Deep water running: limits and possibilities for high performance

Ms. Leonardo Alexandre Peyré-Tartaruga[1] and Dr. Luiz Fernando Martins Kruel[2]

ABSTRACT

The purpose of this study was to analyze the limits and possibilities of deep water running on training of performance runners. Besides, it has been discussed the submaximal acute, maximal acute and chronical responses, following physiological and biomechanical aspects between running on land and deep water running. Heart rate and oxygen uptake's maximal responses are lower in aquatic exercise than in running on land. Experimental evidences suggest the deep water running training for performance athletes, but these studies are limited in training program until ten weeks.

Keywords: Water exercise. Physiological responses. Sport training. Performance runners.

INTRODUCTION

Water exercise has been used for many years as a rehabilitation means for runners(1-5). The main characteristic of deep water running (DWR) is its low impact nature; such feature has made its use common even as cross-training for long distance running athletes(6-9).

The DWR consists of a simulated run, in a swimming pool deep enough not to let the volunteers touch the bottom, keeping the head above water level with the help of a floating device (vest or belt). The movement in the DWR must be as similar as possible to the run on land, although it is clear that there are changes in the cinematic patterns between the two exercises(10-11). The athlete can stand still – in that case being connected to a rope stuck to the pool's edge- doing the movement without changing the activity's site or can freely run, usually using the bigger length. The rope may be used to increase the resistance, help in the posture keeping a more straight position and facilitate the exercise monitoring.

Despite its advantages, the aqueous environment has physical properties remarkably different from the air, and those differences reflect on different physiological responses between the two environments. The main physical properties related to the physiological changes are the thermo conductibility, or more precisely, the bigger ability to transfer heat in the water environment; the hydrostatic pressure that is probably responsible for changes in the cardiovascular responses in a resting situation and in exercise(12-13) and the pushing force, that acts against gravity and helps in the athlete's floatation.

There are significant differences in the physiological and biomechanical responses between the DWR and the run on land. Such differences cause the training control in the water to be differentiated from the commonly used in the training on land. Although the scientific production on the DWR long run training effects is still incipient, some possibilities and limitations can be outlined in order to help the coach with the training development and periodization.

MAXIMAL PHYSIOLOGICAL RESPONSES

Heart rate (HR) and oxygen maximal consumption ($\dot{V}O_{2max}$)

Many studies have compared the maximal HR physiological responses and $\dot{V}O_{2max}$ between DWR and treadmill running (TR)(3,14-20), with a relative consensus in their results. The HR peaks and lower oxygen consumption ($\dot{V}O_2$) are well reported during the DWR when compared to the TR in maximal efforts(3,15-18,21). It is possible that the maximal HR (HR_{max}) presents lower values in the DWR through a smaller stimulation of the sympatic system, more specifically, lower concentrations of adrenaline were observed in the water exercise(22). Moreover, the lower sympatic activity derives from – among other factors – the hydrostatic pressure and the baroreflex activation that determines a venous return facilitation. Besides that, the thermodynamic factor facilitates the body heat exchange with the environment due to the higher density of the water. Concerning the maximal oxygen ($\dot{V}O_{2max}$), there seems to be three factors that explain the decrease of this variable from run on land to the DWR: 1) Due to water density, approximately 800 times higher than air(23), a higher percentage of anaerobic metabolism has to be used during the DWR when compared to the run on land. Higher responses of maximal blood lactate concentration in the DWR confirm such hypothesis(2); 2) Another relevant factor to explain the $\dot{V}O_{2max}$ decrease is related to the exercise technique or specificity, since although the DWR tries to imitate the run on land movement, the runner must adjust such technique to the floatation effects opposed to gravity. Therefore, in the majority of the compared studies, the individuals were on land- runners with no or little practice on DWR. Consequently, the lower $\dot{V}O_{2max}$ values may also derive from the lack of adaptability to the technique and type of contraction conducted by the lower and upper limbs in the DWR(2-3,15,18); 3) It has also been suggested that the lower pressure of perfusion on legs, with a consequent decrease of muscle blood flow, may influence in the $\dot{V}O_{2max}$ during the DWR in relation to the run on land(15).

