Journal of Science and Medicine in Sport 16 (2013) 348–352

Contents lists available at SciVerse ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Ground reaction forces in shallow water running are affected by immersion level, running speed and gender

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ARTICLE INFO

Article history:
Received 4 April 2012
Received in revised form 25 July 2012
Accepted 17 August 2012

Keywords:
Aquatic exercises
Biomechanics
Hydrotherapy
Kinetics

ABSTRACT

Objectives: To analyze the effect of depth of immersion, running speed and gender on ground reaction forces during water running.
Design: Controlled laboratory study.
Methods: Twenty adults (ten male and ten female) participated by running at two levels of immersion (hip and chest) and two speed conditions (slow and fast). Data were collected using an underwater force platform. The following variables were analyzed: vertical force peak (*Fy*), loading rate (*LR*) and anterior force peak (*Fx anterior*). Three-factor mixed ANOVA was used to analyze data.
Results: Significant effects of immersion level, speed and gender on *Fy* were observed, without interaction between factors. *Fy* was greater when females ran fast at the hip level. There was a significant increase in *LR* with a reduction in the level of immersion regardless of the speed and gender. No effect of speed or gender on *LR* was observed. Regarding *Fx anterior*, significant interaction between speed and immersion level was found: in the slow condition, participants presented greater values at chest immersion, whereas, during the fast running condition, greater values were observed at hip level. The effect of gender was only significant during fast water running, with *Fx anterior* being greater in the men group. Increasing speed raised *Fx anterior* significantly irrespective of the level of immersion and gender.
Conclusions: The magnitude of ground reaction forces during shallow water running are affected by immersion level, running speed and gender and, for this reason, these factors should be taken into account during exercise prescription.

1. Introduction

Water exercises are frequently used for physical conditioning and recovery mainly when a less intense mechanical load is necessary. Besides the elderly and obese populations, which may experience musculoskeletal discomfort after exercising on land, athletes also make use of it for physical conditioning and recovery between two competitive events or during rehabilitation.[1–3] The advantage of the aquatic environment in rehabilitation is that it enables introducing activities at an early stage and, consequently, helps to maximize musculoskeletal function with a smaller risk amount.[1,3,4]

However, to achieve success and establish a progressive loading, it is important to know the load intensity applied to the body. For this reason, the underwater analysis of ground reaction forces (GRF) becomes useful in order to quantify the forces magnitude during different water exercises. When walking in water, the vertical GRF is on average, about 50% and 25% of body weight (BW), respectively, at hip and chest immersion.[5,6] Besides the effect of different immersion levels, previous studies have confirmed the influence of upper limb position – outside and inside water, gait speed and gender.[6,7]

With regard to the running movement, there are only few studies, to our knowledge, that analyzed GRFs.[4,8] In a exploratory research, Haupenthal et al.[4] analyzed twenty healthy adults that ran at a self selected speed immersed to the hip and chest. Although it was expected a significant effect of speed and immersion on vertical and anterior GRFs; only the anterior GRF raised with increasing speed. The authors pointed the lack of speed control as a possible reason for the non-significant difference in anterior and vertical GRFs between hip and chest immersions. Furthermore, no comparisons between men and women were carried out to verify whether gender is a significant factor for loading control during running in water. When running on dry land, females usually present greater intensity of GRFs. This effect has also been reported during other daily dynamic activities, such as walking and jumping; as well as when performing specific sports movements.[9,10]

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1440-2440/$ – see front matter
http://dx.doi.org/10.1016/j.jsams.2012.08.006

Given the growing use of water running,[1,3,11] as well as the limited literature regarding GRFs,[4,8] further investigation would be helpful to guide rehabilitation and training in the water environment. Thus, the present study aims to analyze the effects of immersion level, running speed and gender on the vertical and anterior GRFs during water running. It was hypothesized that immersion level, running speed as well as gender would affect GRFs. Specifically, it was expected that an increase in speed would raise anterior and vertical GRFs, that an increase in the immersion level would decrease vertical GRF and that women would present higher magnitude of GRFs than men.

2. Methods

Participants were selected according to the follow criteria: age (between 18 and 35 years); percentage of body fat (between 12 and 20% for men and 20 and 25% for women); being recreational athletes, active in sports such as swimming, soccer or volleyball; and being familiar with aquatic exercises and able to swim. Individuals were excluded if they had suffered any injury or undergone any surgery in the previous 2 years. Twenty adults (10 male and 10 female) met the inclusion criteria and participated in this study. Written consent was obtained from all participants and the protocol for this study was previously approved by the Ethical Committee for Research on Humans of the University of the State of Santa Catarina, which also provided the Ethical Guidelines followed in this study. Mean (SD) age, height, and body mass for the male participants were 23.0 (3.0) years, 1.78 (0.04) m, and 73.6 (6.1) kg respectively and, for the females, were 23.0 (2.0) years, 1.68 (0.05) m, and 56.6 (3.7) kg.

