COMPARISON OF GROUND REACTION FORCES BETWEEN IN-PLACE AND FORWARD WATER RUNNING AT TWO LEVELS OF IMMERSION

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This study compared GRF of in-place and forward water running at two levels of immersion. Twenty healthy subjects executed both exercises at a self selected speed at hip and chest immersion. Variables analyzed were: vertical peak (Fy), anterior peak (Fx anterior) and posterior peak (Fx posterior). Two-factor repeated measures ANOVA was used with $p<0.05$. Although in-place running presented lower values of Fx anterior (0.05 BW at chest and 0.08 BW at hip), both Fx posterior (-0.05 BW at chest and -0.07 BW at hip) and Fy (1.10 BW at chest and 1.29 BW at hip) were greater than forward running (Fx anterior = 0.26 BW and 0.31 BW; Fx posterior = -0.02 BW and -0.03 BW; Fy 0.79 BW and 0.96 BW at chest an hip level respectively). The effect of level of immersion was only significant for Fy and Fx anterior, being greater at hip level.

KEYWORDS: biomechanics, aquatic exercises, hydrogymnastics.

INTRODUCTION: Studies investigating water exercises, such as running and walking, have been conducted in order to analyze biomechanical and physiological variables that could assist on the prescription of these exercises (Alberton et al., 2009; Barbosa et al., 2007; Barela et al., 2006; Haupenthal et al., 2010). The drag force is one of most explored tool when prescribing water exercises. Due to the higher density of the aquatic environment compared to the air, we can modify the resistance of an exercise by changing the projected body area; the bigger the projected area, the higher the resistance provided by water. For this reason, water exercises involving horizontal displacement lead to higher physiological responses than activities conducted on the spot – without a horizontal displacement. While forward running present higher metabolic cost in water than on land, in-place running metabolic cost is lower in water (Alberton et al., 2009).
In relation to biomechanical research, it is not known whether there is a difference in the mechanical load between these two types of exercise. Despite the fact that weight-bearing is facilitated in water due to buoyancy, in-place running and forward running still involves contact forces, thus the components of ground reaction force (GRF) are required for the performance of these exercises. The analysis of GRF during aquatic exercises can quantify the load that the individual must support and, for this reason, can provide useful information to assist practitioners that prescribe exercises in the water environment.
On the basis of these considerations, the aim of this study was to compare GRF during in-place and forward water running at two levels of immersion.

METHODS: Twenty healthy subjects (10 male and 10 female), who were familiar to aquatic exercises, participated in this study. Written consent was obtained from subjects on a consent form previously approved by the Ethical Committee for Research on Humans of the University of The State of Santa Catarina. Mean (SD) age, height, mass and body density were 24.0 (3.0) years, 1.73 (0.08) m, 74.6 (6.8) kg and 1.06 (0.01) g/ml respectively. The sessions were held in the Aquatic Biomechanics Research Laboratory of University of the State of Santa Catarina (UDESC) and at the swimming pool of the Centre of Health and Sports Sciences, UDESC.
In order to collect the vertical and the antero-posterior components of the GRF, a water-proof force plate, which was covered by a non-slip material, was used (dimensions 500 mm X 500 mm X 200 mm, sensitivity of 2 N and error lower than 1%). In addition to the force plate, the acquisition system contained the signal conditioner and A/D convertor ADS2000-IP as well

as the software AqDados 7.02 for signal analysis and editing (Lynx Tecnologia Eletrônica LTDA, São Paulo, SP, Brazil).

After the anthropometrical measurements, the subjects were asked to enter in the pool. The in-place and forward running exercises were demonstrated. In order to familiarise themselves with the equipment, subjects were given a five-minute practice. Both exercises were executed at a self selected speed at two levels of immersion. The two levels chosen were hip level, which corresponded to the subject's iliac crest, and chest level, which corresponded to the subject's xiphoid process. The choice of levels of immersion was made by the researchers according to anatomical points that could be easily identified and are widely used by professionals who prescribe aquatic exercises in their daily work routines (Roesler et al., 2006; Haupenthal et al., 2010).

