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KINETIC ANALYSIS OF TWO WATER FITNESS EXERCISES:
HORIZONTAL ADDUCTION AND ROCKING HORSE

VOLUME 1

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HORIZONTAL ADDUCTION AND ROCKING HORSE

Dissertation of Master degree in Biokinetics, supervised by Ph.D. Luís Manuel Pinto Lopes Rama and Ph.D. Mário Jorge de Oliveira Costa, submitted to the Faculty of Sport Sciences and Physical Education of the University of Coimbra.

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Abstract

The primary purpose of this work was to examine the strength dynamic approach in two basic water fitness exercises. With this in mind the following aims were considered: (i) assess to the effect of musical cadence in propulsive force production; (ii) assess to the upper-limbs' asymmetry; and (iii) determinate the relative peak of force in water compared to dry-land. Results showed that: (i) the propulsive peak force increase from slower to faster musical cadences; (ii) the horizontal adduction promote higher values of propulsive peak force during an incremental protocol; (iii) the dominant and non-dominant upper-limbs had a similar exertion into the same cadence for both exercises; (iv) the musical cadence of 135 $b \cdot min^{-1}$ seems to promote a symmetric motion during the both exercises; (v) the relative peak of force reached ~68% of the force in dry-land condition; and (vi) a higher variation of the relative peak force was found at lower cadences. The main conclusions were that water fitness exercises elicit different propulsive forces during an incremental protocol, where the cadence of 135 $b \cdot min^{-1}$ seems the most appropriate to maintain the motion pattern without asymmetries for strength development purposes.

Keywords: water exercises; musical cadence; propulsive forces; asymmetries; isometric force.

Resumo

O principal objetivo deste trabalho foi analisar a abordagem dinâmica da força em dois exercícios de hidroginástica. Assim, os seguintes objetivos foram considerados para estudo: (i) avaliar o efeito da cadência musical na produção de força propulsiva; (ii) avaliar as assimetrias nos membros superiores; e (iii) determinar o pico de força relativo em água, comparando com os valores em seco. Os resultados mostram que: (i) o pico de força propulsiva aumenta das cadências mais lentas para as mais rápidas; (ii) a adução horizontal promove valores de força propulsiva mais elevados durante um protocolo incremental; (iii) o membro superior dominante e não dominante obteve uma exercitação similar à mesma cadência em ambos os exercícios; (iv) a cadência musical de 135 $b \cdot min^{-1}$ parece promover um movimento simétrico durante ambos os exercícios; (v) o pico de força relativo atingiu ~68% da força em seco; e (vi) uma maior variação do pico de força relativo foi encontrado em cadências mais lentas. As principais conclusões foram que os exercícios de hidroginástica provocam diferentes valores de forças propulsivas durante um protocolo incremental e a cadência de 135 $b \cdot min^{-1}$ parece ser a mais apropriada para manter o padrão de movimento, sem a presença de assimetrias, no desenvolvimento da força.

Palavras-chave: exercícios de hidroginástica; cadência musical; força propulsiva; força isométrica.

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List of Abbreviations

($b \cdot min^{-1}$) beats per minute

(CFD) computational fluid dynamics

(D) dominant upper-limb

(D_{HA}) dominant upper-limb for horizontal adduction

(D_{RH}) dominant upper-limb for rocking horse

(ES) effect size

(HA) horizontal adduction

(IF_D) isometric peak force of dominant upper-limb

(N) newton

(n) number of subjects

(ND) non-dominant upper-limb

(ND_{HA}) non-dominant upper-limb for horizontal adduction

(ND_{RH}) non-dominant upper-limb for rocking horse

(ΔForce) peak of force variation

(PF) propulsive peak force

(PF_D) propulsive peak force of dominant upper-limb

(PF_{ND}) propulsive peak force of non-dominant upper-limb

(RF_D) relative peak of force for dominant upper-limb

(RH_{add}) rocking horse adduction

(sec) second

(SD) standard deviation

(SI) Symmetric Index

Chapter 1. General Introduction

Aquatic activities related to health, well-being and social issues increase exponentially in the aquatic centres and trigger a diversity of water fitness programs with distinct formats (e.g., deep-water, jogging, circuit and interval training, aquatic cycling, dance-oriented programs). This boost interest is mainly attributed to water properties and the associated potential benefits, already reported in several papers (Barbosa, Garrido, & Bragada, 2007). Most of the previous reports in this domain were focused on acute and chronic physiological adaptations (e.g., Costa, Cruz, Simão, & Barbosa 2019). However, there is a lack of knowledge of the biomechanical effects, namely through the kinetic approach.

The understanding of propulsive forces was already done in other water activities (Havriluk, 2006; Bartolomeu et al., 2018). However, the complexity of aquatic locomotion hampers the assessment of these forces (Morouço, Keskinen, Vilas-Boas, & Fernandes, 2011). Force data can provide insight of critical aspects of the motion, as such: (i) asymmetries' in force production (Morouço, Marinho, Fernandes, & Marques, 2015), between dominant and non-dominant members; (ii) muscular imbalances (Batalha, Marmeleira, Garrido, & Silva, 2015) and; (iii) relative contribution of upper and lower limbs' (Guignard et al., 2019) on the force applied.

Efforts have been made in sports technology (Barbosa, 2018), primarily to provide the real context of practice during the data collection. Measurement of water forces was made through the years using different methods. Havriluk (1988) validated a differential hand pressure sensor that acquires propulsive forces in an ecological validity environment. However, to the best of our knowledge, just a few papers used such apparatus to measure propulsive forces and existing data was obtained using swimmers and clinical population during the water fitness exercises at maximum velocity (Becker & Havriluk, 2006; Prins, Hartung, Merritt, Blancq, & Goobert, 1994).

Water fitness programmes can be applied with different choreographies methods (e.g., pyramid choreography). A great challenge to water fitness professionals is to choose the most effect choreography method to reach a desirable exertion. This implies that participants should be familiarized with music rhythm (Oliveira et al, 2011), also known as “water tempo”. Some research has been produced in order to better understand the effect of musical cadence in physiological and kinematic response during water fitness sessions (Costa et al., 2011; Oliveira et al., 2011; Teixeira et al., 2015) Thus, the increase in musical cadence creates an increase in the physiological response (Barbosa et al., 2010) and the range 125 to 150 b·min^{-1} seems to be the threshold to reach the optimal exertion (AEA, 2008). Another important issue is the structure of the session mainly the exercise characteristics (e.g., the number of limbs in action). However, it seems that no research attempted to understand the contribution of limbs action in water exercises from a kinetic point of view. Therefore, this approach can help water fitness professionals to prescribe and define the most appropriate exercise to obtain a desirable force production according to a specific musical cadence. Besides, this allows the understanding of how different types of water exercises may impose hypothetical asymmetries that can lead to muscle imbalances.

The presented experiments shown in Chapters 3 to 5 were carried out to bridge the gaps in the state of the art (Chapter 2). Furthermore, Chapter 6 and 7 enables to analyse of the overall results (general discussion) and the main conclusions. The suggestions for future research and references from overall chapters are presented in Chapter 8 and Chapter 9, respectively.

Within this rational, the dissertation features three research experiments: (i) assess to the effect of musical cadence in propulsive force production; (ii) assess to the upper-limbs’ asymmetry; and (iii) determinate the relative peak of force in water compared to dry-land.

Chapter 2. State of art

Fluids Mechanics

Human movement constitutes a mechanical (biomechanical) structure, where the intersegmental displacement and whole-body displacements (kinematics), resulting from the relations between force systems (kinetics) of all masses involved. Therefore, human water locomotion could be explained by the laws of physics (Barbosa & Queirós, 2005, p. 9). The clear understanding of how water reacts to the movements and locomotion is essential to maximise the inherent benefits. Water properties related to the physics principles and laws of motion need to be well understood to help instructors to design well-succeeded programs (Torres-Ronda & del Alcázar, 2014).

Water is more than 800 times dense than air (Carr, 2004, p. 117), implying that the resistance to the movement in this environment is higher than in air. Actions in water with lower velocity adopting a streamline position, are subject to laminar flow (Hall, 2012, p.478). In vertical water exercises, the aim is to increase the demand, creating additional drag. Irregular movement generates a turbulent flow with higher velocities compared with the surrounding fluid. The rotation movements' created eddies that increase the resistance. Surface tension is created by the force exerted between the molecules in fluid surface. When considering water activities, the water-air interface is not recommended (Barbosa & Queirós, 2005, p. 133). This characteristic affects the movements with the increasing of the force momentum, which possibility a higher probability to induce some injury (AEA, 2018, p. 111).

Hydrostatic pressure force acts perpendicular to the volume of water displaced due to the immersed surface (Barbosa & Queirós, 2015, p. 9). Pressures' increases with depth and the fluid density (Semat & Katz, 1958, p. 149) that is critical factor while executing head-out water exercise. According to Archimedes' principles, the buoyant force acting on a body is equal to the weight of the fluid displaced by the body. So, buoyant force (F_b) is calculated as the product of the displaced volume (V_d) and the fluids' specific weight (γ): $F_b = V_d\gamma$ (Hall, 2012, p. 479). Many benefits are related to this characteristic such as the decrease of the effect of gravity and the reduce weight bearing or compression of joints, which mean a reduction in the vertical ground reaction force (Nakazawa, Yano, & Miyashita, 1994).