SUBMAXIMAL PHYSIOLOGICAL RESPONSES

Although it is clear that the $\dot{V}O_2$ maximal responses and HR are lower during the DWR than during the run on land, Mercer and Jensen(21) verified that there are no differences in the HR between the DWR and treadmill run when analyzed in submaximal intensities, more specifically in 20, 30 and 40 milliliters (ml) by kilogram (kg) per minute (min) rates. Furthermore, the HR-$\dot{V}O_2$ relation was similar during submaximal exercise in the DWR and treadmill run. The similarity between the FC-$\dot{V}O_2$ relation during DWR and treadmill run may be evidence that the run styles are similar(21). Howev-

1. Professor de Graduação da Faculdade da Serra Gaúcha e Faculdade Cenecista de Osório. Pesquisador do Laboratório de Pesquisa do Exercício da Esef/UFRGS.
2. Professor de Graduação e Pós-Graduação da Esef/UFRGS. Coordenador do GPAA/UFRGS.

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Correspondence to: Campus Olímpico, Rua Felizardo, 750, Jd. Botânico – 90690-200 – Porto Alegre, RS. E-mail: leonardo.tartaruga@ufrgs.br or kruel@esef.ufrgs.br

er, studies comparing the run on land mechanics against the DWR mechanics, demonstrate that quantitatively the two exercises are different[10-11,25].

According to Beaver and Wasserman[26] the increase in the blood lactate concentration happens with a decrease in the sodium bicarbonate concentration ($[HCO_3^-]$), due to the of lactic acid bicarbonate tamponing. The $[HCO_3^-]$ in lower concentration is also influenced by the excess of production of carbonate dioxide. Therefore, the excess of carbonate dioxide production may provide an indirect measure of the $[HCO_3^-]$ decrease. Thus, the carbonate dioxide measure in relation to oxygen (O_2) utilization may be a useful estimate of lactate accumulation. Hence, the respiratory index is widely used to evaluate the amount of energy used by the body and the substrate that has been more oxidized. The contents of carbon and O_2 from glucose, from free fatty acids and from amino acids differ severely. As a result, the oxygen amount used during the metabolism depends on the kind of substrate that is being oxidized. Thus, a respiratory index higher than 0,85 shows a predominance of carbohydrates utilization and lower than 0,85 a predominance of fats.

The respiratory index in the aqueous environment is similar to the one found on land in submaximal levels and in the maximal effort[4,15-16,20,22]. Glass *et al.*[2] also found such behavior independently of the gender. One may affirm from the results, that the percentage of utilization of carbohydrates and fats is similar between the exercises in aqueous and on land environments.

The lactate removal is an interesting aspect concerning the lactate and exercises on aqueous environment. It has been believed for some time in the sports field, that the physical activity in aqueous environment could be responsible for an increase in the velocity of lactate removal after exhaustive efforts when compared to exercise on land. Barros *et al.*[26] analyzed the lactate removal after soccer field matches using three types of recovery: passive, stretching associated to trotting and water exercise. The recovery through water exercise determined a lower concentration of lactate (1,63 $mmol.L^{-1}$) than recovery with the stretching associated with trotting (2,91 $mmol.L^{-1}$) and the passive (2,77 $mmol.L^{-1}$). Thus, the authors concluded that the water exercise was more efficient in the lactate removal than the other ways of recovery. However, the mechanism for such behavior was not established, and an objective control of the effort intensity used in the active recoveries was not mentioned in this study. Villar and Denadai[27] found a greater velocity of lactate removal through run on land and in deep swimming pool, both in aerobic threshold intensity, when compared to the passive recovery, however, when comparing the medium in which the active recovery was developed, no significant differences were observed in the velocity of removal. Therefore, according to these authors, there are not metabolic advantages in DWR for the lactate removal.

CHRONIC PHYSIOLOGICAL RESPONSES

Besides the comparisons of physiological maximal and submaximal responses between the DWR and run on land, experimental studies with training programs varying from four to ten weeks, were also conducted to test diverse physiological values. According to Hertler *et al.*[28], it is possible to keep the $\dot{V}O_{2max}$ and the concentric and eccentric isotonic force of knee extensors and flexors and ankle plantar dorso-flexors and flexors, in a DWR program in a period of four weeks for runners. Hamer and Morton[14] found similar results to the authors mentioned before., where it was possible to observe the steadiness of aerobic power, anaerobic power, work and muscle power in recreational runners ($\dot{V}O_{2max}$ = 49,32 ± 5,42 $ml.kg^{-1}.min^{-1}$).

