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ORIGINAL ARTICLE

Electromyographic signal and force comparisons during maximal voluntary isometric contraction in water and on dry land

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Abstract This study was designed to compare surface electromyographic (sEMG) signal and force production during maximal voluntary isometric contractions (MVCs) in water and on dry land. The reproducibility of sEMG and isometric force measurements between water and dry land environments was also assessed. Nine women performed MVC for elbow flexion and extension, hip flexion, and extension against identical fixed resistance in both environments. The sEMG signal from *biceps brachii*, *triceps brachii*, *rectus femoris,* and *biceps femoris* was recorded with waterproof adhesives placed over each electrode. The sEMG and force production showed no significant difference between water and dry land, except for HEX ($p = 0.035$). In addition, intraclass correlation coefficient values were significant and ranged from moderate to high (0.66–0.96) for sEMG and force production between environments. These results showed that the environment did not influence the sEMG and force in MVC.

Keywords Maximal voluntary isometric contraction · Water · Dry land · Force · Electromyographic signal

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Introduction

Muscle activity in water environment has been widely investigated in different exercises through the analysis of the electromyographic (EMG) signal amplitude. Several studies that assessed the amplitude of the EMG signal from different muscle groups found smaller values for water exercises than for those performed on dry land, both in dynamic exercises (Masumoto et al. 2004, 2005; Miyoshi et al. 2006) and isometric ones (Clarys et al. 1985; Fujisawa et al. 1998; Kalpakcioglu et al. 2009; Pöyhönen et al. 1999; Pöyhönen and Avela 2002).

With regard to isometric exercises, few studies have analyzed and compared muscle force simultaneously with the amplitude of the EMG signal during exercises in water and on land. Amongst these studies, Pöyhönen et al. (1999) assessed the force of knee extensor muscles and the surface electromyographic (sEMG) signal from *vastus lateralis* and *vastus medialis* muscles during maximal and submaximal isometric contractions performed by 20 subjects (12 women and 8 men) in both exercise environments. Results demonstrated lower values for sEMG activity in water environment, but similar force production values were observed between environments. On the other hand, Pöyhönen and Avela (2002) analyzed the maximal voluntary isometric contractions (MVCs) during ankle plantar flexion and found lower values for force production and sEMG signal from *soleus* and *medial gastrocnemius* muscles. The rationale behind this lower muscle activity in water environment is not clear as some authors explain it as a consequence of the methodological limitations of a protocol of water exercises, while others ascribe it to physiological changes that result from water immersion (Masumoto and Mercer 2008; Pöyhönen et al. 1999).

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Conversely, some studies have yielded similar results for the amplitude of the EMG signal when comparing water and dry land environments at similar levels of submaximal force. The study by Rainoldi et al. (2004a) evaluated the responses of the sEMG signal from *biceps brachii* (BB) muscle of ten men who performed isometric contractions with 50% of MVC on dry land, in water without electrode insulation, and in water with electrode insulation. The results showed that the sEMG signal obtained in water environment without electrode insulation was low. However, the signal obtained in water environment with electrode insulation was similar to the one on dry land. The authors explain that water movement directly on the electrodes introduces low-frequency components, changing the sEMG signal amplitude data. Nevertheless, insulation allows the sEMG signal obtained in water environment to be similar to the one on dry land. Therefore, some authors declare that it is possible to obtain a similar EMG signal between water and dry land environments when some factors are controlled, such as the type of protocol, adjusted use of electrode insulation, and similar skin temperature between both environments with control over water temperature, which reflects muscle temperature (Alberton et al. 2008; Carvalho et al. 2010; Rainoldi et al. 2004a; Veneziano et al. 2006).