When water surface is at the waist, xiphoid process and the neck level, a decrease of the weight of respectively 50%, 70% and 90% occurs (Koury, 1996 *apud* Barbosa & Queirós, 2015, p. 137). In line of this, Barbosa, Garrido, and Bragada (2007) concluded

that acute physiological adaptations of one head-out water exercise (rocking horse) during immersion up to the hip joint has similar effects to the ones observed in dry-land tasks, leading to incorrect use of the water properties. As known, water fitness exercise needs to be practised on a deeper of corresponding to the water surface at the xiphoid process, or near to that (Kruel, Moraes, Avila, & Sampedro, 2001), to obtain the beneficial effect of hydrostatic pressure. The buoyant and gravity forces influence the balance of the body. The body position is determinate by the localization of the centre of buoyancy and the centre of gravity that usually, are close to each other (Burkett, 2018, p. 148). However, the variation of the position of the centre of gravity in articulated bodies' changes in agreement with the body composition and anthropometric dimensions. So, balance in the aquatics can be classified as stable, unstable or indifferent and will be established when the weight of the liquid displaced equalized the weight of the body (Semat & Katz, 1958, p.165).

Displacement in water condition depends on the interaction of propulsive forces and resistance forces. Three main theories explain the propulsion mechanism, supported by the laws of motion when a body is immersed in a fluid. Hydrodynamic factors can interfere with this force as following: the segmental velocity and the spatial orientation of the motor surfaces, the fingers position and the attack angle of propulsive segments, therefore their importance water fitness exercises (Barbosa et al., 2010). The magnitude of the force applied is directly proportional to the drag it creates. One common example is when considered the hand's position, thus small cross-sectional area (e.g. closed hand) means a decreased in drag force, while when a seashell form is adopted, the magnitude of those variables increase considerably (Barbosa & Queirós, 2015, p. 137).

Methods for propulsive force assessment

Considering the complexity of data collection in sports research (Arellano, Terres-Nicol, & Redondo, 2006; Payton, Baltzopoulos, & Bartlett, 2002), is need to highlight the different methods and apparatus used, mostly in the aquatic environment. Methods to assess propulsive forces based in bi-dimensional and three-dimensional kinematics analysis (Berger Hollander & Groot, 1999), and tethered-swimming with a strain gauge (Dos Santos, Pereira, Papoti, Bento, & Rodacki, 2013) or with a load cell (Mourouço, Keskinen, Vilas-Boas, & Fernandes, 2011), which consist of swimming with a cable attached to waist. Improvements in equipment´s design and data acquisition enable a estimation or quantification of force values using different assessment methodologies namely: (i) inverse dynamics; (ii) computational fluids dynamics (CFD), and; (iii) pressure sensors.

Inverse dynamic enables the determination of forces or momentum developed in a given mechanical system (Loss et al., 2002), based in intersegmental or body human kinematics and inertia properties. The use of the 2nd Newton law ($F = ma$) allows to estimate force values that are responsible for causing the movement (Hall, 2012, p. 63).

CFD methodology, refers to the solution of the problems involved in the flow, using computer-based simulations (Marinho, 2009). The aim of this method is focused on understanding the effects of drag in water movements (Costa et al., 2015). At this point, the existent CFD approaches in water are mostly focused on studying swimmers (Cohen, Clearly, Harrison, Mason, & Pease, 2014).

Sensors (e.g., accelerometer or gyroscopes) are developed to enhance the analysis in the motion from a biomechanical point of view (Pansiot, Lo, & Guang-Zhong, 2010). This analysis conducted in the real context of practices' allows to directly measure the forces that emerge from the environment. To improve the forces estimation or measurements, innovative efforts have been made in technology.

Therefore, pressure sensors have been developed to acquired propulsive forces in upper (Pereira, Schutz, Ruschel, Roesler, & Pereira, 2015; Tsunokawa, Mankyu, Takagi, & Ogita, 2019) and lower limbs' (Bartolomeu et al., 2018). A differential hand pressure in swimming that measures force production during motion (Havriluk, 1988) was validated and used in water activities on rehabilitation (Prins, Hartung, Merritt, Blancq, & Goobert, 1994). Actually, this hydrodynamic measurement system (Aquanex System v.4.2, Swimming Technology Research, USA) and the connected sensors, measure the force values produced by hands, upper or lower limbs', also, when using available equipment (e.g. fins, paddles). Additionally, Aquanex records underwater video or synchronizes underwater video with force data, which allows the synchronization of peak force and mean force with the path of the underwater trajectories.

Force assessment in water activities

Muscle imbalances affects daily routines and performance in sports. Dynamometers' are considered a standard reference to access force parameters (Versijk, Loon, Meijer, & Sacelberg, 2009) and isokinetic equipment's are considered the most effective method to access force production (Stark, Walker, Phillips, Fejer, & Beck, 2011). In-water activities, researchers frequently use dry-land assessment to obtain maximum strength values aiming to understand the acute and chronic strength responses connected to the susceptibility to injury, namely for shoulder complex in swimming (Batalha, Dias, Marinho, & Parraca, 2018).

Water activities can be distinguished considering the plan of motion: (i) horizontal water activities; and (ii) vertical water activities. When the body adopts a horizontal position, as happens in swimming, surf or bodyboarding, or even, underwater hockey, horizontal activities are assumed. The force measurement presents a higher relevance for performance, especially in swimming (Psycharakis, Paradisis, & Zacharogiannis, 2011). Through the use of the Aquanex System, Pereira et al. (2015) studied 14 swimmers to analyse the symmetry of the force applied by the hands swimming the butterfly (three-repetition of 25-m). The authors found significant differences in maximum force (F_{max}, N) between dominant (124.8 ± 39.6 N) and non-dominant (110.7 ± 36.7 N) ($p < 0.01$). In this study the Symmetry Index (SI, %) showed values above 10% to F_{max} (12.6 ± 10.1 %), diagnosing muscular imbalances.

In water fitness, the instructors commonly use the following structure to promote general fitness: (i) warm-up; (ii) cardiorespiratory conditioning; (iii) muscular conditioning; and (iv) stretching/warm-down (Barbosa & Queirós, 2005, p. 157). However, it seems that the standard guidelines for muscular strength prescription (AEA, 2018, p. 8) during water fitness programs are rarely determined in scientific knowledge foundations. Usually, the muscular strength programs in water, are defined similar to dry-land exercises.

Prins et al. (1994) determined the dynamic force production in persons with residual poliomyelitis weakness, through the force measurement by pressure sensors. Fifteen subjects, nine in the experimental group and six of the control group, used Aquanex to determinate the peak force (PF) values. The protocol (pre-test and post-test) consisted of five repetitions at maximal velocity in upper and lower limbs' exercises. Results showed that experimental group improved significantly. Maximum PF in upper limbs' of experimental group was found in left arm at shoulder abduction (59.6 ± 25.4 N) and minimum PF in right arm at shoulder adduction (36.0 ± 20.8 N). According to authors, this preliminary study demonstrated the efficacy of water exercise in improving significantly the dynamic force production in a clinical population.

Nowadays, research in swimming follows a multi-factorial approach to analyse the impact over the performance, where muscular strength influence should not be discarded (Barbosa et al., 2010a). However, common imbalances in swimmers can inhibit performance. Becker and Havriluk (2006) conducting a study with 19 competitive swimmers to understand the bilateral imbalances in swimmers by measured peak hand force (right and left hand) with Aquanex System during horizontal arm abduction and adduction (standing position), and swimming (freestyle and backstroke). Results found that the values were significantly higher ($p < 0.01$) for horizontal arm adduction ($Add_{Rhand} = 79.4 \pm 38.6$; $Add_{Lhand} = 75.7 \pm 34.1$) and in freestyle ($F_{Rhand} = 154.2 \pm 49.6$; $F_{Lhand} = 148.1 \pm 50.4$). The same authors concluded that aquatic exercises may be necessary in swimming training regimen to improve muscular imbalances.

Therefore, programmes can be applied with different choreographies methods, as proposed by Aquatic Exercise Association (2018, pp. 194-196): (i) freestyle choreography; (ii) pyramid choreography; (iii) add-on choreography; (iii) patterned choreography, and; (v) layer technique. To reply some of this choreographies instructors must use a variety of exercises. Sanders (2000) reported six main groups of the water fitness exercises: (i) walking; (ii) running; (iii) rocking; (iv) kicking; (v) jumping; and (vi) scissors. Water fitness exercise should consider the music in order to motivate the participants' (Costa et al., 2011), maintain the synchronization (Barbosa, Marinho, Reis, Silva, & Bragada, 2009) and lead up to a desirable exertion (Barbosa et al., 2010). Musical cadence or “water tempo” are characterized by the countdown of only one beat in every two beats (Kinder & See, 1992) and allows to be synchronized with the specific movement.

Furthermore, to the best our knowledge, the existent studies do not yet: (i) compare the effects of the cadences in the propulsive force applied during water activities; and (ii) analyse the relative peak of force production in water, considering the maximum force (isometric peak force) in dry-land.