The in-place running exercise was performed for one minute at each level. Six valid trials of forward running were performed. The trials were considered valid when subjects touched one foot at once to the force plate without looking downwards. The cadence during in-place running was verified through Fast Fourier Transform (FFT) while speed during forward running was measured with a system composed of an electronic synchronized stopwatch and 2 photocell timing lights positioned 2.5 m apart. The order of the immersion levels and exercises were randomly allocated by drawing lots and the participants had an interval of two minutes between each condition.

All curves were exported and analyzed through a processing routine created with the Scilab 4.1.2 software (Institut Nationale de Recherche en Informatique et en Automatique, Ecole Nationale des Ponts et Chauss, France), which consisted of the following phases: (1) application of calibration coefficient and filters (low-pass Butterworth 20 Hz, determined after analyzing the spectral density of the signal strength); (2) normalization by the body weight measured outside the water; (3) selection of each step curve – 6 curves per subject; (4) verification of the vertical (Fy), anterior (Fx anterior) and posterior (Fx posterior) peaks of the GRF. For this study, the peaks were defined as the maximum positive (Fy and Fx anterior) or maximum negative (Fx posterior) value presented by the force component, normalized by body weight, occurring at any period of time from the beginning until the end of the curve; (5) average calculation of 6 step curves per subject for Fy, Fx anterior and Fx posterior.

SPSS software version 17.0 (SPSS Inc., Chicago, IL, USA) was used to analyze the data. Mean and standard deviation were calculated for Fy, Fx posterior and Fx anterior in each analyzed condition. Two factor repeated measures ANOVA was used for the comparison between levels of immersion and exercise type. An alpha level of $p<0.05$ was used for all statistical tests.

RESULTS AND DISCUSSION: Table 1 shows the movement speed during in-place running (in steps/min) and forward running (in m/s) in water.

Table 1
Self-selected speed during in-place running (in steps/min) and forward running (in m/s) at two levels of immersion

Level	Type of Running	
	IN-PLACE (steps/min)	FORWARD (m/s)
Chest	105 ± 12	0.67 ± 0.07
Hip	110 ± 15	0.88 ± 0.10

The analysis of GRF during exercise has been considered important due to the fact that it indicates the stress intensity to which body structures are submitted to, and also provides substantial information in order to identify which movement presents higher impact GRF (Haupenthal et al., 2010; McClay et al., 1994). This study analyzed the GRF during forward and in-place water running at hip and chest levels of immersion. The values of the vertical force peak (Fy), anterior force peak (Fx anterior) and posterior force peak (Fx posterior) are shown on Table 2.

Table 2
Mean and standard deviation of vertical peak force (Fy), posterior peak force (Fx posterior) and anterior peak force (Fx anterior) during the in-place and forward water running at hip and chest levels

Variables	**Level**	**Type of Running** IN-PLACE	FORWARD	***P***
Fy (BW)	Chest	1.10 ± 0.22	0.79 ± 0.24	**< 0.001**
	Hip	1.29 ± 0.24	0.96 ± 0.20	
	P	**< 0.001**		
Fx Anterior (BW)	Chest	0.05 ± 0.02	0.26 ± 0.06	**< 0.001**
	Hip	0.08 ± 0.03	0.31 ± 0.07	
	P	**= 0.001**		
Fx Posterior (BW)	Chest	-0.05 ± 0.03	-0.02 ± 0.02	**< 0.001**
	Hip	-0.07 ± 0.03	-0.03 ± 0.02	
	P	**= 0.182**		

BW = Body weight

No interaction was observed between levels of immersion and exercise type for any of the analyzed variables. Fy and Fx anterior were significantly higher at hip level regardless of the exercise type ($p<0.001$). Higher values at hip immersion were already expected due to buoyancy in water. The buoyancy force resulting from hydrostatic pressure is responsible for one of the advantages of exercising in water, the body weight discharge. This force is directed upward, which directly influences the vertical component of the GRF, and its intensity, according to Archimedes' principle, is equal to the weight of the fluid displaced by the body. This principle highlights the importance of understanding the effects of different depths of immersions when prescribing exercises with loading control.
In-place running presented a higher intensity of Fy compared to forward running at both levels of immersion ($p<0.001$). However, in relation to Fx anterior, the opposite occurred. Higher values of Fx anterior were found during forward running.
Figure 1 illustrates the effect of exercise type on Fy and Fx anterior.

