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ORIGINAL ARTICLE

Cardiorespiratory, neuromuscular and kinematic responses to stationary running performed in water and on dry land

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Abstract The purpose of this study was to analyze the cardiorespiratory, neuromuscular and kinematic responses obtained during the stationary running in aquatic and dry land environments. Twelve women took part in the experimental protocol. Stationary running was performed for 4 min at three submaximal cadences and for 15 s at maximal velocity, with the collection of kinematic (peak hip angular velocity (AV)), cardiorespiratory (oxygen uptake (VO_2)) and neuromuscular variables (electromyographic (EMG) signal from the *rectus femoris* (RF), *vastus lateralis* (VL), *semitendinosus* (ST) and short head of the *biceps femoris* (BF) muscles) in land-based and water-based test protocols. Factorial ANOVA was used, with an alpha level of 0.05. AV was significantly higher when the exercise was performed on land, and became significantly higher as the execution cadence increased. Similarly, VO_2 was significantly higher in the land-based exercise and rose as cadence increased. With the increase in the submaximal execution cadences, there was no corresponding increase in the EMG signal from the VL, BF, RF and ST muscles in either environment, though such a significantly increase was seen between the submaximal cadences and the maximal velocity. Dry land presented significantly greater EMG signal responses for all muscles at the submaximal cadences, except for the ST muscle. However, at the maximal velocity, all the analyzed muscle groups showed similar responses in both environments. In summary, for both environments, cardiorespiratory responses can be maximized by increasing the submaximal cadences, while neuromuscular responses are only optimized by using maximal velocity.

Keywords Aquatic exercise · Electromyography · Heart rate · Oxygen uptake · Angular velocity

Introduction

Studies that investigate individuals performing water-based exercises in a vertical position have been developed in the physiological and biomechanical research areas. The physiological and biomechanical responses that occur during exercise in water immersion are different from those obtained during exercise on dry land, because they vary according to the use of the physical properties of the water. So, it is possible to use exercises that produce a higher drag force (F_d) in water, caused by the greater fluid density (ρ) of the water compared with the air, by the increase in the projected frontal area (A), velocity of movement (v) and/or drag coefficient (C_d), as shown by the general fluid equation $F_d = ½\rho A v^2 C_d$ (Alexander 1977). On the other hand, it is possible to use exercises that evoke a lower drag force in water, due to the ease of movement afforded by buoyancy and, consequently, by the low apparent weight during immersion (Harrisson et al. 1992; Kruel 1994).

One way to increase resistance in the aquatic environment is to raise the velocity of movement of exercises. Studies that analyzed the cardiorespiratory and neuromuscular responses during water aerobic exercises performed at different velocities found a significant increase in oxygen uptake (VO_2) (Alberton et al. 2005, 2009; Cassady and

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Nielsen 1992; Masumoto et al. 2009) and in the electromyographic (EMG) activity of different muscles (Kelly et al. 2000; Masumoto et al. 2008; Müller et al. 2005) at higher execution paces.

On the other hand, when comparing one exercise performed at specific submaximal intensities in aquatic and dry land environments, studies have shown contrasting results depending on the type of exercise used. Modalities that involve horizontal displacement of the body, such as walking, present a higher VO_2 (Hall et al. 1998; Shono et al. 2000) and EMG signal (Masumoto et al. 2008; Shono et al. 2007) in the aquatic environment at the same velocity compared with dry land. In contrast, exercises involving vertical displacement of the body, such as water resistance or stationary exercises, seem to diminish the metabolic cost (Alberton et al. 2009; Heithold and Glass 2002; Kruel 2000) and neuromuscular activity (Kelly et al. 2000; Müller et al. 2005) in the aquatic environment when they are performed at the same cadence as on dry land. There is evidence to suggest this is due to the reduction in apparent weight that occurs with the increased immersion depth (Harrisson et al. 1992; Kruel 1994), so that stationary exercises are facilitated by buoyancy at submaximal intensities. However, exercises involving vertical displacement of the body performed at the maximal velocity in both environments present a distinct pattern. Research studies by Kelly et al. (2000) and Müller et al. (2005) found similar neuromuscular activity in both environments during resistive exercises for shoulders and abdomen, respectively, when the exercises were performed at maximal velocities. Thus, the reduced apparent weight seems to be compensated by greater drag force, caused by the higher execution velocity, producing an overload in the aquatic environment similar to that observed on land.