Besides keeping the physiological values, the DWR was also able to improve the aerobic conditioning ($\dot{V}O_{2max}$ in treadmill) of individuals initially sedentary, as well as the run on land[29].

Wilber *et al.*[6] also conducted an experimental work with middle and long run distance runners for six weeks; with one group training run on land and the other group training the DWR. The sessions were of 30 min to 90-100% $\dot{V}O_{2max}$ or 60 min to 70-75% $\dot{V}O_{2max}$, five days per week. The run savings, $\dot{V}O_{2max}$ and anaerobic threshold between the two groups were evaluated at the end of the sessions. Significant differences between the run on land training and the DWR training were not found on these variables. Such data suggest that the DWR may be used as an effective alternative for on land runners training in order to keep performance level.

Besides keeping the physiological values, for some authors[30-31] water exercise may develop muscle strength, especially in the hip extensor muscles. In the Pöyhönen *et al.*[30] study, the effects of a 10 week- progressive strength training were investigated and an increase in the muscular torque production, in the muscle activation and in the transversal cut area of the knee extensor and flexor muscles were found. Nevertheless, the differences in the muscular function and coordination linked to the change in angular breadth between the DWR and run on land[10-11] bring an issue that confirm the hypotheses raised by Ritchie and Hopkins[7,32] in relation to the lack of specificity of the DWR.

The literature also dedicates attention to the chronic responses of the lactate during strength tests in individuals submitted to exercise programs in the water environment, in order to evaluate the possibilities of maintenance or improvement of the performance of runners on land. During a maximal test of $\dot{V}O_2$, the increase of blood lactate is dependent on the number of recruited muscular fibers, as well as on the exercise intensity. Well-trained individuals are able to produce and tolerate levels of blood lactate relatively high during intense exercise. Therefore, the capacity to tolerate high indices of lactic acidosis demonstrates that the athlete can exercise for a longer period and in a higher intensity before exhaustion. Maximal indices of lactate were not altered with the DWR training for 6 weeks in relation to the control group running on land in the same period. The fact that the lactate and running time indices were not altered assumes the possibility of maintenance of the tolerance to the lactate with the DWR for runners on land[6]. Bushman *et al.*[7] also affirm that the blood lactate indices are not altered with the DWR training. Moreover, the same authors evaluate the running velocity in the lactate threshold moment, not being reported differences between the experimental group (trained in deep water) and the control group (trained on land), in a 4 weeks study. Therefore, it is possible to maintain the lactate responses at maximal indices in trained runners, for up to 6 weeks, with the DWR training[6-7]. The questioning about these chronic responses are related to the possibility to maintain the physiological values for more than 6 weeks of training inside water and whether the technique is not altered with such training.

McConnel *et al.*[33], found maintenance of the $\dot{V}O_{2max}$ after 4 weeks of training with reduced training volume (44%), reduced training frequency (50%), and training intensity (lower than 70% of the $\dot{V}O_{2max}$) in performance distance runners. The performance of these athletes was not modified either. The volume, frequency and training intensity reductions seem to be insufficient to cause decrease in the aerobic ability and performance, however, such maintenance may be due to the limited training time (4 weeks). Houmard *et al.*[34] did not find statistically significant difference in the running savings during a 10 weeks-training program with decrease in the training volume. According to the results by McConnel *et al.* and Hickson and Rosenkoetter, (1981), likewise, the $\dot{V}O_{2max}$ maintenance was found during a 15 weeks-program, however, they simply reduced the training frequency (from 6 days per week $^{-1}$ to 2-4 days per week^{-1}). In the study by Peyré-Tartaruga[9], the training program n land was reduced (30%), and these 30% were transferred to the DWR, where it was possible to maintain the performance three most explanatory physiological variables ($\dot{V}O_{2max}$, running savings and ventilatory threshold). Hence, the DWR responded to one of the main objectives of the use of a complementary training (*cross-training*) for performance athletes, which is to maintain or help in the central training adaptations, especially cardiovascular.

In the work by Peyré-Tartaruga[9], the biomechanical behavior was not altered either before and after the 8 training weeks between the group that trained only on land and the group that trained 30% with DWR and 70% on land. As mentioned before, the problem of the lack of specificity hypothesized by the literature[3,32] and tested by some authors[9-10,24], was not able to modify the running biomechanical pattern.

