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GROUND REACTION FORCES DURING STATIONARY RUNNING IN WATER AND ON LAND: EFFECT OF IMMERSION, MOVEMENT CADENCE AND BODY DENSITY

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SUMMARY

We analyzed the peak of the vertical component (Fy_{max}) of the ground reaction forces during stationary running in water and on land. The effects of immersion (no immersion, immersion to the hip, and immersion to the chest), movement cadence (eight sub-maximal cadences) and the effect of body density were analyzed. A predictive model of Fy_{max} was created through multiple regression analysis. The level of immersion, the cadence, and body density had a significant effect on Fy_{max}. Although Fy_{max} values were higher on land regardless of the movement cadence, there was a significant interaction between immersion and cadence. On land (no immersion) Fy_{max} continuously increased with increasing cadence. For hip and chest immersion, Fy_{max} increased up to cadences of 145steps/min and 130steps/min, respectively, and then started to decrease. Decreasing body density was associated with lower values of Fy_{max}. A predictive model was developed for stationary running in water and it explained 69% of the variability in Fy_{max}. The results confirm the intuitive expectation that running in water can be used as an effective way to reduce Fy_{max}. However, there is need to account for the level of immersion, the movement cadence and, to a lesser extent, the body density of subjects.

INTRODUCTION

Water exercises are frequently used for physical conditioning and recovery mainly when a less intense mechanical load is preferred. Besides the elderly and obese populations, which may experience musculoskeletal discomfort after exercising on land, athletes also make use of water exercises for physical conditioning, recovery between events, or during rehabilitation [1,2]. However, to achieve success and provide progressive loading, it is important to know the load intensity applied to the body and, for this reason, the underwater analysis of ground reaction forces (GRF) may play an important role.

Stationary running; which consists of running without changing location, is an exercise frequently used in aerobic classes, track and field, others sports, and in rehabilitation programs. Its use is based on several objectives, such as physical conditioning and coordination training, mainly when a sufficiently large area for running is not available. Because of the common use of stationary running in water and on dry land, this exercise has recently been studied [3,4]. However, these investigations focused only on physiological parameters such as heart rate, rate of perceived exertion, and oxygen uptake and, therefore, there is a lack of biomechanical data regarding the execution of water exercises. Fontana *et* al. [5] analyzed the vertical and antero-posterior peaks of GRF during stationary running on land and in water at three different cadences, 90 steps/min, 110 steps/min and 130 steps/min. Although significant differences in the vertical peak force (Fy_{max}) were found between all three cadences on dry land, no significant differences between 110 and 130 steps/min for the water running were observed. Further investigation is needed in order to better understand this interaction between immersion and cadence. This study was aimed at analyzing the effect of the immersion depth, cadence and body density on Fy_{max} during stationary running

METHODS

Thirty-two healthy subjects (16 M; 16F) participated in this study. Mean (SD) age, height, and mass for the subjects were 25 (4.0) years, 1.72 (0.09) m, and 70.7 (12.7) kg, respectively. $Fy_{max}$was measured for eight cadences and three different immersion conditions - immersed to the chest; immersed to the hip; and no immersion. Cadences ranged from 85 to 190 steps/min for chest immersion, from 100 to 205 steps/min for hip immersion, and from 115 to 210 steps/min for the dry-land condition. Levels of immersion and cadence were presented in a random order and a minimum of 1 min rest was enforced between tests.

Data for the vertical component of the GRFs were collected (1000Hz) with two force plates(dimensions 400 mm X 400 mm X 100 mm, sensitivity of 2 N, 300 Hz of natural frequency and an error of less than 1%). The data acquisition system included a signal conditioner an A/D convertor, ADS2000-IP, and a signal analysis and editing software, AqDados 7.02. Anthropometric data were acquired as follows: (a) body mass; (b) height and (c) subjects' skin folds using a calliper (CESCORF LTDA). For the male subjects, body density was calculated via a regression equation using the sum of the thoracic, abdominal, and thigh skin folds [6]. For women, the sum of the triceps, supra iliac, and thigh skin folds were used [7].

After the anthropometrical data acquisition, the stationary running exercise was demonstrated and subjects performed it first on land and then in water. Subjects were given 5 minutes of practice at each immersion condition and were then instructed to perform the stationary running exercise for 40 seconds. Trials were considered valid when the subjects touched the force platform with only 1 foot at a time (reflective of a flight phase), without looking down, and with constant cadence. Cadence was controlled with a metronome and verified during data analysis. In addition, participants were asked to perform the exercise with a hip flexion of approximately 90 degrees. A practitioner with 5 years of experience in exercise prescription was responsible for ensuring proper running motion.