Notwithstanding, the above-mentioned studies have analyzed the cardiorespiratory and neuromuscular patterns in the aquatic environment separately. In addition, the kinematic responses to these aquatic exercises have not yet been analyzed. Therefore, to the best of our knowledge, no study has investigated the cardiorespiratory, neuromuscular and kinematic responses during a water-based exercise involving vertical displacement of the body at submaximal and maximal intensities. Since the physiological and biomechanical pattern of stationary running performed in water is different from that of water walking with horizontal displacement, it is important to obtain more knowledge regarding the cardiorespiratory and neuromuscular responses in that exercise and whether they present a similar patterns with the increase in the intensity of effort, in order to improve the prescription of the water aerobics. The purpose of the present study was to analyze the cardiorespiratory, neuromuscular and kinematic responses during the performance of stationary running at different cadences in aquatic and dry land environments. It was hypothesized that cardiorespiratory, neuromuscular and kinematic responses would be higher on the dry land environment at submaximal cadences but similar in both the environments at the maximal velocity. In addition, we speculated that higher cardiorespiratory, neuromuscular and kinematics responses would be observed at higher cadences.

Materials and methods

Subjects

Twelve physically active and healthy women volunteered to take part in the present study (Mean ± SE—age, 22.33 ± 0.57 years; height, 1.63 ± 0.02 m; body mass, 59.11 ± 1.88 kg; VO_{2peak}, 44.78 ± 2.20 ml kg^{-1} min^{-1}). Subjects were familiar with the aquatic environment, had engaged in water aerobics programs for at least 3 months, were free of any musculoskeletal, bone and joint, or cardiac and pulmonary diseases and were not taking any medication. Calculation of the sample "*n*" was carried out using the PEPI program (version 4.0) with a power of 90%. In order to participate in this study, all subjects were required to read and sign the written informed consent, which contained all the information about the procedures and potential risks involved in participation. The study was approved by the Local Research Ethics Committee (2006566) and is in accordance with the Declaration of Helsinki.

Experimental procedures

Each subject took part in three data collection sessions: sample characterization, familiarization and experimental protocol. An interval of 48 h was allowed between the sessions. Several restrictions were imposed on the volunteers: no food 3–4 h before and no stimulants or intense physical activity 12 h before the experimental protocol (Cooke 1996).

Sample characterization

In the initial session, body mass and height were measured using an analog medical scale (resolution of 0.1 kg) and a stadiometer (resolution of 1 mm) (FILIZOLA; São Paulo, Brazil). After that, a maximal test was carried out on a treadmill (model 10200 ATL, INBRAMED; Porto Alegre, Brazil) in order to evaluate peak oxygen uptake (VO_{2peak}). The protocol consisted of an initial velocity of 5 km h^{-1} with 1% inclination during 2 min. After this warm-up, the velocity was increased every minute by increments of 1 km h^{-1}, and inclination was maintained until the subjects reached their maximal effort. The assessment was considered valid when some of the following criteria were met at the end of the test (Howley et al. 1995): estimated maximal heart hate was reached (220-age); plateau in VO_2 with increase in the treadmill velocity; a respiratory exchange ratio greater than 1.15 was reached; maximum respiratory rate of at least 35 breaths per minute.

Familiarization

In this session, the subjects performed the exercise at all cadences and in the environments that would later be used during data collection. In addition, all details of the care that would need to be taken when performing the exercise were explained.

Experimental protocol

This session started with the preparation of the subjects. Initially, any hair was removed from the surface of the muscles, which were then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent placement of the electrodes on the *rectus femoris* (RF), *vastus lateralis* (VL), *semitendinosus* (ST) and short head of the *biceps femoris* (BF). The innervation zone of each muscle of the right leg was determined with the aid of an electrostimulator (model EGF 4030, CARCI; São Paulo, Brazil). Bipolar electrodes were placed 2 cm distal away from the innervation zone. Surface electrodes with 10 mm radius of conductive area and 15 mm overall radius and a pre-amplifier with monopolar configuration (model Mini Medi-Trace 100, Kendall Ag/AgCl; Tyco, USA) were used. The distance between the centers of the electrodes was maintained at 30 mm. The resistance level inter-electrode, considered suitable below 3,000 ohms, was measured before each session using a digital multimeter. The reference electrode was positioned on the clavicle. For the aquatic protocol an insulation procedure was performed in order to avoid interference due to the contact of electrodes with water, which can produce noise in the EMG signal (Rainoldi et al. 2004). The insulation was done with waterproof transparent adhesive tape (model Tegaderm, 3M; St. Paul, MN, USA), according to the method described by Figueiredo et al. (2006). Silicone glue was placed at the exit point of the cables (dried for approximately 1.5 h) to prevent water from entering. The cables and preamplifiers were fixed with adhesive tape. Previous studies found that these insulation procedures did not interfere with the EMG signal (Alberton et al. 2008; Carvalho et al. 2010). In addition, reflective markers were placed on the greater trochanter and lateral femoral epicondyle for filming in order to determine the angular position of the hip over the range of motion, the hip angular velocity (AV) and the alignment of the EMG signal. All the aforementioned procedures were carried out by the same researcher.