According to the above mentioned results, the EMG signal responses during isometric contractions performed in water environment have displayed conflicting results in the literature, and the different findings in these studies may be caused by the distinct methodological approaches (i.e. use or not of insulation, muscles from lower and upper limbs, segment position during MVC). In addition, the force production responses have been measured in submaximal voluntary isometric contractions in order to control the load in water and on dry land environments (Carvalho et al. 2010; Kalpakcioglu et al. 2009; Rainoldi et al. 2004a; Veneziano et al. 2006); with regard to MVC, this variable has been poorly researched in order to compare the maximal force production responses between environments (Carvalho et al. 2010; Pöyhönen et al. 1999; Pöyhönen and Avela 2002). Besides, it is important to highlight that the majority studies presented in the literature analyzed just one muscle group from lower or upper limbs during these isometric contractions. Given that the neuromuscular responses of water exercises have been the subject of further investigation and also considering that investigations use MVC performed on land to normalize the EMG signal of exercise protocols carried out in water without knowing whether this normalization is being underestimated (Masumoto et al. 2007a, b, 2008, 2009; Shono et al. 2007), it is of paramount importance to have a better understanding of EMG activity and of force production of different muscle groups in isometric contractions in water and on dry land environments.

Therefore, the aim of the present study was to compare the force of elbow and hip flexor and extensor muscles and the responses of the sEMG signal from *biceps brachii* (BB), *triceps brachii* (TB), *rectus femoris* (RF), and *biceps femoris* (BF) muscles during MVC between water and dry land environments. In addition, the reproducibility of force production and of the sEMG signal during MVC in both environments was assessed. Based on previous studies, it was hypothesized that force production (Pöyhönen et al. 1999) and sEMG signal (Alberton et al. 2008; Rainoldi et al. 2004a; Veneziano et al. 2006) would be similar between environments.

Materials and methods

Subjects

Nine healthy young women agreed to participate in this study (age 22.89 ± 1.76 years, height 163.22 ± 5.80 cm, body mass 56.79 ± 5.27 kg and body fat percentage 26.27 ± 3.43%). All of them participated in water aerobic classes at the School of Physical Education at the Federal University of Rio Grande do Sul for at least 1 year. In addition, the female gender was chosen due to the popularity of this type of exercise in this population. Body mass and height were measured using an Asimed analog scale (resolution of 0.1 kg) and an Asimed stadiometer (resolution of 1 mm), respectively. Body composition was assessed using the skinfold technique. The same technician obtained all anthropometric measurements, on the right side of the subject's body. Skinfold thickness was obtained with a Cescorf skinfold caliper. A seven-site skinfold equation was used to estimate body density (Jackson et al. 1980), and body fat was subsequently calculated using the Siri equation (Heyward and Stolarczyc 1996). Subjects were all physically active and they were free from acute or chronic musculoskeletal disorders. The study was approved by the Research Ethics Committee of the Federal University of Rio Grande do Sul (2007891). Besides, all subjects were informed about the procedures and potential risks and gave their written informed consent to participate in the study.

Experimental procedures

Trials consisted of MVC in water and on dry land. Subjects performed trials in different environments against identical fixed resistance provided by a cage-like structure. Each subject completed all the tests within a single day, and the trials (dry land vs. water) and muscle groups (elbow and hip flexors and extensors) were carried out in random order. Trials consisted of three MVCs of 5 s duration for elbow flexion (EFL) and extension (EEX) and for hip flexion

(HFL), and extension (HEX), with a 3-min interval between each MVC. Verbal encouragement was provided to motivate all subjects to achieve their maximal voluntary contraction levels.

During the trials subjects were sitting with the knee, hip, and elbow at 90º and were bound to a chair using Velcro strips at the hip and trunk. The thigh segment was allowed to rest partially upon a chair, with the distal portion (popliteal fossa) strapped with a non-elastic belt at 90° amplitude. The forearm segment was maintained at elbow flexion 90° with supine radio-ulnar strapped with a handle. To perform the trials in water the subjects were immersed at a height between the shoulder and the xiphoid process. Throughout the experiment, the water temperature was maintained at 31.0 ± 0.1°C and room temperature at 26.6 ± 0.7°C (Evans et al. 1978; Pöyhönen and Avela 2002; Sheldahl et al. 1984).