Propulsive asymmetries in water activities

Robinson, Herzog and Nigg (1987) proposed one equation to calculate the asymmetries’ as result from ground reaction forces during the gait cycle. Symmetric Index (SI) represents the absolute value between forces produced by dominant and non-dominant member during a continuous movement, and is used in injury prevention assessment and in the analysis of the movement quality.

In swimming the asymmetries in the force application can affect the hydrodynamic position and are direct related to the side dominance, breathing preference or muscle imbalances, that promotes a decrease in swimming efficiency (Sanders, Thow, & Fairweather, 2011). Mourouço, Marinho, Fernandes and Marques (2015) studied the magnitude of upper limb kinetic asymmetries in front crawl at maximal intensity and using tethered swimming. Results showed that asymmetrical force was observed in the majority of the subjects (66,7 %). In this sense, absolute SI was higher than 10% which represents a cut-off to determinate asymmetries (Robinson, Herzog, & Nigg, 1987). Nevertheless, the application of SI to obtain asymmetries during the water exercises seems inexistent.

Chapter 3. The effect of musical cadence in propulsive force during water fitness exercises.

Abstract

The aim of this study was threefold: (i) to compare the dominant and non-dominant upper-limb propulsive force; (ii) to analyse the differences between musical cadences on the same exercise pattern; and (iii) to compare the propulsive forces in two exercises on the same cadence. Thirty-two young healthy subjects (age: 21.66 ± 1.79 years-old, body mass: 69.32 ± 10.88 kg, height: 168.90 ± 9.58 cm) performed two incremental protocols: horizontal adduction (HA) and rocking horse (RH_{add}), with cadences ranging from 105 until 150 $b \cdot min^{-1}$. Aquanex System was used to obtain propulsive forces in upper limbs', especially the propulsive peak force for the dominant (PF_D) and non-dominant (PF_{ND}) upper-limb. No differences between PF_D and PF_{ND} into the same cadence for HA and RH_{add}. Significant differences were found for majority musical cadences in HA and RH_{add} when comparing different cadences. Also, differences were found in lower cadences when considering both exercises into the same cadence. It seems that when increase musical cadence, young health subjects, increase the propulsive peak force and both exercises had a similar exertion during incremental protocols.

Key-words: water exercises; propulsive forces; musical cadence.

Introduction

Improvements in equipment's design and data acquisition enable a sustainable estimation or quantification of force values using different assessment methodologies (e.g., inverse dynamics, computational fluids dynamics or pressure sensors). Sensors (e.g. accelerometer or gyroscopes) are developed to enhance the analysis in the motion from a biomechanical point of view (Pansiot, Lo, & Guang-Zhong, 2010). This analysis conducted in the real context of practices' enables to directly measure the force values of the variables that emerge from the environment. Therefore, pressure sensors have been developed to acquired propulsive forces in upper (Pereira, Schutz, Ruschel, Roesler, & Pereira, 2015; Tsunokawa, Mankyu, Takagi, & Ogita, 2019) and lower limbs' (Bartolomeu et al., 2018). Indeed, a differential hand pressure in swimming that measures propulsive forces was validated (Havriluk, 1988).

In this sense, a feasible way to understand the role of propulsive forces during water fitness exercises is possible by changing the musical cadence. Furthermore, to the best our knowledge, there are no studies comparing the effects of several cadences in propulsive force applied during water fitness exercises.

The aim of this study was threefold: (i) to compare dominant and non-dominant upper-limb propulsive peak force into the same cadence; (ii) to analyse the differences between musical cadences into the same exercise and upper-limb; and (iii) to compare the horizontal adduction and rocking horse into the same cadence. It was hypothesized that propulsive peak force for both upper-limbs´ would increase to follow the musical cadence into the incremental protocol and that values could be higher for dominant upper-limb in HA, when comparing with RH_{add}. However, differences in propulsive peak force between cadences could be more pronounced in the slower cadences and the two exercises can lead to differences between your exertions.

Materials and Methods

Subjects

Thirty-two young healthy subjects, eleven women and twenty-one men (age: 21.66 ± 1.79 years-old, body mass: 69.32 ± 10.88 kg, height: 168.90 ± 9.58 cm), volunteered to participate in this study. The following inclusion criteria were considered: (i) being clinically healthy and physically active; (ii) have at least one year of experience in water fitness programs; (iii) non-pregnant; and (iv) not having muscle-skeletal or neurologic injury, conditions or syndromes diagnosed in the past six months. All participants were informed of the benefits and experimental risks prior to give their written informed consent for the participation (Appendix I). All procedures were in accordance with the Helsinki Declaration in respect to human research and with local ethics board approval (CE/FCDEF-UC/00362019)

Design and procedures

Data collection was held in a 25-m indoor pool (12.5-m width and maximal depth of 1.80-m) with a mean water temperature of 29º C and 73.5% of humidity. Participants were randomly assigned to perform in different days the following water fitness exercises (Figure 1): (a) horizontal upper-limbs adduction (HA); and (b) rocking horse with horizontal upper-limbs adduction (RH_{Add}). The HA is characterized as maintaining a static trunk with lower limbs fixed to the ground (Costa, Cruz, Simão, & Barbosa, 2019) when performing the upper limbs' action. During the motion of the arms, fully extension is required, without any restriction in the range of motion of shoulders at abduction. Both hands positioned at a 90º angle considering the water surface. In RH_{Add} the upper limbs have the same pattern of motion as in HA. Lower limbs actions have a continuous and simultaneous motion with horizontal upper-limbs' adduction and abduction (Barbosa et al., 2010). In every cycle between leaps the same knee flexion was assumed, when the participants' performed arms abduction and the opposite leg did a hyperextension when adduction was reached. The level of water surface was set at near xiphoid process, as recommended by Barbosa, Garrido and Bragada (2007).

Figure 1. The basics water fitness exercises "horizontal adduction" (A) and "rocking horse" (B).

All selected exercises are prescribed on regular basics in water fitness programs. Each exercise was performed over an incremental protocol, with 4 musical cadences, starting at 105 beats per minute ($b\cdot min^{-1}$) and increasing every 30 seconds by 15 $b\cdot min^{-1}$, up to 150 $b\cdot min^{-1}$. The musical cadence was controlled by a metronome (Korg, MA-30, Tokyo, Japan) plugged-in to a sound system and both exercises were performed at “water tempo”. The test was concluded when the participant reduced the range of motion and failed the set cadence or when completed the 30-second (sec) at each cadence.

Measures

Propulsive forces were assessed by a hydrodynamic measurement system previously validated (Havriluk, 1988) with 0.2 % of measurement error. The Aquanex System (v.4.2, Swimming Technology Research, Richmond, VA, USA) is composed by two independent sensors that are positioned between phalanges of middle and ring fingers of both hands and allowed assess to propulsive peak force of dominant (PF_D) and non-dominant (PF_{ND}) upper-limbs in Newton (N). A signal-processor (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA) was used to export data with a 5Hz cut-off low-pass 4th order Butterworth filter upon residual analysis. First positive and negative peak (one cycle) were discarded.

Statistical procedures

Exploratory data analysis was used to identify potentially outliers. Shapiro-Wilk test was used to confirm the normality of distribution ($p > 0.05$). Since the normality failed, non-parametric procedures were adopted. Descriptive statistics (mean, standard deviation and 95% of confidence interval) were calculate for pooled sample. A non-parametric Wilcoxon Signed-Rank Test was used to compare differences in the selected variables and Friedman test was conducted to compare differences between cadences. The level of statistical significance was set at $p \leq 0.05$. Additionally, effect size (ES) was calculated based on Cohen’s *d* (Cohen, 1988) to assess the magnitude of the mean differences between cadences and interpreted according to author’s recommendation: (i) small ($d \geq 0.20$); (ii) moderate ($d \geq 0.50$) and; (iii) large ($d \geq 0.80$).

Results

The overall trend during the water incremental protocol was to observe an increase in the propulsive peak force for the both limbs´, from slower to faster cadences, which can be easily confirmed in Figure 2 and Figure 3.

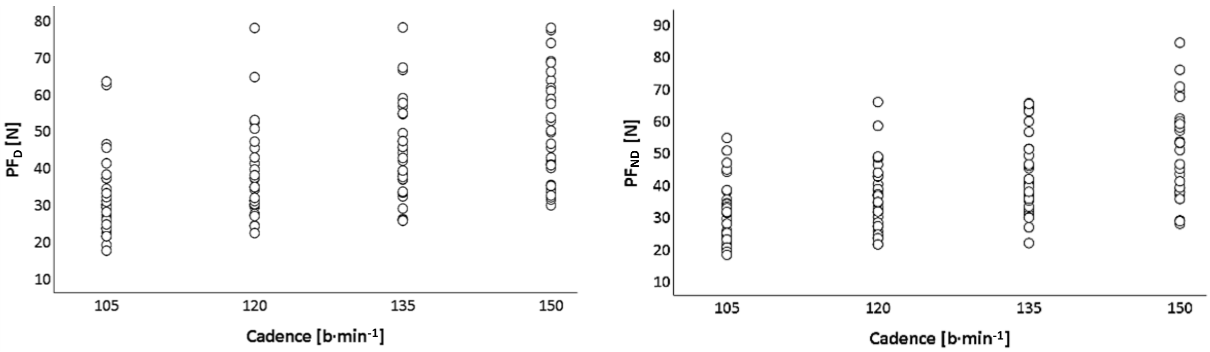

Figure 2. Scattergram for the propulsive peak force of dominant (PF_D) and non-dominant (PF_{ND}) upper-limb in the horizontal adduction performed during the water incremental protocol.