Maximum voluntary isometric contraction (MVC) tests were performed in order to estimate maximal EMG amplitude for each muscle, i.e., RF, VL, ST and BF. These MVC tests were measured on the land environment before and after the exercise protocol. Each one was performed for 5 s, with the contraction of the muscle groups, in which each of the aforementioned muscles acts as an agonist. The pre-exercise MVC values were used for further normalization of the EMG signal (Knutson et al. 1994). Moreover, the post-exercise MVC values were used to assess possible changes in the physiological status of the examined muscles and the interference of water on the EMG signal at the end of the session through correlation with the pre-exercise values.

The angles, measured with a goniometer (CARCI; São Paulo, Brazil), were adjusted so that they could be maintained during the performance of the MVC against manual resistance in both the flexion and extension directions. In addition, these angles are within of the range of the motion used during the performance of the dynamic protocol. For the RF and ST muscles, the EMG signal was recorded with the subjects lying face-up with 90° of hip flexion. For the RF, the knee was maintained at 90° of flexion, with the isometric contraction of the hip flexors. For the ST muscle, the knee was maintained at full extension (0°), with isometric contraction of the hip extensors. Afterward, the subjects were maintained seated with 90° of hip and 70° of knee flexion in order to record the EMG signal from the VL and BF muscles.

The dry land protocol was always performed first, followed by the aquatic protocol, with a 2-h interval between the two. During this interval, the insulation procedure was carried out. This order was chosen in order to preserve the insulation procedure. Each protocol began with the collection of cardiorespiratory variables while subjects were at rest out of the water. The subjects remained in a supine position for 10 min and then in the orthostatic position for 5 min for the evaluation of VO_2.

Stationary running (Fig. 1) was chosen for this study since it is widely used in water aerobics classes and also because of its relatively simple movements. The subjects started the exercise in the standing position with their arms at the side of the body. The first phase of the movement consisted of a right hip and knee flexion at 90°, with left shoulder flexion at 90° and left elbow extension with the fist extended; the second phase consisted of a full right hip and knee extension, left shoulder hyperextension and left elbow flexion at 90° with the fist extended. This movement was repeated alternately with the right and left limbs. The movements of the upper limbs were performed only to provide the subject with balance.

The subjects performed this exercise on dry land and in the aquatic environment at three submaximal cadences and

Fig. 1 Stationary running exercise

also at maximal velocity. Based on previous studies (Alberton et al. 2007a, b; Cassady and Nielsen 1992) the cadences of 60, 80 and 100 bpm were chosen and reproduced by a digital metronome (model MA-30, Korg; Japan). The subjects performed the exercise for 4 min at submaximal intensities, with recording of the VO_2, EMG signal and filming from the 3rd to the 4th minute. At maximal velocity, the exercise was performed for 15 s, and only neuromuscular and kinematic data were recorded throughout the execution of the movement. All intensities were performed randomly with a 5-minute interval between them.

On dry land, the exercise protocol was conducted in a room with temperature between 22 and 26°C. In the aquatic environment, the exercise protocol was performed in a deep pool measuring 25 × 16 × 2 m. Depth reducers were used to ensure that the subjects were immersed between the xiphoid process (while standing and at rest) and shoulders (during the movement). The water temperature was maintained between 30 and 31°C.

In order to evaluate VO_2, a mixing-box-type portable gas analyzer (model Aerosport KB1-C, INBRAMED; Ann Arbor, MI, USA) was used. The gas analyzer was calibrated prior to each collection session (King et al. 1999). The sampling rate of the collected values was 20 s. The EMG data were collected using a 14-bit electromyograph (model Miotool400, MIOTEC Biomedical Equipment; Porto Alegre, Brazil), with a common-mode rejection ratio of 110 dB and 2,000 Hz per channel with a 4-channel system. The hardware filter is from 0.1 to 1,000 Hz, Butterworth architecture with two poles. In order to align the EMG data with the angular position of the hip, a light signal was triggered with the onset of EMG data collection. A video camera, which was positioned in the sagittal plane on the subjects' right side, at a distance of 3 m, was used to obtain the angular position (AP) for maximal hip flexion and peak hip AV. The film was shot through an underwater window in the side of the pool using a video camera (model 50 Hz JVC GR-DVL9800, Mini DV Digital Camcorder; Japan) and a cold-cathode lamp to illuminate the reflective markers.

