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Full Length Article

Vertical ground reaction force in stationary running in water and on land: A study with a wide range of cadences

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ABSTRACT

Purpose: The aim of this study was to analyze the effect of cadence, immersion level as well as body density on the vertical component (Fy_{max}) of ground reaction force (GRF) during stationary running (SR). *Methods:* In a controlled, laboratory study, thirty-two subjects ran at a wide range of cadences (85–210 steps/min) in water, immersed to the hip and to the chest, and on dry land. $Fy_{max.}$ was verified by a waterproof force measurement system and predicted based on a statistical model including cadence, immersion ratio and body density. *Results:* The effect of cadence was shown to depend on the environment: while Fy_{max} increases linearly with increasing cadence on land; in water, Fy_{max} reaches a plateau at both hip and chest immersions. All factors analyzed, cadence, immersion level and body density affected Fy_{max} significantly, with immersion (aquatic × land environment) showing the greatest effect. In water, different cadences may lead to bigger changes in Fy_{max} than the changes obtained by moving subjects from hip to chest immersion. A regression model able to predict 69% of Fy_{max} variability in water was proposed and validated. *Conclusion:* Cadence, Immersion and body density affect Fy_{max} in a significant and non-independent way. Besides a model of potential use in the prescription of stationary running in water, our analysis provides insights into the different responses of GRF to changes in exercise parameters between land and aquatic environment.

1. Introduction

The prescription of water exercises during musculoskeletal rehabilitation and physical training is based primarily on the premise of a reduction on the mechanical load imposed to body structures when compared to exercises performed on land. In the last decades, numerous studies have focused on the analysis of ground reaction forces (GRF) during different exercises in water, such as walking (Barela, Stolf, & Duarte, 2006; Miyoshi, Shirota, Yamamoto, Nakazawa, & Akai, 2004; Nakasawa, Yano, & Miyashita, 1994), stationary running (Alberton et al., 2013; Alberton, Finatto et al., 2015; Fontana, Ruschel, Haupenthal, Hubert, & Roesler, 2015), forward running (Haupenthal, Ruschel, Hubert, Fontana, & Roesler, 2010b; Haupenthal, Fontana, Ruschel, dos Santos, & Roesler, 2013) and jumping (Colado et al., 2010; Dell'Antonio et al., 2016; Donoghue, Shimojo, & Takagi, 2011; Triplett et al., 2009). Since

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GRFs are closely related to the mechanical loading acting on body structures, knowing its magnitude and its response to modifiable exercise parameters is a key factor in the prescription of water exercises to individuals under loading restrictions.

In the aquatic environment, the main factor causing load relief is buoyancy. According to the Archimedes' principle, buoyancy force intensity is equal to the weight of the fluid displaced by the body during immersion. Water is about 800 times denser than the air (Di Prampero, 1986) and almost as dense as the human body, therefore water immersion can result in a substantial reduction in the "apparent body weight" when compared to dry land (Barela et al., 2006; Harrison & Bulstrode, 1987). Because of the direct relationship between buoyancy force and the volume of liquid displaced by the body with immersion, one of the main parameters that are used to control loading during water exercises is the level of immersion (Fontana et al., 2012; Haupenthal et al., 2013; Orselli & Duarte, 2011; Stuart, Justin Doble, Presson, & Kibiak, 2015).

In addition, similarly to exercising on dry land, the speed/cadence used in water exercises is also a parameter that requires control. Previous studies have shown for different water exercises that an increase in speed results in a significant increase in the vertical component of GRF (Fy_{max}) (Alberton et al., 2013; Chevutschi, Alberty, Lensel, Pardessus, & Thevenon, 2009; Fontana et al., 2012). In the case of forward running in water, this increase in Fy_{max} with increasing speed, seem to not depend on immersion level or on gender (Haupenthal et al., 2013).