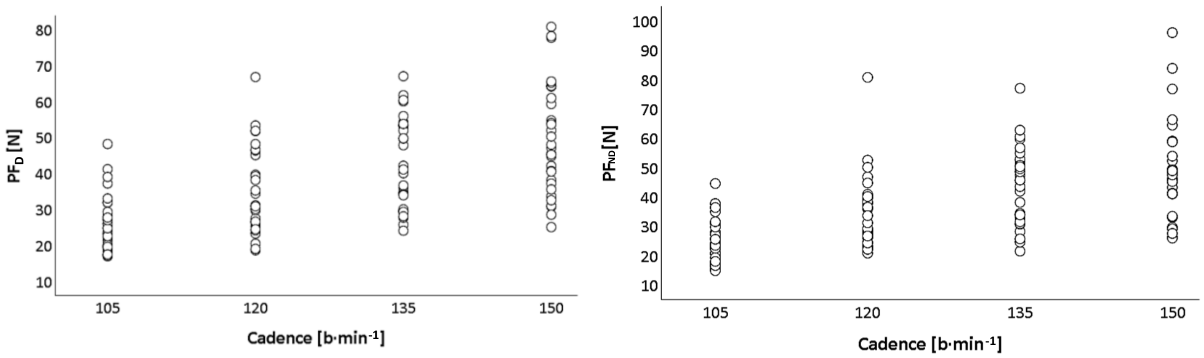

Figure 3. Scattergram for the propulsive peak force of dominant (PF_D) and non-dominant (PF_{ND}) upper-limb in the rocking horse horizontal adduction performed during the water incremental protocol.

Table 1 presents a comparison between propulsive peak force of dominant (PF_D) and non-dominant (PF_{ND}) limb. Larger values were found in HA for PF_D and PF_{ND} when comparing with RH_{add}. There was no differences between PF_D and PF_{ND} into the same cadence for HA and RH_{add}. A small ES was found for all variables.

Table 1. Descriptive statistic (Mean ± SD) for dominant member and non-dominant limb into the same cadence.

Cadence [b·min^{-1}]	Variables	HA Range	HA Mean ± SD	HA p	HA ES	RH$_{add}$ Range	RH$_{add}$ Mean ± SD	RH$_{add}$ p	RH$_{add}$ ES
105	PF$_D$ [N]	17.51 - 63.33	31.44 ± 10.89	0.13	0.11	16.99 - 48.19	25.81 ± 7.60	0.50	0.06
	PF$_{ND}$ [N]	18.14 - 54.55	30.29 ± 9.78			14.84 - 44.54	25.34 ± 7.58		
120	PF$_D$ [N]	22.26 - 77.84	37.20 ± 12.16	0.21	0.09	18.66 - 66.78	34.15 ± 11.72	0.65	0.06
	PF$_{ND}$ [N]	21.38 - 65.77	36.17 ± 10.54			20.80 - 80.71	33.45 ± 12.16		
135	PF$_D$ [N]	25.61 - 77.98	43.32 ± 13.11	0.76	0.00	24.11 - 67.01	42.48 ± 12.50	0.93	0.01
	PF$_{ND}$ [N]	21.81 - 65.42	43.27 ± 12.43			21.48 - 77.01	42.66 ± 13.50		
150	PF$_D$ [N]	29.78 - 77.88	50.03 ± 14.52	0.20	0.08	25.11 - 80.75	49.74 ± 15.09	0.45	0.09
	PF$_{ND}$ [N]	27.81 - 84.24	51.23 ± 14.46			25.92 - 95.97	48.28 ± 16.46		

b·min^{-1}, beats per minute; HA, horizontal adduction; RH$_{add}$, rocking horse adduction; PF$_D$, propulsive peak force of dominant limb; PF$_{ND}$, propulsive peak force of non-dominant limb; N, newton.

Table 2 shows the differences between musical cadences into the same exercise and upper-limb. The trend was to find higher values during the cadences increment from ~31 N (105 b·min^{-1}) to ~51 N (150 b·min^{-1}) in HA and ~25 N (105 b·min^{-1}) to ~48 N (150 b·min^{-1}) for RH$_{add}$. Significant differences were found for HA$_{105\text{-}120}$ (PF$_D$, $p < 0.01$, d = 0.49; PF$_{ND}$, $p = 0.03$, d = 0.57), HA$_{105\text{-}135}$ (PF$_D$, $p < 0.01$, d = 0.97; PF$_{ND}$, $p < 0.01$, d = 1.15), HA$_{105\text{-}150}$ (PF$_D$, $p < 0.01$, d = 1.43; PF$_{ND}$, $p < 0.01$, d = 1.68), HA$_{120\text{-}135}$ (PF$_D$, $p = 0.01$, d = 0.48; PF$_{ND}$, $p < 0.01$, d = 0.61) and HA$_{120\text{-}150}$ (PF$_D$, $p < 0.01$, d = 0.95; PF$_{ND}$, $p < 0.01$, d = 1.18). There was also meaningful differences for PF$_D$ in RH$_{105\text{-}135}$ ($p < 0.01$, d = 1.59), RH$_{105\text{-}150}$ ($p < 0.01$, d = 1.98), RH$_{120\text{-}135}$ ($p = 0.01$, d = 0.68), RH$_{120\text{-}150}$ ($p = 0.01$, d = 1.14) and for PF$_{ND}$ during the RH $_{105\text{-}120}$ ($p = 0.03$, d = 0.79), RH$_{105\text{-}135}$ ($p < 0.01$, d = 1.56), RH$_{105\text{-}150}$ ($p < 0.01$, d = 1.77), RH$_{120\text{-}135}$ ($p < 0.01$, d = 0.71) and RH$_{120\text{-}150}$ ($p < 0.01$, d = 1.01). No differences were found for PF$_D$ and PF$_{ND}$ values in HA$_{135\text{-}150}$ and RH$_{135\text{-}150}$ neither for PF$_D$ in RH$_{105\text{-}120}$.

Table 2. Descriptive statistic (Mean ± SD) for propulsive peak force in two water fitness exercises at different cadences.

Variables	Cadence [b·min^{-1}] 105	120	135	150
HA PF$_D$ [N]	31.44 ± 10.89	37.20 ± 12.16 $^{\alpha,**}$	43.32 ± 13.11 $^{\alpha,**,\ \beta,**}$	50.03 ± 14.52 $^{\alpha,**,\ \beta,**}$
PF$_{ND}$ [N]	30.29 ± 9.78	36.17 ± 10.54 $^{\alpha,*}$	43.27 ± 12.43 $^{\alpha,**,\ \beta,**}$	51.23 ± 14.46 $^{\alpha,**,\ \beta,**}$
RH$_{add}$ PF$_D$ [N]	25.81 ± 7.60	34.15 ± 11.72	42.48 ± 12.50 $^{\alpha,**,\ \beta,**}$	49.74 ± 15.09 $^{\alpha,**,\ \beta,**}$
PF$_{ND}$ [N]	25.34 ± 7.58	33.45 ± 12.16 $^{\alpha,*}$	42.66 ± 13.50 $^{\alpha,**,\ \beta,**}$	48.28 ± 16.46 $^{\alpha,**,\ \beta,**}$

b·min^{-1}, beats per minute; HA, horizontal adduction; RH$_{add}$, rocking horse adduction; PF$_D$, propulsive peak force of dominant limb; PF$_{ND}$, propulsive peak force of non-dominant limb; N, newton; *, $p \leq 0.05$; **, $p \leq 0.01$; $^{\alpha}$, different from 105 b·min^{-1}; $^{\beta}$, different from 120 b·min^{-1}.

Table 3 reports a comparison analysis between HA and RH_{add} into the same musical cadence. Significant differences were found in musical cadence of 105 $b·min^{-1}$ for PF_D and PF_{ND} with a large and moderate ES, respectively. There also significant differences in the cadence of 120 and 135 $b·min^{-1}$ for PF_D and in the 150 $b·min^{-1}$ for PF_{ND}.

Table 3. Descriptive statistic (Mean ± SD) for dominant and non-dominant limb propulsive peak force between two exercises.

Cadence [$b·min^{-1}$]	Variables	HA Range	HA Mean ± SD	RH_{add} Range	RH_{add} Mean ± SD	*p*	ES
105	PF_D [N]	17.51 - 63.33	31.44 ± 10.89	16.99 - 48.19	25.81 ± 7.60	0.00	0.91
	PF_{ND} [N]	18.14 - 54.55	30.29 ± 9.78	14.84 - 44.54	25.34 ± 7.58	0.00	0.56
120	PF_D [N]	22.26 - 77.84	37.20 ± 12.16	18.66 - 66.78	34.15 ± 11.72	0.03	0.25
	PF_{ND} [N]	21.38 - 65.77	36.17 ± 10.54	20.80 - 80.71	33.45 ± 12.16	0.07	0.24
135	PF_D [N]	25.61 - 77.98	43.32 ± 13.11	24.11 - 67.01	42.48 ± 12.50	0.55	0.06
	PF_{ND} [N]	21.81 - 65.42	43.27 ± 12.43	21.48 - 77.01	42.66 ± 13.50	0.80	0.05
150	PF_D [N]	29.78 - 77.88	50.03 ± 14.52	25.11 - 80.75	49.74 ± 15.09	0.79	0.02
	PF_{ND} [N]	27.81 - 84.24	51.23 ± 14.46	25.92 - 95.97	48.28 ± 16.46	0.01	0.19

$b·min^{-1}$, beats per minute; HA, horizontal adduction; RH_{add}, rocking horse adduction; PF_D, propulsive peak force of dominant limb; PF_{ND}, propulsive peak force of non-dominant limb; N, newton.