Data processing

Cardiorespiratory data

The mean value for VO_2 at rest was obtained from the values collected in the last 3 min for each situation, in the supine and orthostatic positions. During the exercise the mean value for VO_2 was obtained from the data collected from the 3rd to the 4th minute for each cadence in each environment. Also, VO_2 values were expressed as percentages of the VO_{2peak} values ($\%VO_{2peak}$).

Kinematic data

A software (Dvideow software, Laboratory of Biomechanics & Institute of Computing, UNICAMP; Campinas, Brazil) was used to reconstruct the reflective markers into two-dimensional coordinates. The reflective markers corresponding to the first ten repetitions were digitalized either automatically or manually. The hip angle was measured using markers on the hip (greater trochanter of the femur) and the knee (lateral epicondyle of the femur) in relation to the vertical line. In the standing position, the reference value for the complete extension of the hip and knee was 0°. These data were later filtered using a fifth-order low-pass Butterworth filter, with a cutoff frequency of 8 Hz, and processed, generating files containing the AP and AV graphs for hip joint over time (Matlab software version 5.3, MathWorks, Inc.; Natick, MA, USA). From these graphs, out of ten repetitions, five, in which the angle of maximum flexion of the hip (90°) was within a range of ±5°, were selected for each cadence. Therefore, there was an average of five replicates for the presentation of data. The peak AV for hip flexion and extension was also obtained from these graphs. The average of the five replicates, corresponding to the chosen AP, was calculated for the presentation of the AV data. In addition, the starting and finishing time points for the subsequent EMG slices were obtained based on these five repetitions.

Neuromuscular data

The signal captured by the electromyography was recorded onto a PC (Miograph software, MIOTEC Biomedical Equipment; Porto Alegre, Brazil). Later, the files were exported for analysis (SAD32 software, Mechanical Measurements Laboratory, UFRGS; Porto Alegre, Brazil). The digital signal was filtered using a fifth-order band-pass Butterworth filter, with cutoff frequencies between 25 and 500 Hz. According to the literature, the main frequencies of the EMG signal are between 20 and 250 Hz (DeLuca 1997). However, a higher cutoff frequency, corresponding to 25 Hz, was chosen in order to ensure the absence of interference from low-frequency noise, since in experiments in an aquatic environment the movement of the water might displace the cables. The signal curves corresponding to the pre- and post-exercise (5 s) MVC were sliced between 2 and 4 s to obtain the root mean square (RMS) value. The RMS values obtained from the MVC of each muscle during pre-exercise were used to normalize the EMG data collected from the different experimental situations. The individual starting and finishing time points of each repetition based on the AP were used to make slices in the acquired EMG signal corresponding to each total repetition of the exercise. The RMS value corresponding to each of the five total repetitions of the exercise was obtained and the average of five replicates was calculated for each muscle. These values were normalized and expressed as a percentage of the MVC (%MVC) for the presentation of the RF %MVC, VL %MVC, ST %MVC and BF %MVC data.

Statistical analysis

In order to analyze the collected data, descriptive statistics were used, with the data presented as means ± standard error (SE). The Lilliefors (K–S) test was used to verify the normal distribution of data. The paired two-tailed Student's *t* test was used in order to compare the VO_2 at rest collected before the water-based and land-based protocols. The intraclass correlation coefficient (ICC) was used to verify the reliability of the EMG signal of the VL, RF, BF and ST in the pre- and post-exercise MVC. Factorial ANOVA for mixed models was used to analyze the cardiorespiratory (environment and cadence), neuromuscular (environment and cadence) and kinematic (environment, cadence and phase) variables. When applicable, Tukey's post-hoc tests were used to detect significant differences. In addition, when the interaction was significant, the main factors were tested again using the *F* test. An alpha level of 0.05 was adopted. The R-project and SPSS version 17.0 were employed.

Results

Kinematic responses

The descriptive values for AP are presented in Table 1. The statistical analyses showed that AP values were not significantly different between environments ($p = 0.100$) and cadences ($p = 0.248$). Moreover, the minimum and maximum values demonstrated that the mean AP amplitude was maintained within the established range, i.e., ±5° from the target angle (90°).

Regarding the duration of repetitions, i.e., the time taken to perform a complete cycle (successive right heel contact), there was no significant difference between the environments for the submaximal cadences, with values for aquatic and terrestrial environment corresponding to 2.00 ± 0.01 and 1.99 ± 0.01 s for 60 bpm ($p = 0.483$), 1.50 ± 0.01 and 1.48 ± 0.01 s for 80 bpm ($p = 0.068$) and 1.19 ± 0.01 and 1.20 ± 0.01 s for 100 bpm ($p = 0.483$), respectively. These values indicate that the individuals performed the exercise in the cadence proposed by the metronome. On the other hand, at maximal effort, significant differences were found between the environments ($p = 0.003$), with the exercise performed on dry land (0.47 ± 0.01 s) being faster than in the aquatic environment (0.64 ± 0.02 s).