Measurements

In order to evaluate muscle activities, the sEMG of each muscle was taken using circular, 20-mm-diameter, silver/silver chloride surface electrodes (242, HAL, São Paulo, Brazil) with an inter-electrode distance of 20 mm. Hair was shaved away from the site of electrode placement and the skin was abraded and cleaned with alcohol to keep the inter-electrode resistance low (<3 kΩ). The innervation zone (IZ) was determined by an electrical stimulator (EGF 4030, CARCI), with sliding of an active circumferential electrode (radius of 1 cm) on the muscular surface of the assessed lower and upper limbs. Stimulation was obtained by a faradic current with adjustable exponential pulse between 1 and 10 Hz and duration of 200 ms. Intensity was increased until it reached visible or palpable motor threshold (Dainty and Norman 1987). This electrode placement method, which is widely used nowadays, suggests that the EMG signal be collected with electrodes placed in a midpoint position between the muscle IZ and the distal insertions of the muscle of interest (DeLuca 1997; Rainoldi et al. 2004b). Therefore, the electrodes were placed 2 cm above the IZ, longitudinally to the direction of the muscle fiber of all muscles. The sEMG signals were captured from the following muscles on the right side of the body: short head of BB, lateral head of TB, RF and long head of BF. A reference electrode was placed on the clavicle. Extreme care was necessary to insulate electrodes with transparent waterproof adhesive tape (Tegaderm, 3 M) according to the method described by Figueiredo et al. (2006) (Fig. 1). Silicone glue was placed at the exit point of the cables (dried for approximately 1.5 h) to prevent water from entering. In addition, to prevent the movement of cables from interfering with sEMG signals, these cables were fixed with adhesive tape (Silver Tape, 3 M).

The raw sEMG signal was recorded with a four-channel system (Miotool400, MIOTEC, Porto Alegre, Brazil) at the sampling rate of 2,000 Hz, with a common-mode rejection ratio >110 dB. Force signal was simultaneously measured by a load cell (ZX250, ALFA). This load cell was attached to one extremity by a chain, coupled to the lower or upper part of the cage, and attached to the other extremity, perpendicularly to the body segment by a handle placed on the