All GRF data were exported and analyzed using Scilab 4.1.2 software. Data were calibrated and low pass filtered at 20Hz using a recursive Butterworth filter. Data were then normalized to the subject's body weight (BW) measured outside the water. Thirty steps were then selected from each subject for analysis, and the peak vertical GRF identified. Differences in GRF for the three immersion conditions and the different cadences were analysed using SPSS software, version 17.0, with α=0.05. Means and standard deviations were calculated. A predictive model of Fy_{max} was developed using multiple stepwise regression.

RESULTS AND DISCUSSION

The level of water immersion, cadence and body density, had significant effects on Fy_{max} during stationary running. Although Fy_{max} values were higher on land regardless of running cadence, there was a significant interaction between level of immersion and cadence (p = 0,002): on land, Fy_{max} increased with increasing cadence; while for running in water, Fy_{max} increased to a certain point, and then started to decrease with increasing cadence. This threshold cadence was observed at 130 steps/min for immersion to the chest and at 145 steps/min for immersion to the hip (Figure 1).

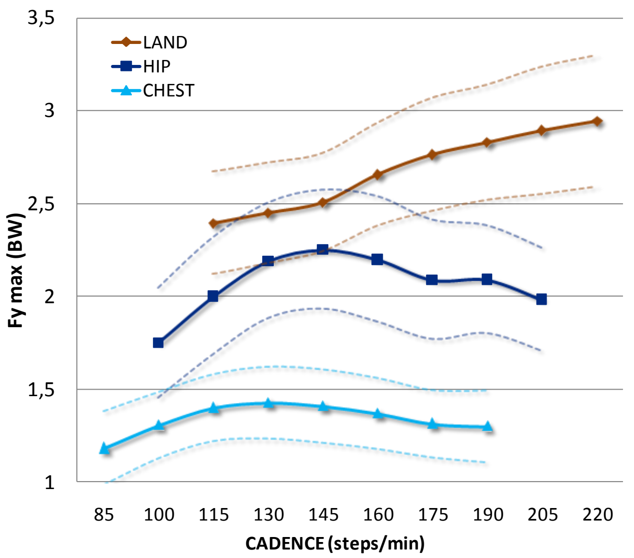

Figure 1: Effect of cadence on peak vertical ground reaction force (Fy_{max}) during stationary running immersed to the hip, chest, and on dry land. Dashed lines indicate ±1SD of the mean.

An initial regression model that was developed for on-land and water stationary running predicted 75% of the variability of Fy_{max} with an RMS error of 0.32 BW.A regression model developed exclusively for water immersion running explained 69% of the variability of Fy_{max} with an RMS error of 0.25 PC(Table 1).

Table 1: Stepwise Regression analysis for predicting $Fy_{max}$from immersion ratio, body density and movement cadence during stationary running in water.

Model-R^2	Variables	B	SE	β
-----------	Constant	0.331	0.747	--------
1° – 0.64	Immersion ratio	- 3.842	0.129	**- 0.784 ***
2° – 0.65	Body density	2.105	0.672	**0.081 ***
3° – 0.66	Cadence	0.021	0.003	**1.610 ***
***4°* – 0.69**	$(Cadence)^2$	-6.96×10^{-5}	<0.001	**-1.545 ***

* p<0.001; Unstandardized (B**)** and standardized coefficients (β)

From Table 1 the following equation evolves: $Fymax = 0{,}331 - 3{,}842 IR + 2{,}105 \times DENS(g/ml) + 0{,}021 CAD(bpm) - 6{,}96 \times 10^{-5} (CAD\ (bpm))^2$. Where IR is the Immersion ratio, which is equal to the depth of immersion (m) divided by the height of the subject (m), and DENS and CAD are body density and running cadence respectively. From **β,** it can be observed that Fy_{max} variability was mainly explained by cadence, followed by the immersion ratio and body density.

Residual analysis indicated that the model was valid since no multi-collinearity between factors and a normal distribution of the standardized residuals were observed. Attention should be given to the data variability, since the model can only predict changes in mean values.

CONCLUSIONS

The results of this study confirm that water running can be used to effectively reduce Fy_{max} during exercise. Fy_{max} can be controlled through the amount of immersion and the running cadence, and the body density of the subject should also be considered. The choice of running cadence to achieve a certain Fy_{max} depends on the immersion level. The presence of a threshold beyond which increasing cadence does not increase Fy_{max} may pose an interesting problem when prescribing stationary running in water.

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