Table 1 Mean, standard error (SE), minimum (Min) and maximum (Max) values for the variable maximal hip flexion angular position (AP) on dry land and aquatic environment

	Cadence (bpm)	Dry land environment				Aquatic environment			
		Mean	SE	Min	Max	Mean	SE	Min	Max
AP (°)	60	89.74	±0.88	85.31	94.98	88.84	±0.99	85.91	94.99
	80	89.53	±0.76	85.38	93.33	90.06	±1.00	86.00	95.00
	100	88.12	±0.55	85.73	90.47	89.82	±0.99	85.02	94.63
	Max	88.54	±0.78	85.00	93.31	89.39	±0.89	84.99	93.73

Max maximal effort

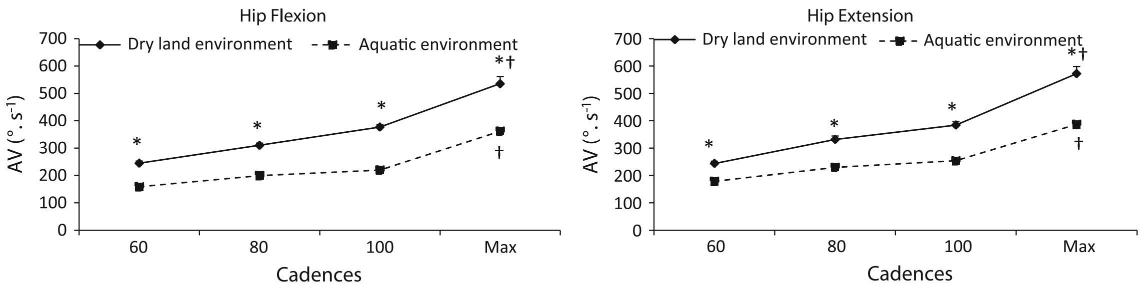

Fig. 2 Peak hip angular velocity (*AV*) for different cadences performed in aquatic and dry land environments. *Max* maximal effort. *Asterisk* indicates significant differences between environments. *Dagger* indicates significant differences between all cadences (Max > 100 bpm > 80 bpm > 60 bpm)

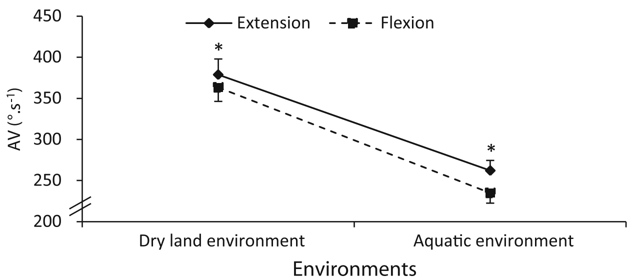

Fig. 3 Environment × phase interaction. *Asterisk* indicates significant differences between environments

However, AV showed distinct results. Significant differences were observed between the environments ($p < 0.001$), with higher values for dry land; between cadences ($p < 0.001$), with higher values for maximal velocity, followed by cadences 100, 80 and 60 bpm and between phases ($p < 0.001$), with higher values for hip extension compared with hip flexion (Fig. 2). The environment × cadence ($p = 0.103$), cadence phase ($p = 0.764$) and environment × cadence × phase ($p = 0.518$) interactions were not significant. However, the environment × phase interaction was significant ($p = 0.01$); thus, the phase factor was tested again using the F test and the results confirmed the presence of significant differences between extension and flexion in both environments (Fig. 3). However, it can be seen that the difference was more pronounced in the aquatic environment.

Cardiorespiratory responses

The responses of VO_2 at rest measured before the land-based and water-based protocols in the supine (3.39 ± 0.16 ml kg^{-1} min^{-1}; 3.15 ± 0.24 ml kg^{-1} min^{-1}, respectively) and orthostatic position (4.01 ± 0.32 ml kg^{-1} min^{-1}; 3.65 ± 0.25 ml kg^{-1} min^{-1}, respectively) were compared and, according to the results (supine position: $p = 0.444$; orthostatic position: $p = 0.489$), no significant differences were found between the two moments. The results suggest that the subjects initiated both test protocols with comparable levels of VO_2 at rest and that the magnitude of the alterations found in this variable during the protocols can be attributed to the effort made during their execution.

During the exercise protocols, VO_2 and $\%VO_{2peak}$ responses demonstrated a similar behavior to that of the AV. Significant differences were found between the environments ($p < 0.001$), with higher values for dry land, and between cadences ($p < 0.001$), with higher values for 100 bpm, followed by 80 and 60 bpm (Fig. 4). The environment × cadence interaction was not significant for any of these variables (VO_2, $p = 0.593$; $\%VO_{2peak}$, $p = 0.658$).