Discussion

The aim of this study was to analyse the effect of musical cadence in the propulsive force. Results suggested that the both upper-limbs had a similar exertion into the same cadence and both exercises showed different values of propulsive peak force between musical cadences.

Firstly, we tried to clarify how much propulsive force was applied in water fitness exercises. It was observed that young healthy subjects reached values near to 50 N at 150 $b·min^{-1}$. Propulsive forces from upper and lower limbs are, on a regular basis, estimated in swimming as a key-role to enhancing the performance (Lauder, Dabnichki, & Bartlett, 2001) and to prevent injuries (Becker & Havriluk, 2006). A study conducted in front crawl swimming reported values near to 163 N and 122 N for dominant upper and lower limb, respectively (Bartolomeu et al., 2018). While assessing swimmers during the horizontal adduction, Becker and Havriluk (2006) reported values near to 76 N and 80 N for the right and left hand, respectively. However, the role of musical cadence imposes a continuous segmental frequency and velocity, which lead to the same pattern motion during the exertion. Therefore, when the musical cadence increase, the same happens to the limb’s velocity (Costa et al., 2011). In this sense, our results suggests that, the propulsive force increases while following the musical cadence in both HA and $RH_{add.}$ Differences were found between cadences for the majority variables, which mean that the rhythm can be useful to achieve the desired intensity of exertion during for the strength development.

While assessing swimmers during butterfly, Pereira et al. (2015) found significant differences in maximum force (N) between dominant (124.8 ± 39.6 N) and non-dominant (110.7 ± 36.7 N). As expected, there was a trend in our study to obtain higher values in PF_D. However, it seems that both limbs´ do not promoted significant differences in both exercises. This may be explained by the optimal coordination during the exertion, which indicates that hypothetical asymmetries’ may do not exist. Moreover, we were interested in comparing the kinetics between both exercises. The RH_{Add} promote lower propulsive values compared to HA probably due to the imbalances, caused by multiple hops and the range of motion of the knee. For instance, we can have similar exertion pattern when adopted a static position or an imbalance position at higher musical cadences, because the short time contact with the ground can lead to similar propulsive force values.

Conclusion

The dominant member are enable to apply higher propulsive force during an incremental protocol and HA showed higher propulsive values. There are differences in propulsive peak force for the majority of musical cadences and higher cadences promotes a similar exertion pattern between HA and RH_{add}. So, water fitness professionals should pay major attention and prescribe the exercises properly when attempting to develop strength in water.

Chapter 4. Assessment of upper-limbs' symmetry in water fitness exercises

Abstract

This study aimed to assess the upper-limbs´ asymmetry in water fitness exercises and dissecting which body side showed a higher force production along the incremental water protocols. Thirty-two young healthy subjects (aged: 21.66 ± 1.79 years-old, body mass: 69.32 ± 10.88 kg, height: 168.90 ± 9.58 cm) performed the horizontal adduction (HA) and rocking horse (RH_{add}), from musical cadence of 105 until 150 b·min^{-1}. Data acquisition required a differential pressure system that allowed to assess: (a) propulsive peak force of dominant upper-limb (PF_D); and (b) propulsive peak force of non-dominant upper-limb (PF_{ND}). Most actions were asymmetric except for the 135 b·min^{-1} cadence that elicits symmetric motion in both exercises. Faster cadences elicited a larger percentage of the total subjects that applied more propulsive peak force (PF) in dominant upper limb for rocking horse (D_{RH}), while the same pattern was found in lower cadences for dominant upper-limb (D_{HA}). It seems that during HA the D_{HA} generated a greater peak propulsive force value during the cadence of 105 and 120 b·min^{-1}, when comparing with non-dominant upper-limb (ND_{HA}). In RH_{add} the same pattern was found during the cadence of 105 and 135 b·min^{-1}, while ND_{RH} was more recruited during the cadence of 120 b·min^{-1}. In conclusion, the musical cadence of 135 b·min^{-1} seems to elicit a symmetric motion in both exercises.

Keywords: water exercises, propulsive forces, asymmetries, musical cadence.

Introduction

Human bodies are expected to be asymmetrical in nature, as their force production ability. Based on this reasoning, force data acquisition may provide new insights into the critical aspects of motion, such as muscular imbalances (Batalha, Marmeleira, Garrido, & Silva, 2015; Sanders et al., 2012). Muscle imbalances can elapse from asymmetric actions while exercising and increase the susceptibility to injury. The persistence in asymmetric patterns can deteriorate the current status of a given joint, impairing, in some cases, daily life activities. Thus, it is important to analyze how motor behavior or coordination, changes in water fitness sessions, considering different sort of stimuli.

In the past, Robinson, Herzog, and Nigg (1987) designed and proposed a Symmetric Index (SI) to assert the asymmetries that result from ground reaction forces during the gait analysis. Nowadays, in time-based sports, such as running or swimming, the SI is used to demonstrate asymmetric patterns and their relationship with acute or chronic injury (Dos Santos, Pereira, Papoti, Bento, & Rodacki, 2013; Zifchock, Davis, & Hamill, 2006). In swimming, the force application asymmetries could affect hydrodynamic position and are direct related with body side dominance, breathing preference or muscle imbalances, that promotes a decrease in swimming efficiency (Sanders, Thow, & Fairweather, 2011).

Using the Aquanex System, Pereira, Schutz, Ruschel, Roesler, and Pereira (2015) studied 14 swimmers in an attempt to characterize force symmetry. The force applied by the hands during the butterfly stroke showed values higher than 10% for symmetry index (12.6 ± 10.1 %), diagnosing muscular imbalances. In the same domain, while testing swimmers, Morouço, Marinho, Fernandes, and Marques (2015) showed that the majority of the subjects (66.7%) had an asymmetrical force production. To the best of our knowledge, this kind of study was never done in water fitness exercises. This approach will help water fitness professionals to prescribe and define the most appropriate musical cadence to achieve a desire strain effect.

The aim of this study was to assess the upper-limbs´ asymmetry in water fitness exercises and dissecting which body side showed a higher propulsive force production along the incremental water protocols. It was hypothesized that the increase of propulsive peak force at higher cadences will promote an asymmetrical movement and the dominant upper-limb can produce a higher propulsive force during an incremental protocol.

Materials and Methods

Subjects

Thirty-two young healthy subjects, eleven women and twenty-one men (age: 21.66 ± 1.79 years-old, body mass: 69.32 ± 10.88 kg, height: 168.90 ± 9.58 cm), volunteered to participate in this study. The following inclusion criteria were considered: (i) being clinically healthy and physically active; (ii) have at least one year of experience in water fitness programs; (iii) non-pregnant and; (iv) not having muscle-skeletal or neurologic injury, conditions or syndromes diagnosed in the past six months. All participants were informed of the benefits and experimental risks prior to give their written informed consent for the participation (Appendix I). All procedures were in accordance with the Helsinki Declaration in respect to human research and with local ethics board approval (CE/FCDEF-UC/00362019).

Design and procedures

The experimental study was held in a 25-m indoor pool (12.5-m width and maximal depth of 1.80-m) with a mean water temperature of 29º C and 73.5% of humidity. Participants were randomly assigned to perform in different days the following water fitness exercises: (a) horizontal upper-limbs adduction (HA); and (b) rocking horse with horizontal upper-limbs adduction (RH_{Add}). The HA is characterized as maintaining a static trunk with lower limbs fixed to the ground (Costa, Cruz, Simão, & Barbosa, 2019) when performing the upper limbs' action. During the motion of the arms, fully extension is required, without any restriction in the range of motion of shoulders at abduction. Both hands positioned at a 90º angle considering the water surface. In RH_{Add} the upper limbs have the same pattern of motion as in HA. Lower limbs actions have a continuous and simultaneous motion with horizontal upper-limbs' adduction and abduction (Barbosa et al., 2010). In every cycle between leaps the same knee flexion was assumed, when the participants' performed arms abduction and the opposite leg did a hyperextension when adduction was reached. The level of water surface was set at near xiphoid process, as recommended by Barbosa, Garrido and Bragada (2007).

All selected exercises are prescribed on regular basics in water fitness programs. Each exercise was performed over an incremental protocol, with 4 musical cadences, starting at 105 beats per minute ($b \cdot min^{-1}$) and increasing every 30 seconds by 15 $b \cdot min^{-1}$, up to 150 $b \cdot min^{-1}$. The musical cadence was controlled by a metronome (Korg, MA-30, Tokyo, Japan) plugged-in to a sound system and both exercises were performed at "water tempo". Verbal and visual feedbacks were gave during every cadences. The test was concluded when the participant reduced the range of motion and failed the set cadence or when completed the 30-second (sec) at each cadence.