Moreover, several epidemiological studies estimate that, among competition runners, 24% to 65% of these present lesions due to excessive use during one year period[36]. The causes are not completely clear, however, it is known that the etiology of these lesions is multifactor and diverse[37-39]. One of most cited factors in the literature is the excessive running volume (distance) in the training program of performance runners[38,40-41,43]. The mechanism to the high incidence of lesions due to excessive training volume is caused by a fail any component of the osseo-tendon-muscle system in adapting to the repetitive loads developed during the run. The runners touch the ground with the foot approximately 600 times per km[43] and, in each step, 1,5 to 4 times the body weight is applied to the lower limbs[43-45]. These mechanical loads have two important aspects: first the load intensity, in this case the local stress during a cycle of a step, and second, the load volume, that is, the number of repetitions of these loads, or even the step frequency and the duration time with this stress frequency[47]. The muscle-skeletal structures need stress or deformation stimuli to develop. However, such stimulus has a specific parameter. The authors mentioned before have considered a difficult task to find such parameter. Nevertheless, with the data on lesion caused by excessive effort in running reported in the literature, it is possible to affirm that performance runners nowadays surpass the threshold between the mechanical loads that help in the maintenance and development of the muscular-skeletal system, and the ones that deteriorate the referred system. Two prevention strategies of these lesions can be taken; either decreasing the loads intensity through the decrease of the running velocity[39] or through the decrease of the training running volume. Any decrease in one of these parameters may cause a decrease in performance, especially the training intensity[48]. Thus, the decrease in the mechanical stress without the physiological stress offered by the DWR seems to be a solution to this questioning.

Despite the scarce empirical data, other authors also defend the use of the DWR as a complementary training (*cross-training*) for performance athletes[6-7,49]. Due to the probable decrease of lesions incidence with the DWR introduction, it is possible to expect secondary effects caused by the inhibition of the harmful aspects of the lesion in the athlete, namely, decrease in the training load and psychological aspects such as anxiety, fear and lack of motivation[50]. Once the harmful aspects are avoided, it is possible to guarantee the continuity principle of the sports training. Such principle refers to the need of improvement or maintenance of the reached performance indices through the work's continuity, being the intervenient factors, lesions and social diseases or factors[51-52].

Another factor that may explain the performance maintenance causes, despite the lack of specificity mentioned in the literature[10-11,24], is the possibility to exercise the lower limbs with higher loads due to water's greater density. The possibility of increasing strength inside water has already been mentioned in this work.

Yet, the possibility of increasing strength may be a hypothesis to explain the performance maintenance, compensating thus, the lack of specificity. Paavolainen *et al.*[53] and Millet *et al.*[54] believe that it is possible to improve the running savings through an aerobic resistance training joined to a strength training. Such improvement may be explained by several factors. One of them would be by the increase of the strength and more intense use of slow contraction fibers during a running step due to the decrease of the relative tension peak [from 35 to 50% of pure strength[35]] during the running step. Another explanation for the relation between strength training and performance in resistance competitions is the regulation of the shortening-stretching cycle, with the decrease of the properties of elastic energy storage due to fatigue, hence decreasing the running savings[55]. Despite this evidence, in the study by Peyré-Tartaruga[9] the muscular strength was not evaluated, therefore, studies that evaluate muscular strength are needed to confirm such hypotheses. Another possible mechanism which justifies the performance maintenance with the inclusion of the DWR in performance training of runners refers to the fact that, during exercise in the water environment, the muscular contractions are predominantly concentric[11], therefore, compromising more contraction components of the muscle than in exercises with exocentric actions[56], the running on land for instance, and consequently the athletes who include the DWR, possibly use the contraction components more intensively than the athletes who train only on land.

Therefore, based on this discussion with the literature, it is possible to affirm that the DWR may be a complement to training up to 30% of the weekly volume training, since it not only confirms the evidence of maintenance of the predictive physiological characteristics of performance in middle and long distance runners, but it was also possible to demonstrate that the inclusion of the DWR in performance runners training is not harmful to the their running technique, either in submaximal effort situation (running savings) or in fatigue situation[9]. Such data present useful information to the middle and long distance runners's coach to the planning and periodization of the high level training. Through the inclusion of the DWR, new perspectives of optimization of the physiological loads become possible to performance runners, decreasing the influence of the inconvenient limitation in the training planning, due to the possibility of lesions occurrence caused by excessive use.