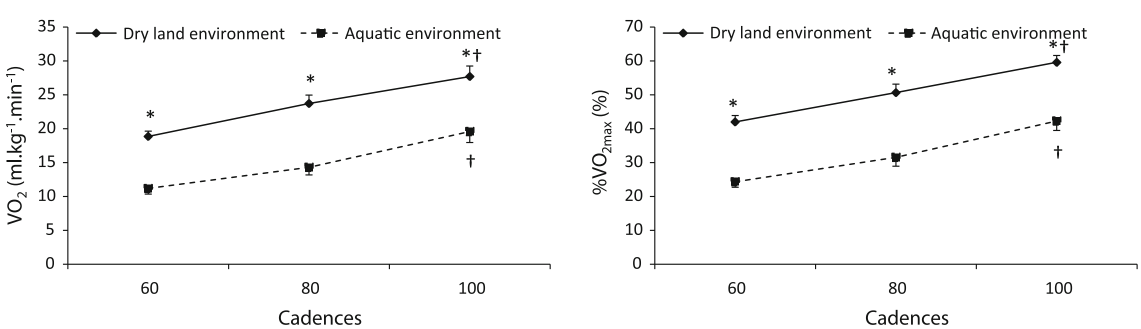

Fig. 4 Oxygen uptake (VO_2) and percentage of the maximal oxygen uptake ($\%VO_{2max}$) for different cadences performed in aquatic and dry land environments. *Asterisk* indicates significant differences between environments. *Dagger* indicates significant differences between all cadences (100 bpm > 80 bpm > 60 bpm)

Table 2 Intraclass correlation coefficients (ICC) for the maximum voluntary isometric contraction variable of the *rectus femoris* (RF), *vastus lateralis* (VL), *semitendinosus* (ST) and short head of the *biceps femoris* (BF) muscles between pre- and post-exercise situations

	ICC	Sig.
RF (μV)	0.942	0.003
VL (μV)	0.920	<0.001
ST (μV)	0.819	0.003
BF (μV)	0.764	0.005

Neuromuscular responses

The ICC results for the EMG signal from the RF, VL, ST and BF recordings between pre- and post-exercise MVC are presented in Table 2. ICC values were high and significant, indicating the reproducibility of the EMG signal. These findings suggest that the exercise protocol did not elicit alterations in the EMG data due to changes in the physiological status of the analyzed muscles (DeLuca 1997) or interference of water in insulation (Rainoldi et al. 2004).

The RF, VL, ST and BF %MVC responses showed a similar pattern among the muscles, with significant differences between the environments ($p < 0.001$) and between cadences ($p < 0.001$). However, the environment × cadence interaction was significant for all muscles (VL, $p < 0.001$; RF, $p = 0.004$; BF, $p = 0.001$; ST, $p = 0.032$), indicating that the behavior of neuromuscular variables between the environments depends on the rhythm of execution. Thus, the main factors were tested again using the *F* test (Fig. 5).

The results for cadence indicate that, for all muscles, the exercise performed at maximal velocity elicits significantly higher EMG activity than that performed at all submaximal cadences, for both environments. For submaximal cadences, the results indicated a similar pattern for all muscles, without significant differences between 60, 80 and 100 bpm, except for the VL muscle on dry land. For this environment, the VL %MVC showed significant differences between cadences 60 and 100 bpm.

The results for environment indicate that, for submaximal cadences, the RF %MVC, VL %MVC and BF %MVC variables elicit higher values for dry land compared with the aquatic environment. For the ST %MVC, the values were similar between the environments. In contrast, for maximal velocity, the results indicated that, for all analyzed muscles, the EMG signal presented similar responses in both the environments.

Discussion

The main finding of the present study was that the increase in the VO_2 and AV with the higher submaximal cadences,