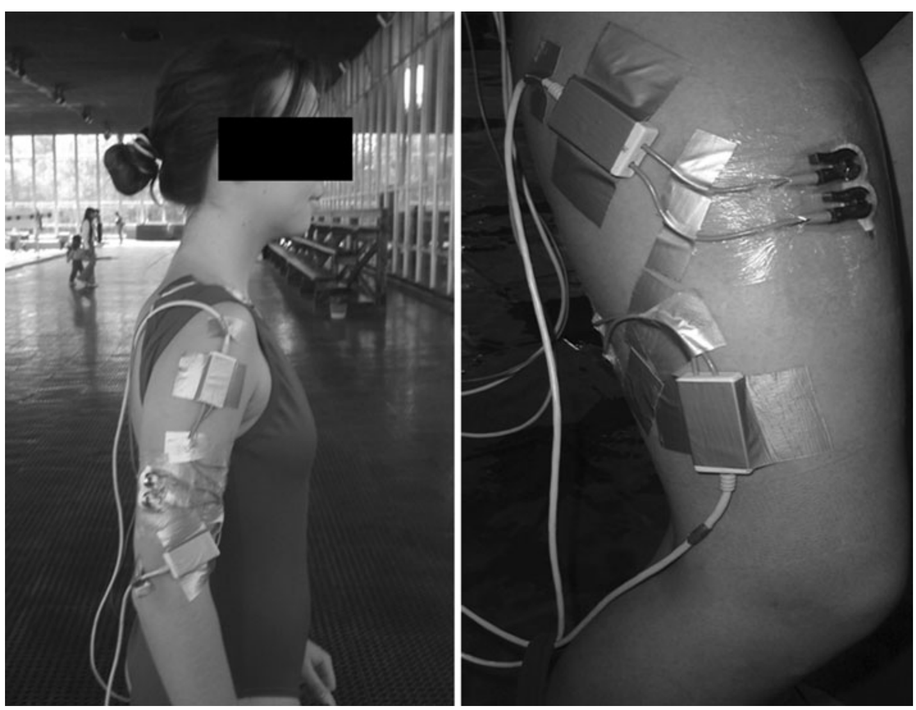

Fig. 1 Electrodes insulated with waterproof transparent adhesive tape

Fig. 2 Load cell placement

thigh or on the forearm segment (Fig. 2). The handle was attached to the thigh segment through a non-elastic belt positioned 3 cm above popliteal fossa. For the forearm segment the handle was attached in the middle of the hand (handgrip). This load cell was treated with waterproofing material. Its nominal capacity amounts to 250 kg and it is made of stainless steel, whose sensitivity is 2 mV/V ± 0.1%, the combined error is smaller than 0.03% and the useful working temperature ranges from −5 to +60°C. The load cell was calibrated prior to data collection and on land, according to the manufacturer's instructions. The force and EMG signals were fed into a computer (Latitude 131L, Dell, Austin, USA) and stored within the Miograph software. Subsequently, data analyses were performed using the SAD32 software. All sEMG data were digitally filtered using a fifth-order Butterworth band-pass filter with cutoff frequencies of 20–500 Hz. The force signal was filtered using a fifth-order Butterworth low-pass filter with a cutoff frequency of 8 Hz (Winter 1990). The higher value obtained between the three MVCs for each muscle group, with steady force production signal during the central 2–4 s was chosen for further analysis (Häkkinen et al. 2003). Slices for force production and sEMG for each muscle were made during the selected period (2–4 s), in order to determine the root mean square (rmsEMG) and average force values.

Statistical analysis

The data are presented as mean ± standard error of the mean (SE). The normality of the data distribution was tested using the Shapiro–Wilk's test. EMG and force comparisons between environments were analyzed by a paired two-tailed Student's *t* test. In addition, the reliability analysis in water and on dry land was determined using the intraclass correlation coefficient (ICC). An alpha level of 0.05 was used for all statistical tests, which were performed using the SPSS software (version 17.0).

Results

The present data showed no significant difference between sEMG and force production during the MVC in water and on dry land ($p > 0.05$), except for HEX ($p = 0.035$) (Tables 1, 2).

Besides, ICC values were significant and ranged from moderate to high for sEMG and force production (Tables 3, 4).

The sEMG and force production data from each subject in water and on dry land are presented in Figs. 3 and 4.

Discussion

The primary results of the present study show that the sEMG signals of the BB, TB, RF, and BF muscles are not

Table 1 Mean (±SE) values of *root mean square* of *biceps brachii* (BB), *triceps brachii* (TB), *rectus femoris* (RF) and *biceps femoris* (BF) muscles while maximal voluntary isometric contraction in water and on dry land

Muscle	Water		Dry land		*p* value
	Mean	SE	Mean	SE	
BB (μV)	445.87	±88.56	400.08	±46.43	0.722
TB (μV)	527.09	±116.51	486.76	±126.79	0.462
RF (μV)	133.16	±23.80	130.00	±26.77	0.761
BF (μV)	126.90	±41.11	122.27	±33.97	0.807

Table 2 Mean (±SE) values of force production of elbow flexors (EFL), elbow extensors (EEX), hip flexors (HFL), and hip extensors (HEX) while maximal voluntary isometric contraction in water and on dry land

	Water		Dry land		*p* value
	Mean	SE	Mean	SE	
EFL (N)	118.48	±12.35	127.30	±10.49	0.374
EEX (N)	93.10	±8.72	92.41	±9.8	0.895
HFL (N)	242.75	±37.63	245.39	±40.98	0.956
HEX (N)	345.84	±28.71	417.28	±20.68	0.035*