TRAINING CONTROL IN DWR

The training control in the DWR may be mainly conducted by three means: HR, subjective sensation to effort and step frequency.

The HR is a type of effort intensity indicator up to levels close to the $\dot{V}O_{2max}$[57]. It is possible through the HR to control the training inside water; however, some measures are important before applying such method. Firstly, one should consider more the lower responses in the HR in the DWR than in the exercise on land. Therefore, any determination of the intensity come from a direct measure (effort test) or indirect (formula or field test) conducted outside water, should be modified in order to avoid the super estimation of the training intensity. However, the best way to determine the maximum effort is during a specific effort test of DWR. The HR is a good strategy to control the training intensity of a group of athletes.

The subjective sensation to effort scale is an effective way to control the training load inside water[58]. There are subjective sensation to effort scales specifically created to runners during the DWR. The most well-known is the scale by Wilder and Brennan[1] used in several studies [7-10,24,49]. Athletes running in five subjective intensities to effort reached cardiac rates similar to the ones reached in run on land, considering the normal bradycardia in these effort intensities[8]. Each effort level is described by running intensities – level 1 corresponds to very mild or trotting rhythm; level 2 corresponds to mild or spinning rhythm; level 3 corresponds to moderate or 5/10 km competition rhythm; level 4 corresponds to strong or 400/800 m sprint competition rhythm and level 5 corresponds to very strong or 100/200 m sprint competition rhythm.

The transfer of the effort intensity of running on land session for the DWR is conducted as following: for instance, a 500 m sprint on land usually conducted for 2 minutes, when transferred to the DWR, instead of asking the athlete to perform 500m for 2 minutes, a 'strong' running intensity is asked for 2 minutes. Therefore, a change of the athlete's focus attention from the distance to the effort subjective sensation is observed in order to fulfill the task. In the running on land, the runner concentrates on the completion of a given distance (500 m) in a specific time, however, in the DWR the athlete must concentrate to fulfill the task in a given effort intensity (strong) in the time equal to the one covered in the running on land[10].

Another way of monitoring the effort intensity in the DWR is the frequency of steps, since it presents a good correlation with HR[15,59]. Nonetheless, such kind of effort control may be conducted only in an individual training situation. dual.

CONCLUSION

The knowledge limitations produced in relation to this kind of training for performance runners are diverse. The reduced number of works in the biomechanical adaptations of the DWR training field and the training time used in the studies, which was not longer than 10 weeks, do not let us generalize the results of the studies for more than 10 weeks. Moreover, the strength and flexibility responses in DWR training in performance athletes are also issues that have not been conclusive so far.

Although these issues are not conclusive, it is possible to affirm that the DWR is beneficial to performance runners, not only as physical rehabilitation means, but also as a means of preventive training of lesions caused by excessive use, favoring the principle of the sports training continuity.