A third important factor that may potentially affect the intensity of GRFs during water exercises but has received much less attention is body density. Body density is directly related to the apparent body weight in water (Harrison & Bulstrode, 1987). The lower the body density, the greater the buoyancy and the lower the apparent body weight in water. Obese and over-weight individuals (lower body density), who may feel uncomfortable when exercising on land and to whom water exercises are often recommended (Gappmaier, Lake, Nelson, & Fisher, 2006; Greene et al., 2009; Lee & Oh, 2014), may experience a bigger reduction in GRFs during water exercise than lean subjects.

Stationary running is a common exercise in water – and on land – and has been focus of increasing interest in the literature (Alberton et al., 2011, 2017; Fontana et al., 2012; Fontana et al., 2015; Kutzner et al., 2017). One interesting feature of this exercise is that the movement speed is not as greatly affected by water immersion as in other exercises. While, for example, maximum speed in forward running at chest immersion decreases 70% compared to running on land (Chevutschi et al., 2009), the maximum speed of stationary running at the chest immersion is only 17% lower than on dry land (Fontana et al., 2015). More interestingly, this similarity in maximum cadence between environments, seems to be accompanied by similar levels of muscle activation (rectus femoris, vastus lateralis, biceps femoris) (Alberton et al., 2011; Alberton, Finatto et al., 2015; Alberton, Pinto et al., 2015) and oxygen consumption (Kruel et al., 2013) in stationary running, despite the substantial reduction in GRF when subjects are immersed in water (58%) (Fontana et al., 2015). Concerning stationary running at submaximal cadences, previous studies have shown significant effects of immersion and results that suggest a non-linear effect of cadence on Fy_{max} during stationary running in water: increasing cadence from 90 to 110 steps/min led to an increase in Fy_{max} of 15% at the hip level and 11% at the chest level. In contrast, a further increase from 110 steps/min to 130steps/min did not affect Fy_{max} significantly (Fontana et al., 2012).

Although the main rationale for prescribing water exercises is the reduction in the mechanical loading acting on the individual, systematic analyses of the effect of immersion and a wide range of cadences on GRF during stationary running are scarce. To the best of our knowledge, there is no previous study that tested how well vertical ground reaction forces can be predicted based on cadence, immersion level and body density. Through a statistical model based on the above-introduced factors, one may be able to better understand and control the parameters that influence GRF during stationary running in water.

Therefore, the aims of this study was i) to analyze the vertical component of GRF during stationary running in water and on dry land at a wide range of cadences, and ii) to test how well a statistical model based on cadence, immersion level and body density can predict Fy_{max}. We hypothesized that cadence, immersion and body density affect Fy_{max} in a significant and non-independent way. In general, we expected Fy_{max} to increase with increasing cadence and body density and with decreasing water depth.

2. Methods

2.1. Subjects

Thirty-two healthy subjects (16 male and 16 female) volunteered to take part in the study (25 ± 4 years of age, 1.72 ± 0.09 m of height, 70.7 ± 12.7 kg of body mass and 1.055 ± 0.018 g/ml of body density). Most subjects who participated in the study were graduate and undergraduate students from the Health and Sports Sciences Center of the University where the study was conducted. The study was advertised on campus using posters and word of mouth with messages from the approved subject information sheets. The information given reinforced the fact that subjects with normal and above/below normal BMI were needed.

Subjects were included based on the following criteria: (a) good health status based on confirmed absence of pain, injuries or surgeries in the last two years and (b) swimming ability. All included subjects were active in sports such as swimming, soccer, volleyball and track and field and had previously taken swimming lessons. Informed consent was obtained from all participants, and their rights were protected. To allow for greater inter-individual variability than that permitted in previous studies (Fontana et al., 2012; Haupenthal, Ruschel, Hubert, Fontana, & Roesler, 2010a), no inclusion criteria was drawn with regards to subjects body density.

2.2. Instruments

Data for the vertical component of GRF was collected (1000 Hz) with 2 force plates based on Roesler and Tamagna (1997)