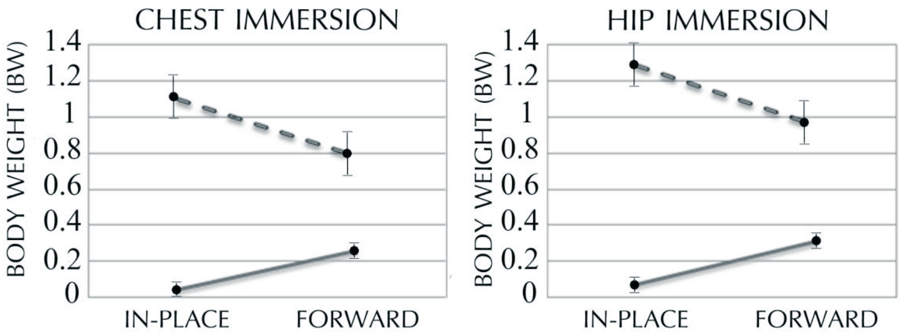

Figure 1: Effect of exercise type (in-place running and forward running) on vertical peak force (dashed line) and anterior peak force (solid line) at chest (left) and hip (right) immersion.

This different effect of exercise type on Fx anterior and Fy can be explained by different intensities of water resistance. During forward locomotion, the individual must overcome a higher water resistance as the projected area is also bigger. Therefore in order to move forward a higher intensity of Fx anterior is needed. Since there is no intention to move forward during in-place running, the intensity of Fx anterior is low and represents only the individual effort to maintain their position and execute the exercise on the spot. The higher values of Fy found during in-place running might have happened because of the greater vertical displacement present during this exercise when compared to forward running. When

prescribing an exercise in water, the practitioner must be aware that in-place exercises might present higher vertical load than exercises with forward displacement.
Regarding Fx posterior, although both exercises presented low intensity values of this component, a significant effect of exercise type was observed, with higher values during in-place running. The lower intensity of Fx posterior during water forward running was observed and explained by Haupenthal et al. (2010). The authors suggested it might occurs because subjects tend to lean their body forward in an effort to gain speed, touching the force plate only when the leg has already passed the longitudinal body axis and thus not presenting a deceleration phase. In contrast to the other variables analyzed, different levels of immersion did not affect the intensity of Fx posterior.
When prescribing an aquatic exercise to a person with load restrictions, it is not only essential that the practitioner is aware of the load intensity during such exercise but also the direction of the load applied. Body tissues are considered anisotropic and, therefore, respond differently to different load directions. As expected, in-place running presented lower values of Fx anterior. However, this exercise presented higher values of Fy and Fx posterior compared to forward running. Furthermore, it can be observed that the mean values of Fy and Fx posterior reported in this study for in-place running immersed to chest level were even higher than forward running at hip level. Therefore, not only the different physiological demand described on literature (Alberton et al., 2009) but also the different mechanical load between this exercises found in this study must be considered when prescribing aquatic exercises.

CONCLUSION: This study analyzed the vertical and antero-posterior components of ground reaction force during in-place running and forward running at two levels of water immersion, hip level and chest level. It was observed that, although in-place running presented lower values of anterior force peak (Fx anterior), both posterior force peak (Fx posterior) and vertical force peak (Fy) were significantly greater during this exercise when compared to forward running. The effect of level of immersion was only significant for Fy and Fx anterior, being greater at hip level. No interaction was observed between level of immersion and exercise type for any of the analyzed variables. Knowing the effect of different kinds of water exercises as well as different levels of immersion on the intensity of GRF components is fundamental for developing a rationale behind prescription. Through a better understanding of the applied biomechanics, the practitioner may structure more appropriate exercise programs.

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