* $p < 0.05$

Table 3 Reproducibility of *root mean square* of *biceps brachii* (BB), *triceps brachii* (TB), *rectus femoris* (RF), and *biceps femoris* (BF) muscles while maximal voluntary isometric contraction in water and on dry land demonstrated by intraclass correlation coefficients (ICC)

	ICC	*p* value
BB		
Water	0.69	0.021
Dry land		
TB		
Water	0.91	<0.001
Dry land		
RF		
Water	0.92	0.001
Dry land		
BF		
Water	0.89	0.004
Dry land		

Table 4 Reproducibility of force production of elbow flexors (EFL), elbow extensors (EEX), hip flexors (HFL), and hip extensors (HEX) while maximal voluntary isometric contraction in water and on dry land demonstrated by intraclass correlation coefficients (ICC)

	ICC	*p* value
EFL		
Water	0.66	0.018
Dry land		
EEX		
Water	0.87	0.001
Dry land		
HFL		
Water	0.92	<0.001
Dry land		
HEX		
Water	0.70	0.026
Dry land		

significantly different between water and dry land environments. The same was true for force production, except for HEX, which yielded a higher force on dry land than in water. Moreover, the ICC test values indicate that all variables can be reproducible in both environments.

Some studies showed lower EMG signals in water environment than on dry land during submaximal and maximal isometric contractions (Clarys et al. 1985; Fujisawa et al. 1998; Kalpakcioglu et al. 2009; Pöyhönen et al. 1999; Pöyhönen and Avela 2002). These studies used fine-wire electrodes, waterproof electrodes, or surface electrodes protected by a waterproof film. In order to further look into the possible explanations to this decrease in muscle activity during isometric contractions in water environment, Pöyhönen and Avela (2002) assessed the Achilles and Hoffmann tendon reflexes along with the activity of the *soleus* and *medial gastrocnemius* muscles during MVC performed by six men for ankle plantar flexion in water and dry land environments. This study revealed a 13% reduction in force production during underwater exercises, in addition to a 29–35% decrease in the EMG signal of the investigated muscles collected with surface and fine-wire electrodes. Based on this study, the authors concluded that water immersion hinders neuromuscular function, and the central mechanism is the one that best explains this, because a reduction of Ia afferent activity induced by the pressure receptors through presynaptic inhibition may, in part, be responsible for the decrease in the EMG signal in water. Besides, according to other authors (Clarys et al. 1985; Fujisawa et al. 1998; Kalpakcioglu et al. 2009; Pöyhönen et al. 1999), this reduction in the EMG signal in water environment may be triggered by impairment of the neuromuscular system, which is caused by the decline in individuals' apparent weight and by hydrostatic pressure that acts upon the body during immersion.

On the other hand, some studies conjecture that it is possible to obtain similar EMG signal responses from both environments when some factors are controlled (Alberton et al. 2008; Carvalho et al. 2010; Rainoldi et al. 2004a; Veneziano et al. 2006). The study by Veneziano et al. (2006) makes it clear that water temperature should be controlled and that electrodes should be insulated while obtaining the sEMG signal in water environment. These authors assessed the sEMG signal of the *abductor pollicis brevis* muscle during isometric exercises with 40% of MVC performed by ten men in dry land and water environments, with forearm immersion, and the results indicate no difference in the sEMG signal between environments. Besides, the study developed by Carvalho et al. (2010) demonstrated that when the MVC was performed in water without insulation, the sEMG from BB was lower compared with that performed on dry land with similar responses of force production; on the other hand, when the MVC was performed