Measures

Propulsive forces were assessed by a hydrodynamic measurement system previously validated (Havriluk, 1988) with 0.2 % of measurement error (Aquanex System v.4.2, Swimming Technology Research, Richmond, VA, USA). The system is composed by two independent sensors that are positioned between phalanges of middle and ring fingers of both hands and allowed assess to peak force of dominant (PF_D) and non-dominant (PF_{ND}) upper-limbs in Newton (N). A signal-processor (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA) was used to export data with a 5Hz cut-off low-pass 4th order Butterworth filter upon residual analysis. First positive and negative peak (one cycle) were discarded. Symmetric Index (SI, %) was estimated according to that proposed by Robinson, Herzog and Nigg (1987).

$$\mathrm{SI}\ (\%) = \frac{2(x_d - x_{nd})}{(x_d + x_{nd})} \times 100 \qquad (1)$$

Where:

x_d represents the force produced by dominant upper-limb;

x_{nd} represents the force produced by non-dominant upper-limb.

Symmetry data was interpreted as suggested by the same authors, where: if SI = 0 %, perfect symmetry; if 0 % > SI < 10%, symmetric motion; and if SI ≥ 10%, asymmetric motion. Thus, positive values in SI indicates that more force is being generated by the dominant upper-limb (D) and negative values show that greater force production is done by the non-dominant upper-limb (ND).

Statistical procedures

Exploratory data analysis was used to identify potentially outliers. Descriptive statistics (mean and standard deviation) were calculate for total sample.

Results

Figure 1 depicts a typical propulsive force curve between dominant and non-dominant upper-limb force in HA, during the incremental protocol. Overall trend was to an increase in the absolute propulsive peak force from slower to faster cadences. Hypothetical upper-limbs asymmetries can be easily observed in each cycle into the same cadence.

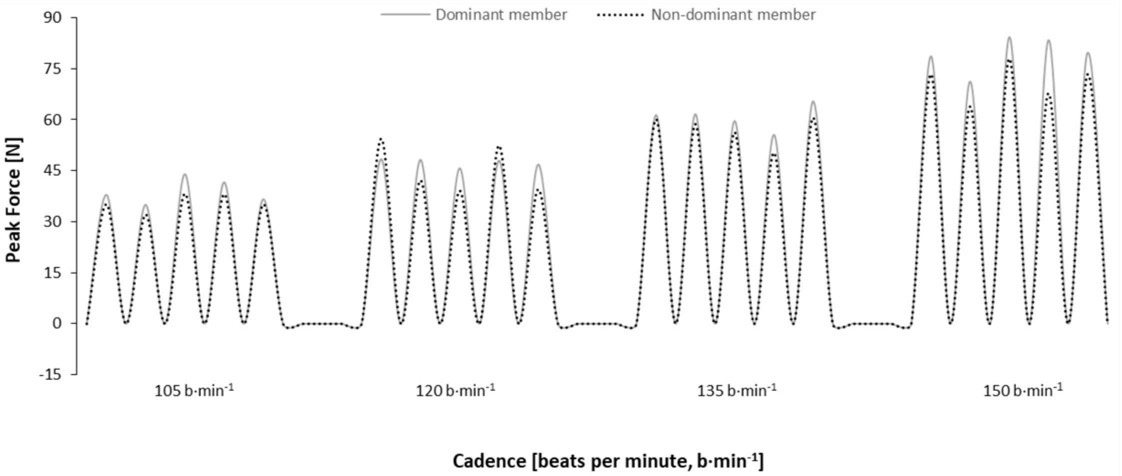

Figure 1. Example of the peak propulsive force between the dominant (solid line) and non-dominant upper-limb (dashed line) during horizontal adduction (HA) in incremental protocol.

Table 1 reports the symmetric index (SI, %) for HA and RH_{add}. A symmetric motion was found for the HA at musical cadence 105, 120 and 135 $b \cdot min^{-1}$. However, RH_{add} elicited an asymmetric motion at majority of the cadences, except for the 135 $b \cdot min^{-1}$.

Table 1. Descriptive statistic (Mean ± SD) for the Symmetric Index (SI).

		HA	**RH_{add}**
Cadence [$b \cdot min^{-1}$]	Variable	Mean ± SD	Mean ± SD
105	SI [%]	10.94 ± 7.43 (a)	12.76 ± 9.91 (b)
120	SI [%]	10.77 ± 7.54 (a)	14.84 ± 9.15 (b)
135	SI [%]	9.57 ± 5.50 (a)	10.63 ± 7.99 (a)
150	SI [%]	11.95 ± 7.44 (b)	14.64 ± 10.54 (b)

$b \cdot min^{-1}$, beats per minute; SD, standard deviation; SI, symmetric index; (a), symmetric motion; (b), asymmetric motion.

Figure 2 presents the positive and negative SI according to the each cadence and the total sample (n = 32). The HA dominant upper-limb (D_{HA}) was the largest at 105 (68.75 %) and 120 b·min^{-1} (59.38 %). At 135 and 150 b·min^{-1} the trend was for a similar amount of force for both sides (D_{HA} - 50 %; ND_{HA} - 50 %). The RH_{add} had a greater PF applied in D_{RH} at 105 (56.25 %), 135 (59.38 %) and 150 b·min^{-1} (53.13 %), whereas 120 b·min^{-1} seems recruited more the ND_{RH} (56.25 %).

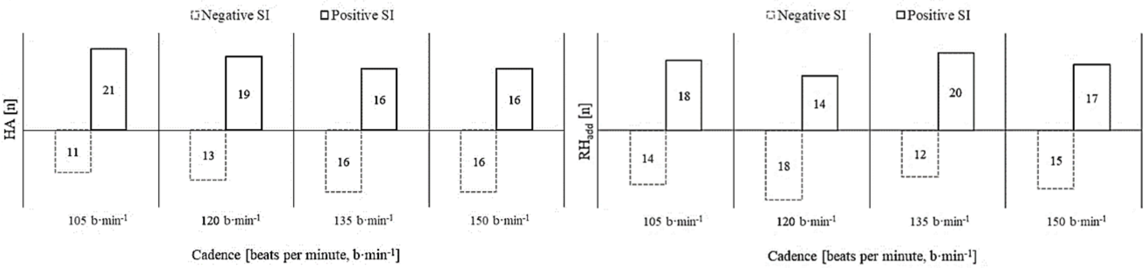

Figure 2. Positive (D, solid line) and negative (ND, dashed line) symmetric index (SI) during horizontal adduction (HA) and rocking horse in incremental protocol.

Discussion

The aim of this study was to assess the symmetry and analyze which lateral side showed higher force production during the horizontal adduction and rocking horse in an incremental protocol. The main findings were that the cadence of 135 b·min^{-1} elicited a more symmetric action and the propulsive force applied according the dominant and non-dominant upper-limb demonstrated a different pattern between the two exercises.

The lateralization phenomenon that characterizes symmetry can be established early in human life (Carpes, Mota, & Faria, 2010). Within this rational, the body side choice plays an important role when asymmetries' arise in any type of motion. Many factors can explain this phenomenon, as reported by Sanders, Thow, and Fairweather (2011): (i) bilateral imbalances; (ii) antero-posterior imbalances and; (iii) deficits in strength. In-water activities, the action of the upper-limbs has been considered as the main responsible for locomotion (Dos Santos et al., 2013). Likewise, the adduction and abduction of upper-limbs can reach a higher range of motion (Costa et al., 2011), especially when all (four) limbs are in action. The current study aimed to quantify the asymmetries' imposed by the incremental protocol. Our results showed a trend for a more asymmetric pattern on the RH_{add} than on HA in the most cadences. Requiring an alternative segmental action, RA_{add} claim some optimal level of coordination between upper and lower limbs. When analyzing the kinematics of "side kick", Oliveira et al. (2011) reported a reduced displacement of the center of mass in the vertical axis to follow the higher musical cadences. Exercises that require an imbalance position like jumping's at lower cadences will necessary require more time to return to the ground contact. This may be the main reason for RH_{add} had reach only the symmetric motion at 135 b·min^{-1}. Nonetheless, both exercises elicited an asymmetric motion at 150 b·min^{-1}. Probably, three factors can help explaining such phenomenon: (i) the motor control decrease during the action of limbs to reach the cadence; (ii) the exhaustion/fatigue by the higher intensity of exertion and; (iii) hypothetical decrease in elbow range of motion. Moreover, we were interested in examining the role of the dominant and non-dominant upper-limb along an incremental protocol. The results showed that in HA a larger percentage of the total subjects applied higher values of PF_D and in RH_{add} the same trend was found during the faster cadences. This suggest that the motor control function is constantly changed by the effect of the musical cadence. Indeed, our results suggest that musical cadence of 135 b·min^{-1} is appropriated to minimize the asymmetries' during the water fitness exercises execution while working strength.