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REFERENCES

1. Wilder RP, Brennan DK. Physiological responses to deep water running in athletes. Sports Med 1993;16:374-80.
2. Glass B, Wilson D, Blessing D, Miller E. A physiological comparison of suspended deep water running to hard surface running. J Strength Cond Res 1995;9:17-21.
3. Frangolias DD, Rhodes EC. Metabolic responses and mechanisms during water immersion running and exercise. Sports Med 1996;22:38-53.
4. Dowzer CN, Reilly T, Cable NT. Effects of deep and shallow water running on spinal shrinkage. Br J Sports Med 1998;32:44-8.
5. Burns AS, Lauder TD. Deep water running: an effective non-weightbearing exercise for the maintenance of land-based running performance. Mil Med 2001; 166:253-8.
6. Wilber RL, Moffatt RJ, Scott BE, Lee DT, Cucuzzo NA. Influence of water run training on the maintenance of aerobic performance. Med Sci Sports Exerc 1996; 28:1056-62.
7. Bushman BA, Flynn MG, Andres FF, Lambert CP, Taylor MS, Braun WA. Effect of 4 weeks of deep water run training on running performance. Med Sci Sports Exerc 1997;29:694-9.
8. Peyré-Tartaruga LA, Coertjens M, Black GL, Tartaruga MP, Oliveira AR, Kruel LFM. Influence of deep water run training supplement on the maintenance of aerobic performance and kinematics of middle-distance runners. In: Gianikellis K, editor. Proceedings of XX International Symposium on Biomechanics in Sports. Cáceres: University of Extremadura Press, 2002;92-5.
9. Peyré-Tartaruga LA. Efeitos fisiológicos e biomecânicos do treinamento complementar de corrida em piscina funda no desempenho de corredores de rendimento. Dissertação de mestrado, Universidade Federal do Rio Grande do Sul, 2003.
10. Peyré-Tartaruga LA, Larronda ACC, Tartaruga, MP, Kruel LFM. Importance of the lower limbs for the horizontal velocity on treadmill running and on deep water running. In: Muller R, Gerber H, Stacoff A, editors. Proceedings of The International Society of Biomechanics XVIII Congress. Sport Biomechanics I Section, 2001;p.109.
11. Nilsson J, Tveit P, Thorstensson A. Running on land and in water – A comparative biomechanical study. Proceedings of XVIII Congress of The International Society of Biomechanics. Orthopaedic Biomechanics & Rehabilitation I Section, 2001; p.241.
12. Arborelius M, Balldin UI, Lilja B, Lundgren CEG. Hemodynamic changes in man during immersion with the head above water. Aerospace Med 1972;43:590-8.
13. Blomqvist CG. Cardiovascular adaptation to weightlessness. Med Sci Sports 1983; 15:428-31.
14. Hamer PW, Morton AR. Water-running: training effects and specificity of aerobic-anaerobic and muscular parameters following an eight-week interval training programme. Aust J Sci Med Sport 1990;22:13-22.
15. Town GP, Bradley SS. Maximal metabolic responses of deep and shallow water running in trained runners. Med Sci Sports Exerc 1991;23:238-41.
16. Butts NK, Tucker M, Grening C. Physiologic responses to maximal treadmill and deep water running in men and women. Am J Sports Med 1991;19:612-4.
17. Butts NK, Tucker M, Smith R. Maximal responses to treadmill and deep water running in high school female cross country runners. Res Q Exerc Sport 1991;62: 236-9.
18. Svedenhag J, Seger J. Running on land and in water: comparative exercise physiology. Med Sci Sports Exerc 1992;24:1155-60.
19. Frangolias DD, Rhodes EC. Maximal and ventilatory threshold responses to treadmill and water immersion running. Med Sci Sports Exerc 1995;27:1007-13.
20. Gehring MM, Keller BA, Brehm BA. Water running with and without a flotation vest in competitive and recreational runners. Med Sci Sports Exerc 1997;29: 1374-8.
21. Mercer JA, Jensen RL. Heart rates at equivalent submaximal levels of $\dot{V}O_2$ do not differ between deep water running and treadmill running. J Strength Cond Res 1997;5:55-60.
22. Connelly TP, Sheldahl LM, Tristani FE, Levandoski SG, Kalkhoff RK, Hoffman MD, Kalbfleisch JH. Effect of increased central blood volume with water immersion on plasma catecholamines during exercise. J Appl Physiol 1990;69:651-6.
23. Di Prampero PE. The energy cost of human locomotion on land and in water. Int J Sports Med 1986;7:55-72.
24. Larronda ACC, Peyré-Tartaruga LA, Petersen RDS. Efeitos das restrições do ambiente e da tarefa na coordenação intramembro durante a corrida em piscina funda. Anais do III Seminário de Comportamento Motor. CD-ROM: Seção de controle motor, 2002.
25. Beaver WL, Wasserman K. Muscle RQ and lactate accumulation from analysis of the $\dot{V}_{CO2}$-$\dot{V}_{O2}$ relationship during exercise. Clin J Sport Med 1991;1:27-34.
26. Barros TL, Santana M, Santos AB. Efeito da hidroginástica na remoção de ácido láctico pós-competição. Anais do Simpósio Internacional de Ciências do Esporte. São Paulo, 1994.
27. Villar R, Denadai BS. Efeitos da corrida em pista ou do deep water running na taxa de remoção do lactato sanguíneo durante a recuperação ativa após exercícios de alta intensidade. Rev Motriz 1998;4:25-30.
28. Hertler L, Provost-Craig M, Sestili D. Water running and the maintenance of maximum oxygen consumption and leg strength in runners [abstract]. Med Sci Sports Exerc 1992;24:S23.
29. Morrow MJ. Effects of ten weeks of deep water running or land based run training. Dissertation in Kinesiology – University of North Texas, 1995.
30. Pöyhönen T, Sipilä S, Keskinen K, Autala A, Savolainen J, Mälkiä E. Effects of aquatic resistance training on neuromuscular performance in healthy women. Med Sci Sport Exerc 2002;34:2103-9.
31. Nakazawa K, Yano H, Miyashita M. Ground reaction forces during walking in water. In: Miyashita M, Mutoh Y, Richardson AB, editors. Med Sci Aquatic Sports 1994;39:28-34.
32. Ritchie SE, Hopkins WG. The intensity of exercise in deep water. Int J Sports Med 1991;12:27-9.
33. McConnel GK, Costill DL, Widrick JJ, Hickey MS, Tanaka H, Gastin PB. Reduced training volume and intensity maintain aerobic capacity but not performance in distance runners. Int J Sports Med 1993;14:33-7.
34. Houmard J, Kirwan J, Flynn M, Mitchell J. Effects of reduced training on submaximal and maximal running responses. Int J Sports Med 1989;10:30-3.
35. Hickson RC, Rosenkoetter MA. Reduced training frequencies and maintenance of increased aerobic power. Med Sci Sports Exerc 1981;13:13-6.
36. Hoeberigs JH. Factors related to the incidence of running injuries. A review. Sports Med 1992;13:408-22.
37. Marti B, Vader JP, Minder CE, Abelin T. On the epidemiology of running injuries. Am J Sports Med 1988;16:285-94.
38. Van Mechelen W. Running injuries. A review of the epidemiological literature. Sports Med 1992;14:320-35.
39. Hreljac A, Marshall RN, Hume PA. Evaluation of lower extremity overuse injury potential in runners. Med Sci Sports Exerc 2000;32:1635-41.
40. Jacobs SJ, Berson BL. Injuries to runners: a study of entrants to a 10,000 meter race. Am J Sports Med 1986;14:151-5.