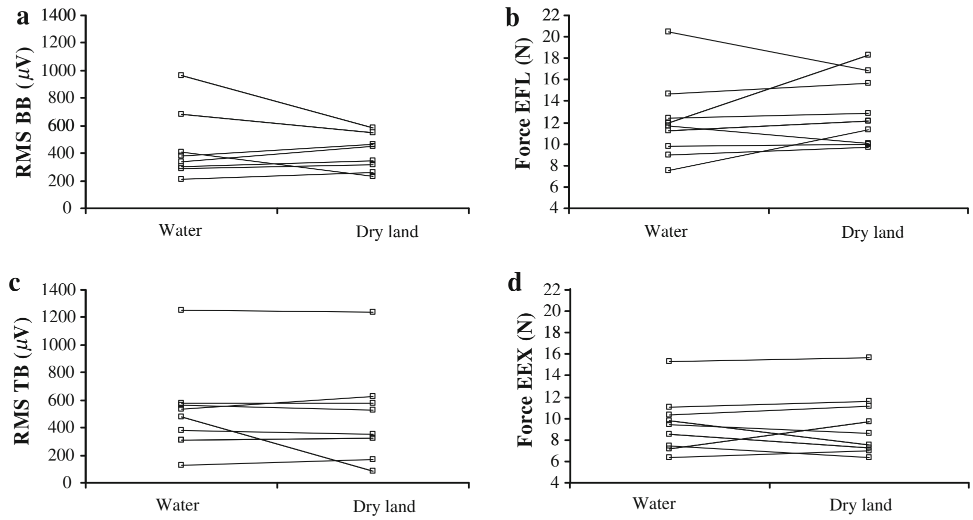

Fig. 3 The sEMG of BB (**a**), force production of EFL (**b**), sEMG of TB (**c**), and force production of EEX (**d**) in water and on dry land from each subject

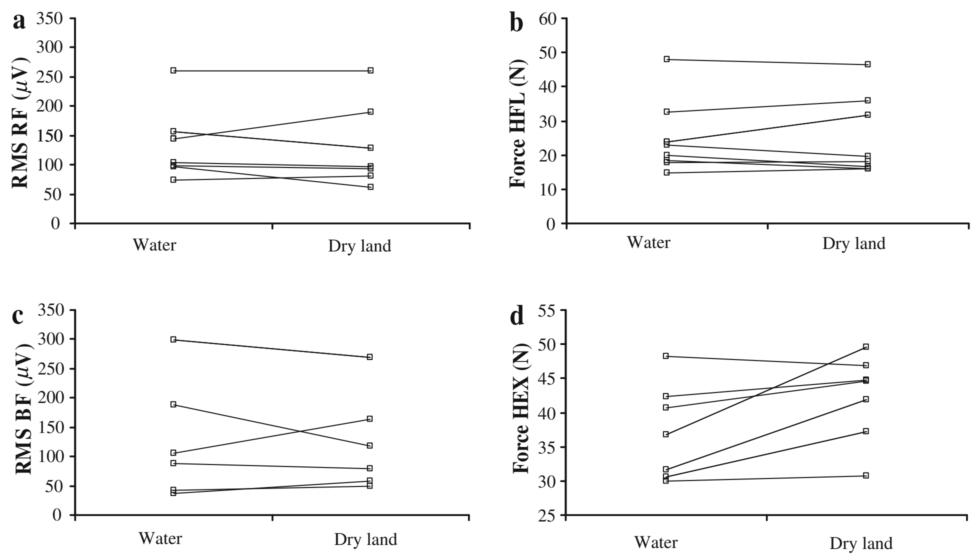

Fig. 4 The sEMG of RF (**a**), force production of HFL (**b**), sEMG of BF (**c**), and force production of HEX (**d**) in water and on dry land from each subject

in water with insulation, both sEMG and force production were similar to those found on dry land environment. Rainoldi et al. (2004a) showed this same pattern at submaximal isometric contractions, which suggests that the electrodes insulation seems an important methodological factor during sEMG collection in water environment. Consequently, sEMG values might be similar between environments when the force production is unchanged in both environments.