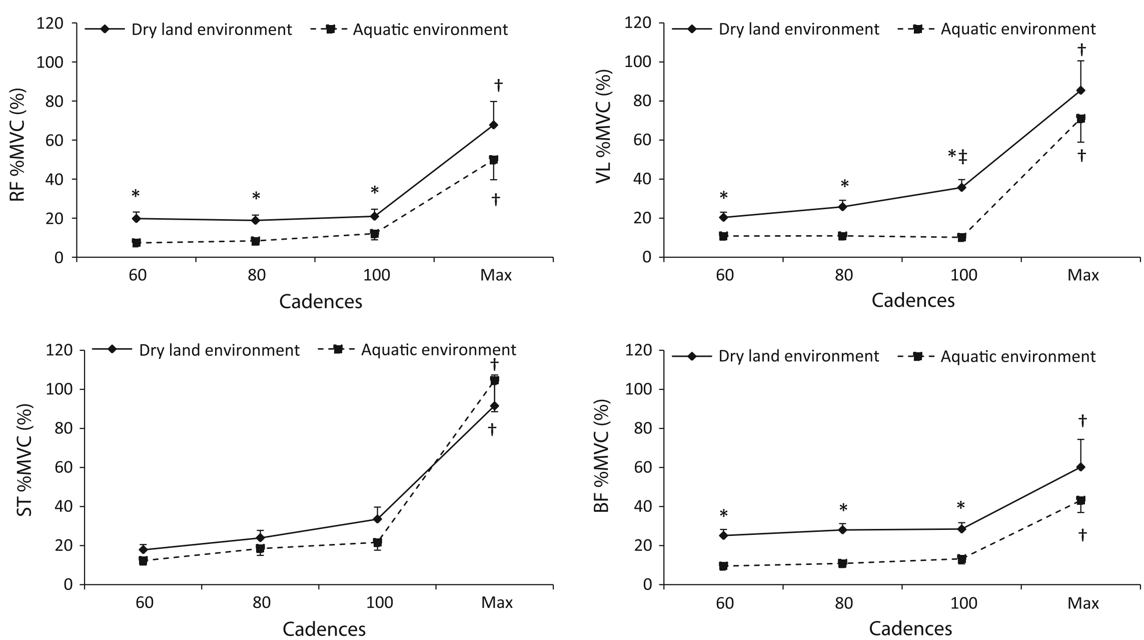

Fig. 5 EMG signal expressed as percentage of the maximal voluntary isometric contraction of *rectus femoris* (RF %MVC), *vastus lateralis* (VL %MVC), *semitendinosus* (ST %MVC) and short head of the *biceps femoris* (BF% MVC) muscles for different cadences performed in aquatic and dry land environments. *Max* maximal effort. *Asterisk* indicates significant differences between environments. *Dagger* indicates significant differences between maximal effort and all cadences (Max > 100 bpm, 80 bpm, 60 bpm). *Double dagger* indicates significant differences between 100 and 60 bpm (100 bpm > 60 bpm)

without a similar increase in the EMG signal for the RF, VL, ST and BF muscles, in contrast to our hypothesis, whereas, when comparing the environments, for the submaximal cadences, the VO_2, AV and EMG signal for the RF, VL and BF were higher on the dry land, according to our main hypothesis. On the other hand, the EMG signal from the ST was similar between environments at all intensities, and at the maximal intensity, no difference between the environments was found in the EMG signal for all the analyzed muscles.

Kinematic responses

Analyzing the difference in kinematic parameters between the environments, the results of the present study demonstrated that the stationary running exercise yielded significantly lower AV values for submaximal cadences tested as maximal velocity in the aquatic environment compared with dry land. Studies that analyzed shallow water walking and deep water running also indicated a different kinematic pattern between different velocities and environments (Kaneda et al. 2009; Kruel et al. 2002; Miyoshi et al. 2004, 2006). In the present study, the execution technique seems to have been different for each environment. For dry land, the exercise presented a longer heel contact than in the aquatic environment; thus, in order to maintain the execution cadence proposed by the metronome, the AV should be faster in that environment. However, during the exercise at maximal effort, the heel contact was not as pronounced as that seen at submaximal cadences and the difference in the AV between the environments was probably caused by the greater effort necessary to move the body against water, due to the higher density and viscosity of this fluid, generating an increased drag force in this environment.

Analyzing the difference in kinematic parameters between phases, the present results demonstrate that the stationary running exercise presented significantly higher AV values for the extension compared with the flexion phase for both environments, albeit the magnitude of the differences was bigger for the aquatic environment (Fig. 4). Although hip flexion is assisted by buoyancy, which acts upward in the aquatic environment, the higher value for hip extension can be explained by the facilitation of the movement due to the weight of the thigh segment, which acts downward on dry land and in the aquatic environment, even if apparent weight is reduced in the latter when compared with dry land.

Cardiorespiratory responses

According to the results of the present study, with the rise in cadence and consequently in AV, there was an increase in the VO_2 and $\%VO_{2peak}$ responses during the performance of the stationary running exercise, both in the dry land and aquatic environments. These data corroborate those of other studies, which also found greater cardiorespiratory responses with the increase in the pace of execution (Alberton et al. 2005, 2009; Cassady and Nielsen 1992; Hall et al. 1998; Masumoto et al. 2009; Shono et al. 2000). These responses are caused by the increase in the velocity of the body against the fluid, evoking a greater water-resistance, since the velocity is squared and directly proportional to it.