41. James SL, Jones DC. Biomechanics aspects of distance running injuries. In: Cavanagh PR, editor. Biomechanics of distance running. Champaign: Human Kinetics, 1990;249-69.
42. Cavanagh PR, Lafortune MA. Ground reaction forces in distance running. J Biomech 1980;13:397-406.
43. James SL, Bates BT, Osternig LR. Injuries to runners. Am J Sports Med 1978;6:40-50.
44. Crossley K, Bennell KL, Wrigley T, Oakes BW. Ground reaction forces, bone characteristics, and tibial stress fracture in male runners. Med Sci Sports Exerc 1999; 31:1088-93.
45. Wenger HA, Bell GJ. The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. Sports Med 1986;3:346-56.
46. O'Bryan R. Indoor workouts. A terrific change of pace. Triathlete 1991;80:32-3.
47. Michaud TJ, Brennan DK, Wilder RP, Sherman NW. Aquarunning training and changes in cardiorespiratory fitness. J Strength Cond Res 1995;9:78-84.
48. Hogg JM, Hayden MA. Pain perceptions among competitive runners. New Studies in Athletics 1997;12:95-9.
49. Matveiev L. Fundamentos do treino desportivo. Lisboa: Horizonte, 1986.
50. Ozolin PV. Sistema contemporaneo de entrenamiento deportivo. La Havana: Científico-técnica, 1989.
51. Paavolainen L, Häkkinen K, Hämäläinen I, Nummela A, Rusko H. Explosive-strength training improves 5-km running time by improving running economy and muscle power. J Appl Physiol 1999;86:1527-99.
52. Millet GP, Jaquen B, Borrani F, Candau R. Effects of concurrent endurance and strength training on running economy and $\dot{V}O_2$ kinetics. Med Sci Sports Exerc 2002;34:1351-9.
53. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. J Biomech 2000;33:1197-206.
54. Knuttgen HG. Human performance in high-intensity exercise with concentric and eccentric muscle contractions. Int J Sports Med 1986;Suppl:6-9.
55. Gilman MB. The use of heart rate to monitor the intensity of endurance training. Int J Sports Med 1996;21:73-9.
56. Fujishima K, Shimizu T. Body temperature, oxygen uptake and heart rate during walking in water and on land at an exercise intensity based on RPE in elderly men. J Physiol Anthropol Appl Human Sci 2003;22:83-8.
57. Wilder RP, Brennan D, Schotte DE. A standard measure for exercise prescription for aqua running. Am J Sports Med 1993;21:45-8.