980; Daniels, Yarbrough, & Foster, 1978; Foster, Daniels, & Yarbrough, 1977; Williams & Cavanagh, 1987). In addition, the 8 weeks of DWR complementary training did not modify running economy, confirming the possibility of DWR as a cross-training modality. Several factors influence the running economy, such as running style, stride frequency, and length (Cavagna, Franzetti, Heglund, & Willems, 1988; Cavanagh & Williams, 1982; Martin & Morgan, 1992;Williams & Cavanagh, 1987). In the current study, these variables were also unchanged. Concerns have been raised regarding the dissimilarities between running styles in the water and on land. Kruel et al. (2002), when comparing the kinematics between deep water running and on-land running at different intensities, showed that stride frequency and length are shorter in DWR than in OLR. Furthermore, at intermediary paces (consistent with long distance racing), the range of shank and thigh motion in DWR was greater than in OLR. The eccentric action of lower limb muscles, as well their stretch-shortening cycle during the support phase in on-land running, are absent in DWR (Nilsson et al., 2001). The activity of *soleus* and *gastrocnemius* during DWR are lower than in OLR (Kaneda, Wakabayashi, Sato, & Nomura, 2007). Town and Bradley (1991) observed that the increased O_2 pulse (HR/VO_2) during DWR suggests that this movement is inefficient compared with OLR. These factors should hinder the transferability of DWR training effects to OLR performance. The reasons are the viscosity friction of the water medium and the non-weight-bearing aspect of DWR. Despite the cardiorespiratory, 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. This argument is also based on pre and post mechanical responses obtained during the fatigue stage of the 500 m test, which show that the inclusion of the DWR training did not adversely or positively affect the running kinematics. To our knowledge, with the exception of the current study, the kinematical effects of the inclusion of DWR on OLR have not been investigated.

Furthermore, several epidemiological studies suggest an annual prevalence of overuse injuries between 24% and 65% among competitive runners (Hoeberigs, 1992; Van Mechelen, 1992). With this high incidence of lower limb injuries incurred by runners, it seems prudent to pursue training techniques to relieve some running-related trauma but without compromising aerobic conditioning and movement pattern. It is an interesting thought that the incidence of these injuries may be reduced, or that recovery from injuries may be improved, by replacing a part of the land running by water training. In particular, a replacement is interesting if it can be made without affecting land running performance. It is relevant to mention that competitive runners run about 2 hours per day while, e.g., elite cyclists cycle 5–6 hours per day. Theoretically, this could mean that runners can improve if they can add some kind of training that is different from actual running so that it does not result in overtraining and injuries. A future study design could be to add DWR training instead of just replacing a part of the land running. In the current study, in which 30% of land-based training was substituted by DWR, the main physiological and kinematical parameters of running remained substantially unaltered.

The present findings suggest that the inclusion of DWR for a reasonable percentage on normal training has functional implications for the training of competitive runners. Particularly, the maintenance in running kinematics and performance, and the previously reported maintenance in running economy, VO_{2peak} and T_{vent} (Bushman et al., 1997; Wilber et al., 1996) indicate that even in high intensities, the DWR training can be used. This indicates that training programs for competitive runners in the preseason period should include the DWR not only for the aerobic training but also on anaerobic training. Therefore, the present results extended previous suggestions (Bushman et al., 1997; Wilber et al., 1996) that the DWR inclusion can to serve not only to maintain the physiological profile, but also to maintain the running mechanics.

In terms of training, the DWR inclusion theoretically can be a strategy for increasing the training time diary and increasing the physiological load on the mechanical overload on lower limbs joints, the principal site of injuries in runners. This also provides further support to previous popular and scientific literature that proposed the use of DWR in training programs for competitive runners.

In conclusion, the present results showed that the kinematic variables were not modified with the inclusion of DWR. Furthermore, there are no significant alterations in fatigued running kinematics. Therefore, for competitive runners, the replacement of 30% of land-based training by DWR over an 8-week period may be of use. The proposition of the stride mechanic improvement in water runners when compared with on-land running from literature (Wilber et al., 1996) is partially refuted in the current study. Further research is necessary to test the hypothesis of decreased frequency of injury with DWR inclusion. Possible practical implications include the following: (a) although there are mechanic differences between the modes of exercise (deep water and on-land running), the deep water running helps to maintain or even to improve the on-land running performance and mechanics in both nonfatigued and fatigued situations on competitive runners; (b) the replacement of land-based training by deep water running (≈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; (c) the deep water running training can be undertaken even in high intensities.

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