Vertical and antero-posterior GRF data were collected with a water-proof force plate (dimensions 500 mm × 500 mm × 200 mm, sensitivity of 2 N and error lower than 1%), constructed by Roesler[12] and validated by Roesler and Tamagna.[13] The force plate was placed at the bottom of a heated swimming pool (30 ± 1 °C) in the center of an 8.0 m-long walkway. The data acquisition system also included a signal conditioner and A/D convertor ADS2000-IP as well as signal analysis and editing software AqDados 7.02 (Lynx Tecnologia Eletrônica LTDA, São Paulo, SP, Brazil). The sampling rate was set at 600 Hz.

Anthropometric data from subject were acquired by the same tester as follows: (a) body mass using an electronic scale (Plenna, model MEA-08128, scale of 0.1 kg, São Paulo, Brazil); (b) height using a stadiometer (Sanny American Medical do Brasil LTDA, scale of 0.01 m, São Bernardo do Campo, SP, Brazil); and (c) cutaneous folds using a scientific caliper (CESCORF Equipamentos Antropométricos LTDA, scale of 0.1 mm, Porto Alegre, RS, Brazil). Percentage of body fat was determined through the calculation of participants' body density.[14] For the males, body density was calculated via a regression equation using the sum of the thoracic, abdominal, and thigh skin folds.[15] In women, the regression equation uses the sum of the triceps, supra iliac, and thigh skin folds.[16] Measurements were conducted by one expert tester, according to the parameters of the International Society for the Advancement of Kinanthropometry.[17] The median of three measures for each skin fold was used for calculation.[18]

To familiarize themselves with the equipment and data collection conditions, participants were given 5 min-practice and were then instructed to perform individually the water running, with their arms crossed in front of the chest, at two immersion levels: (a) chest level, which corresponds to the individual's xiphoid process sterni and (b) hip level, which corresponds to the iliac crest. At each of the levels, there were two speed conditions which were determined based on a previous pilot study. With the slow condition, participants were required to run at both immersion levels at a speed of 0.6 m/s, allowing for a variation of 10%. In the fast condition, speed was not the same between levels since it is more difficult to run fast at chest level. Participants were required to run at 0.7 m/s and 0.9 m/s at chest and hip immersion respectively, also allowing for a variation of 10%. Running speed was checked and controlled through a system comprising a chronometer adapted to start and stop in response to signals from photocells.

Using these procedures, subjects did in average nine trials at each analysis condition to produce six valid attempts. An attempt was considered valid when the participant made contact with only 1 foot at a time, reflective of a flight phase (with no double-support phase), with the left foot on the platform and without looking down or changing the rhythm of the movement. All conditions were randomized and a 2-min interval was respected between them.

All GRF data were exported and analyzed through a processing routine (Scilab 4.1.2 software, Institut Nationale de Recherche en Informatique et en Automatique – INRIA): (1) application of calibration coefficient and filters (low-pass Butterworth 20 Hz, determined from 95% of the spectral density of the signal strength); (2) normalization based on the individual's BW as measured outside the water; (3) verification of the peak value for the GRF in the vertical (*Fy*) and antero-posterior (*Fx anterior*) directions. Peak value was defined as the maximum positive value normalized by BW, occurring at any time for each step on the platform; (4) calculation of loading rate (*LR*). The *LR* was calculated from the linear slope of the vertical GRF, from initial contact to the onset of maximum force; and (5) average calculation of the 6 valid trials per participant for *Fy*, *LR* and *Fx anterior*.

SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA) was used to analyze the data. Mean and standard deviation were calculated for *Fy*, *LR* and *Fx anterior* for each running condition. Three 3-factor mixed model ANOVAs were conducted to analyze the effect of gender, immersion level, and speed on *Fy*, *LR* and *Fx anterior* and also to verify the interaction between factors. The within-participants factors were immersion with 2 levels (hip and chest immersion) and speed with 2 levels (slow and fast). The between-participants factor was gender with 2 levels (male and female). Bonferroni post hoc test was used to analyze simple main effects for significant interactions. An alpha level of 5% was used for all statistical tests.

3. Results

The 3-factor mixed ANOVA did not show any statistically significant 3 or 2-way interactions for *Fy* and *LR*. In contrast, for *Fx anterior*, significant 2-way interactions were observed between speed and gender ($p = 0.029$) and between speed and immersion level ($p < 0.001$). Descriptive data for *Fy*, *LR* and *Fx anterior* for each running condition are shown for men and women in Table 1.

Women experienced significantly higher *Fy* than men ($p = 0.014$) and *Fy* was significantly higher as the speed was increased ($p = 0.018$) and the immersion level diminished ($p = 0.003$). *LR* was only affected by different levels of immersion, being greater when participants ran at hip level ($p = 0.019$).

Fx anterior was higher in the fast condition regardless of the immersion used or the participant's gender ($p < 0.001$). The effects of immersion level and gender on *Fx anterior* seem to depend on the speed condition: when running in the slow condition, individuals were exposed to a higher intensity of *Fx anterior* at chest immersion compared to hip immersion ($p = 0.002$) and no significant differences were observed between gender ($p = 0.120$). However, in the fast condition, *Fx anterior* was significantly higher at hip level ($p < 0.001$) and greater in the women group ($p < 0.001$). Fig. 1, based on the LSMeans from the 3-way ANOVA, presents the effect of immersion level and gender on *Fx anterior* for each speed condition, slow and fast.