Some additional limitation can be addressed to our research: (i) the uncontrolled effect of range motion (i.e., kinematic analysis); and (ii) the use of young, healthy adults as subjects in one activity that is primarily chosen by other cohorts (e.g., older adults or those with disabilities)

Conclusion

The musical cadence of 135 b·min^{-1} seems to elicit the optimal symmetry without compromising the motion pattern in both exercises, Thus water fitness professionals should consider this behaviour as a key to plan and prescribe programs for the strength development.

Chapter 5. Water and dry-land peak force during water fitness exercises

Abstract

The evaluation of propulsive forces in water allows the selection of the most appropriate strategies to develop strength during water fitness sessions. The aim of this study was to analyze the relative peak of force produced and the peak of force variation in two water fitness exercises. Twenty-two young healthy subjects (age: 21.23 ± 1.51 years-old, body mass: 67.04 ± 9.31 kg, height: 166.36 ± 8.01 cm) performed incremental protocols of horizontal adduction (HA) and rocking horse (RH_{add}), from 105 until 150 b·min^{-1}. Data acquisition required an isokinetic dynamometer and a differential pressure system that allowed to assess: (a) isometric peak force of dominant upper-limb (IPF_D); and (b) propulsive peak force of dominant upper-limb (PF_D). Significant differences were found in relative peak force of dominant upper-limb (RF_D) between the majority cadences in both exercises. The RF_D reached ~68% of the maximal isometric force observed in the land condition. In conclusion, an incremental protocol promotes an increase in the propulsive peak force and in the relative peak of force on upper-limbs.

Keywords: water exercise; propulsive force; isometric force; musical cadence.

Introduction

Aquatic activities related to the promotion of health and well-being, increased remarkably in popularity in the past decades. There is a wide variety of water programs focusing on fitness (Neiva, Faíl, Izquierdo, Marques, & Marinho, 2018), performance (Robinson, Devor, & Buckworth, 2004), rehabilitation (Yázigi et al., 2013), and therapy (Marinho-Buzelli, Bonnyman, & Verrier, 2015). The increasing interest is attributed to the potential benefits of water programs, as reported in the literature (e.g., Barbosa, Garrido, & Bragada, 2007). Other potential benefits mentioned include (i) the reduced effect of body weight; (ii) the reduced impact in specific joints (e.g., a decreased ground reaction force); (iii) the reduced muscle pain; (iv) an improved blood flow due to hydrostatic pressure; (v) a three-dimensional body motion and; and (vi) higher social development and commitment. Previous reports focused on acute and chronic physiological adaptations (e.g., Costa, Gonçalves, Marinho, Silva, & Barbosa, 2014). However, there is a lack of knowledge on the biomechanical changes, such as the impact on the kinetics.

Several attempts to the measure of water forces, were made through the years. However, pressure sensors seem to be the most suitable instrument, allowing free motion during testing without constraints. Those differential pressure sensors were validated (e.g., Havriluk, 1988) and allow for the measurement of forces produce during propulsive actions in an ecological validity environment. There is little data on this topic, and the existing body of knowledge is based on evidence gathered in competitive swimmers and patients (e.g., Becker & Havriluk, 2006). Prins, Hartung, Merritt, Blancq, and Goobert (2006) noted, in clinical population (poliomyelitis disability), peak force values near to 45 and 60 N for the right and left hand, respectively, during horizontal arms adduction at maximum velocity

Muscle imbalances are commonly reported as a deficit that affects daily routines and sport performance (e.g., Batalha, Raimundo, Tomas-Carus, Barbosa, & Silva, 2013). Tests to obtain maximum isometric strength are useful to assess the strength potential and to prevent injuries during in-water activities. Researchers frequently use dry-land assessment to avoid acute and chronic strength responses linked to the susceptibility to injury (Batalha, Marmeleira, Garrido, & Silva, 2015). The evaluation in-water and in dry-land it will allows the selection of the most appropriate strategies to develop strength during water fitness sessions. For instance, water fitness professionals must know the maximal force their clients are practicing on water.

The aim of this study was twofold: (i) to analyze the peak of force production of the dominant upper-limb in water compared to dry-land data; and (ii) to analyze the behavior of force production during the incremental protocol. It was hypothesized that the peak of force production would increase to follow the musical cadence and that values could be above 50%, considering dry-land data.

Materials and Methods

Subjects

Twenty-two young healthy subjects, nine women and thirteen men, volunteered to participate in this study. The characteristics of the participants are presented in Table 1. The following inclusion criteria were considered: (i) being clinically healthy and physically active; (ii) have at least one year of experience in water fitness programs; (iii) non-pregnant; and (iv) not having muscle-skeletal or neurologic injury, conditions or syndromes diagnosed in the past six months. All participants were informed of the benefits and experimental risks prior to give their written informed consent for the participation (Appendix I). All procedures were in accordance with the Oviedo Convention and Helsinki Declaration in respect to human research, and with local ethics board approval (CE/FCDEF-UC/00362019).

Table 1. Descriptive statistic (Mean ± SD) for the characteristics of the participants.

	n = 22	
Variable	Range	Mean ± SD
Age [yr]	19 – 26.0	21.23 ± 1.51
Body mass [kg]	49.9 – 81.3	67.04 ± 9.31
Body height [cm]	150.0 – 181.2	166.36 ± 8.01
BMI [kg/m^2]	18.5 – 28.3	24.19 ± 8.12
Hand length (cm)	17.5 – 21.0	19.16 ± 1.10
Biacromial diameter (cm)	34.7 – 43.8	38.38 ± 2.43
Upper-limb volume [L]	1.39 – 2.54	1.94 ± 0.37

yr, years-old; kg; kilogram; cm, centimetre; BMI, body mass index; kg/m^2, kilogram per square meter; L, litre.

Design and procedures

A cross-sectional design was selected for this study with two different approaches. In-water data collection was held in a 25-m indoor pool (12.5-m width and maximal depth of 1.80-m) with a mean water temperature of 29º C and 73.5% of humidity. Participants were randomly assigned to perform in different days, the following water fitness exercises: (a) horizontal upper-limbs adduction (HA); and (b) rocking horse with horizontal upper-limbs adduction (RH_{Add}). The HA is characterized as maintaining a static trunk with lower limbs fixed to the ground (Costa, Cruz, Simão, & Barbosa, 2019) when performing the upper limbs' action. During the motion of the arms, fully extension is required, without any restriction in the range of motion of shoulders at abduction. Both hands positioned at a 90º angle considering the water surface. In RH_{Add} the upper limbs have the same pattern of motion as in HA. Lower limbs actions have a continuous and simultaneous motion with horizontal upper-limbs' adduction and abduction (Barbosa et al., 2010). In every cycle between leaps the same knee flexion was assumed, when the participants' performed arms abduction and the opposite leg did a hyperextension when adduction was reached. The level of water surface was set at near xiphoid process, as recommended by Barbosa, Garrido, and Bragada (2007).

All selected exercises are prescribed as regular basic exercises in water fitness programs. Each exercise was performed over an incremental protocol, with 4 musical cadences, starting at 105 beats per minute ($b \cdot min^{-1}$) and increasing every 30 seconds by 15 $b \cdot min^{-1}$, up to 150 $b \cdot min^{-1}$. The musical cadence was controlled by a metronome (Korg, MA-30, Tokyo, Japan) that was plugged in to a sound system, and both exercises were performed at "water tempo", permitting the music to be synchronized with the specific movement. Verbal and visual feedback was given during every cadence. The test was concluded when the participant reduced the range of motion and failed the set cadence or when the participant completed the 30 seconds at each cadence.

Dry-land data were conducted to analyze isometric peak of force, using an isokinetic dynamometer (Biodex Multi-Joint System 3 Pro, Shirley, NY, USA). Two groups performed a 3-minute warm-up on a stable upper-body ergometer (Monark 891E, Vansbro, Sweden). Cadence was set between 70 and 80 revolutions per minute. A 2-repetition trial was conducted before each test for familiarization purposes (Meeteren, Roebroeck, & Stam, 2002). Immediately, a 3-repetition protocol with dominant the upper-limb in adduction at 45° was performed during 6 seconds (sec) of maximal isometric force and the 15 sec interval between sets (Harbo, Brincks, & Andersen, 2012). Isometric peak force of dominant member (IF_D) was considered at the best repetition and expressed in Newton (N).

Anthropometric assessment

Anthropometric assessment was conducted by one trained researcher following standard procedures (Lohman et al., 1988). Height and body mass were measured using a Harpenden stadiometer (model 98.603, Holtain Ltd., Crosswell, UK) and a SECA scale (model 770, Hanover, USA), respectively. Dominant upper-limb volume was estimated as proposed by Rogowski, Ducher, Brousseau, and Hautier (2008).

Propulsive forces assessment

Propulsive forces were assessed by a hydrodynamic measurement system previously validated (Havriluk, 1988) with 0.2% of measurement error (Aquanex System, v. 4.2, Swimming Technology Research, Richmond, VA, USA). The system is composed of two independent sensors that are positioned between the phalanges of the middle and ring fingers of both hands and allow assess to peak force of dominant (PF_D) and non-dominant (PF_{ND}) upper-limbs in Newton (N). A signal-processor (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA) was used to export data with a 5 Hz cutoff low-pass 4th order Butterworth filter upon residual analysis. The relative peak of force for the dominant upper-limb (RF_D) was considered as follow: $(100 \times PF_D) / (IF_D)$.