Furthermore, analyzing the difference in cardiorespiratory responses between the environments, the results of the present study showed that the stationary running exercise presented significantly lower VO_2 and $\%VO_{2peak}$ responses in the aquatic environment compared with dry land at the tested cadences. These data corroborate those of other studies, such as those obtained by Alberton et al. (2005), Heithold and Glass (2002) and Kruel (2000), which compared cardiorespiratory responses between these environments in stationary exercises or water aerobics routines. It is important to highlight that the exercise used in those approaches have the same characteristics. The stationary running exercise, analyzed in the present study and in the studies by Alberton et al. (2005) and Kruel (2000), involves vertical displacement of the body, changing the support from one lower limb to the other. According to Kruel (1994), shoulder-deep immersion, as used in our study, represents a reduction in apparent weight corresponding to 84.11% of the total body weight out of water. This indicates that the subjects support only around 15% of their total body weight when immersed at this depth, i.e., a lower weight to be carried and displaced in water. Then, this mode of exercise is facilitated by buoyancy at submaximal intensities.

Neuromuscular responses

Analyzing the difference in neuromuscular responses between cadences, the present results suggest that the increase in submaximal cadences, both on dry land and in the aquatic environment, was not enough to raise the EMG signal responses from all analyzed muscles. The data obtained corroborate those of Black et al. (2006), who assessed the RF and BF %MVC during hip flexion at 45° and hip extension in water immersion but did not observe significant differences between cadences of 60 and 80 bpm. Moreover, in the present study, neuromuscular responses demonstrated a different behavior from cardiorespiratory variables, which suffered a significant increase with the rise in the execution cadence. This increase in VO_2 without a concomitant increase in the EMG signal can be caused by the action of other muscle groups (upper limbs, trunk and lower limbs) not investigated in this study, since more muscles than those analyzed must be active during the performance of the stationary running exercise.

However, other studies have observed increases in EMG signal for different muscles, with the increase in pace of execution, both in walking and cycling on dry land (Hof et al. 2002; Hug et al. 2004; McIntosh et al. 2000) and water walking and water-resistance exercises (Kaneda et al. 2009; Kelly et al. 2000; Masumoto et al. 2004; Miyoshi et al. 2004). This significant increase in the EMG signal was found in the present study when comparing submaximal cadences with maximal velocity for all muscles analyzed in both environments. At maximal velocity, the amplitude of the EMG signal during the execution of the stationary running exercise was increased in response to the greater drag force (Alexander 1977). These results are consistent with the responses obtained by Black et al. (2006) and Müller et al. (2005), who analyzed water-resistance exercises and reported significant increases in neuromuscular responses at submaximal execution paces compared with maximal velocity.

Analyzing the difference in neuromuscular responses between the environments at submaximal cadences, the lower EMG signal observed for the RF, VL and BF muscles in the aquatic environment corroborates the findings obtained by Kelly et al. (2000); Masumoto et al. (2004); Müller et al. (2005) and Shono et al. (2007) who investigated the amplitude of the EMG signal of different muscles during dynamic exercises. These findings can be attributed to the lesser effort necessary to perform the exercise with vertical displacement in the aquatic environment at submaximal cadences, as verified by the lower VO_2 responses, with consequent lower muscle activation during its execution. In contrast, for the ST muscle, similar EMG signal responses were found between the environments at all cadences. This can be explained by the fact that on land this muscle acts with the aid of gravity in the extension hip, while in the aquatic environment, this muscle acts as agonist to overcome the drag forces due to the multidirectional flow of the water.

On the other hand, the EMG signal responses from all muscles analyzed at maximal velocity showed no significant differences between dry land and aquatic environments. Other researchers also found similar neuromuscular responses between environments during maximal isometric contractions for different muscles (Alberton et al. 2008; Carvalho et al. 2010; Pinto et al. 2010). Besides, our results are in accordance with Kelly et al. (2000) who found no differences in the EMG activity from the *supraspinatus*, *infraspinatus*, *subscapularis* and *deltoid* muscles during shoulder flexion between environments at higher velocity. These authors suggest that this higher velocity in the aquatic environment seems to be the point at which buoyant forces are suppressed by drag forces, which could explain the present results.

Conclusion

According to the results, we can conclude that performance of the stationary running exercise in the aquatic environment at submaximal cadences presents lower cardiorespiratory and neuromuscular responses. At submaximal intensities, cardiorespiratory responses can be maximized with the increase in cadence; however, neuromuscular responses are only optimized by the use of maximal velocity. Furthermore, at maximal effort, EMG responses can be similar between the environments, although the hip peak AV is lower in water immersion due to the higher drag forces caused by the movement of the body against the water.

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