As in the present study, by analyzing total body immersion, Alberton et al. (2008) compared the amplitude of the sEMG signal between water and dry land environments during MVC performed by eight women for *vastus lateralis* muscle with insulating electrodes. The results also showed similar sEMG activity responses between environments. However, this study did not measure both the force and sEMG activity. With respect to force production, the present study shows that it did not differ between environments for all muscle groups analyzed, except for HEX. Pöyhönen et al. (1999) observed that, even though the sEMG signal of the *vastus lateralis* and *vastus medialis* muscles was lower in water than on dry land, this does not apply to the force production of knee extensor muscles, as no difference was observed in the force between environments; therefore, this result is in agreement with the findings obtained in the present study.

The fact that the force production of hip extensor muscles is higher on dry land than in water, albeit without any difference in the sEMG signal of the BF muscle between the environments, can be explained by hamstrings (large muscle group) position during MVC, which was performed in the direction of the force of gravity. Thus, on dry land, the individual possibly had a higher force production for this muscle group because contraction was made easier by the force of gravity. Nonetheless, in water environment, the resultant force that acts upon the body-thigh segment is attenuated, since there is also a push force acting in the opposite direction of gravity, so the apparent weight of the thigh segment was likely reduced under this condition, leading to smaller force production compared with the MVC performed on dry land. In addition, the lower rate between force and EMG in water environment (i.e. similar sEMG signal for lower force production) probably occurred by the fact that the subjects' bodies are more unstable in water environment (Devereux et al. 2005; Simmons and Hansen 1996). Since the force production of HEX was lower, the sEMG signal might have presented this same behavior; notwithstanding, it is possible that more muscle fibers were recruited for the stabilization of the subjects' thigh segment in water. Moreover, it could be speculated that the women fat percentage ($26.27 \pm 3.43\%$ in the present study) is another factor that might contribute to body floatability and, consequently, instability in water environment.

Intermuscular coordination is another aspect that may have influenced these results, since the activity of other muscles that perform hip extension and that were not recorded in the present study (i.e. *gluteus maximus*, *semitendinosus* and *semimembranosus*) may have influenced the relation between sEMG and force production by BF. This does not apply, however, to elbow extensor muscles, probably due to the smaller forearm segment mass in relation to the thigh segment. With respect to lift force, it apparently did not have a significant influence on force production of hip and elbow flexor muscles, given that the responses were similar between environments.

In the present study, force was measured together with the sEMG signal during an identical MVC protocol carried out in both environments. Furthermore, water temperature was controlled and surface electrodes were insulated, preventing their contact with water. This way, based on the results, it is possible to obtain similar muscle activity and force production from environments. Likewise, the ICC test for the sEMG signal and for force production yielded significant results, attesting to the reproducibility of measurements between the analyzed environments. These findings allow us to infer that the neuromuscular function of the muscles assessed herein is not affected by water immersion.

The data gathered in the present study are very important because they confirm that investigations about the EMG activity of dynamic exercises in water (Masumoto et al. 2004, 2005, 2007a, b, 2008, 2009; Shono et al. 2007) can use MVC on dry land for normalization, in view of the fact that the sEMG signal exhibits the same pattern and magnitude in both environments at similar force levels.

One of the limitations of the present study is that the sample included only women, since the literature describes that gender may influence EMG responses due to different morphological and physiological characteristics between men and women, especially regarding the higher fat percentage observed in women when compared with men. This higher subcutaneous fat found in women could interfere in the inter-electrode resistance (DeLuca 1997). Another limitation is the contribution of other muscles in the force production during the MVC beyond the investigated ones. Suggestions for future studies include the evaluation of force production and EMG signal from different synergist muscles during maximal and submaximal voluntary isometric contractions by men and women in water and on dry land.

Conclusion

The present study demonstrated that the muscle activities and force production during MVC showed no significant differences between environments. However, for hip extension, the force production demonstrated statistically significant difference between wet and dry conditions. Nevertheless, ICC values for sEMG and force production were moderate to high and significant between environments.

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Conflict of interest We wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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