Statistical procedures

Exploratory data analysis was used to identify potential outliers. The Shapiro–Wilk test was used to confirm the normality of distribution ($p > 0.05$). Descriptive statistics (mean, standard deviation, and 95% of confidence interval) are reported. The relationship between water and dry-land conditions was assessed by stepwise regression analysis. The Friedman test was conducted to compare differences between cadences. Additionally, effect size (ES) was calculated based on Cohen's *d* (Cohen, 1988), to assess the magnitude of the mean differences between cadences and interpreted, according to author's recommendation: (i) small ($d \geq 0.20$); (ii) moderate ($d \geq 0.50$); and (iii) large ($d \geq 0.80$).

Results

Higher values were found in the HA isometric peak force of the dominant limb on dry land (75.21 ± 34.10 N) when compared with the propulsive peak force of the dominant limb (PF_D) acquired in the water condition for HA (Table 2).

Table 2. Descriptive statistic (Mean ± SD) of the propulsive peak force of dominant limb in two water fitness exercises at different cadences.

Variables		Cadence [b·min^{-1}]			
		105	120	135	150
HA					
	PF_D [N]	31.45 ± 12.13	35.81 ± 13.04	41.93 ± 14.06	47.66 ± 14.42
RH_{add}					
	PF_D [N]	25.67 ± 8.15	32.40 ± 10.39	40.57 ± 12.83	48.42 ± 14.68

b·min^{-1}, beats per minute; HA, horizontal adduction; RH_{add}, Rocking horse adduction; PF_D, propulsive peak force of dominant limb.

Table 3 shows the relative peak of force for the dominant limb (RF_D) during water incremental protocol. The trend was to find higher values in the RF_D during the cadences increment, from ~45 % (105 b·min^{-1}) to ~66% (150 b·min^{-1}) in HA and from ~38% (105 b·min^{-1}) to ~68% (150 b·min^{-1}) for RH_{add}. Significant differences were found for $HA_{105–120}$ ($p = 0.02$, $d = 0.33$), $HA_{105–135}$ ($p < 0.01$, $d = 0.73$), $HA_{105–150}$ ($p < 0.01$, $d = 1.12$), $HA_{120–135}$ ($p = 0.04$, $d = 0.39$), and $HA_{120–150}$ ($p < 0.01$, $d = 0.76$). There were also meaningful differences in $RH_{105–135}$ ($p < 0.01$, $d = 1.01$), $RH_{105–150}$ ($p < 0.01$, $d = 1.43$), and $RH_{120–150}$ ($p < 0.01$, $d = 0.99$). A large ES was observed between the cadence 105-150 b·min^{-1} for both exercises. No differences were found for $HA_{135–150}$, $RH_{105-120}$, $RH_{120–135}$, and $RH_{135-150}$. However, $RH_{120-135}$ showed a value close to the significance and a medium ES ($p = 0.06$, $d = 0.52$).

Table 3. Descriptive statistic (Mean ± SD) of the relative peak of force in two water fitness exercises at different cadences.

Variables	Cadence [b·min^{-1}]			
	105	120	135	150
HA				
RF_D [%]	44.77 ± 17.46	50.98 ± 19.33 $^{\alpha*}$	59.03 ± 20.95 $^{\alpha**, \beta*}$	66.43 ± 20.47 $^{\alpha**, \beta*}$
RH_{add}				
RF_D [%]	37.75 ± 17.20	46.69 ± 18.07	56.59 ± 19.32 $^{\alpha**}$	67.90 ± 23.64 $^{\alpha**, \beta**}$

b·min-1, beats per minute; HA, horizontal adduction; RH_{add}, rocking horse adduction; RF_D, relative peak of force for dominant upper-limb; *, $p \leq 0.05$; **, $p \leq 0.01$; α, different from 105 b·min-1; β, different from 120 b·min^{-1}.

Table 4 presents the peak of force variation (ΔForce) between cadences in HA and RH_{add}. Lower cadences present a higher percentage in both exercises. In HA, the higher percentage occurred between the cadence 120–135 b·min^{-1}, while, in RH_{add}, it seems that 105–120 b·min^{-1} promoted the highest variation. Nevertheless, the cadence 135–150 b·min^{-1} presented the lowest percentage for the two exercises.

Table 4. Peak of force variation in the incremental protocol (Mean ± SD).

Variables	Cadence [b·min^{-1}]		
	105-120	120-135	135-150
HA			
ΔForce [%]	12.40 ± 10.30	13.92 ± 11.05	10.53 ± 18.81
RH_{add}			
ΔForce [%]	19.07 ± 15.77	18.04 ± 17.15	14.43 ± 19.68

b·min^{-1}, beats per minute; ΔForce, variation of peak force between musical cadences.

Discussion

The aim of the present study was to analyze the relative peak of force and to assess the variation of the relative peak of force over different musical cadences during the exertion of the horizontal adduction and rocking horse. The results confirm the initial hypothesis that along an incremental protocol the propulsive force increase and the relative peak of force reach ~68% of dry-land peak force.

Our results showed that both exercises elicited close to 50 N at the fastest musical cadence (150 b·min^{-1}). Becker and Havriluk (2006) conducted a study in swimmers during the horizontal adduction exercise at maximum velocity and reported values near 76 N and 80 N for the right and left hand, respectively. Differences in results may be explained by limit of exertion. In this sense, our study imposed a limit on the segmental frequency by the musical cadence, which mean that exertion may not have been led up to the maximum velocity of the subjects.

There was a trend to obtain higher values of the propulsive forces through the increase of the musical cadence. The increase in music is expected to induce an increase in limbs' velocity and, as a consequence, in drag force (Barbosa, Marinho, Reis, Silva & Bragada, 2009). Previous studies using Computational Fluid Dynamics (CFD) verified the maximum value of drag force when the hand adopted an angle attack of approximately 90˚, near perpendicular to the flow (Silva, Rouboa, Moreira, Reis, Alves & Vilas-Boas, 2008). This was the case in this study, where the maintenance of the hand at 90˚ promoted higher forces in HA and RH_{add}. Despite some differences already reported between HA and RH_{add} at lower cadences (Santos, Rama, Bartolomeu, Barbosa, & Costa, 2019) both exercises seem, at this stage, to induce a similar strength exertion.

The American College of Sports Medicine (ACSM, 2018, pp. 249-251) guidelines recommend 8–12 repetitions per set with ~60%–80% of the one repetition maximum (1-RM) in 2–3 days·week^{-1} to improve muscular strength and mass on dry-land programs. Standard guidelines for water fitness programs are set by the Aquatic Exercise Association (AEA, 2018, pp. 7-8), considering the American College of Sports Medicine's guidelines.

To the best of our knowledge, this study is the first clarifying the strength level that is applied in water by considering dry-land strength assessment. The RF_D reached from ~38% to 68% of the IF_D, according to exercise and the musical cadence. When analyzing both exercises, it seems that RF_D for HA was higher compared to RH_{add}, except at the 150 b·min^{-1}. This may be explained by the variability of the limbs' range of motion when a static (e.g., HA) or an imbalance position (e.g., RH_{add}) is adopted. Barbosa et al. (2010) demonstrated that the range of motion was maintained while performing the rocking horse at higher cadences. However, the multiple hops can lead to an instability, leading to lower values in lower cadences when compared with the HA. This suggests, as happens in the physiologic domain (Costa, Cruz, Simão, & Barbosa, 2019), that an exercise using the upper and lower-limbs does not promote higher exertion than the exercise that used only upper-limb motions. Moreover, we were interested in examining how the relative peak force increase develops along an incremental protocol. The results showed an increased in the cadence 105-120 b·min^{-1} and also in 120-135 b·min^{-1} for HA and RH_{add}.

Interestingly, the cadence 135-150 b·min^{-1} promoted the lowest relative force variation in both exercises, eliciting the higher exertion between them. The relationship between strength and propulsive forces still remains unclear (Evershed, Burkett & Mellifont, 2014). These values present the first approach to quantify the force generation that the water environment allows a subject to perform during the water fitness exercises. The traditional guidelines need an adjustment for water fitness programs. This means adding the musical cadence near to the load of intensity in the guidelines chart to promote an ideal condition of strength development. It is important to mention that this study was conducted with young subjects, and a hypothetical increase in cadence in adults and elderly people can lead to a decrease in optimal control to follow the rhythm.

Some additional limitation can be addressed in our research: (i) the uncontrolled effect of range motion (i.e., kinematic analysis); and (ii) the assessment of one body side (dominant upper-limb) in dry-land;

Conclusion

Increasing the musical cadence promotes an increase in propulsive peak force by upper limbs in water fitness exercises. In water environment the subjects are able to apply ~68% of the peak force obtained in dry-land at the fastest cadence.

Chapter 6. General Discussion

The main purpose of this dissertation was to do a kinetic analysis of two basic water fitness exercises and the magnitude of the force production in water exercises when compared with the maximal peak force in the laboratory. Results suggest that: (i) the propulsive peak force seems to increase from slower to faster music cadences; (ii) the horizontal adduction promotes higher values of propulsive peak force during an incremental protocol than the rocking horse exercise; (iii) the dominant and non-dominant upper-limbs had a similar exertion into the same cadence for both exercises; (iv) the musical cadence of 135 $b \cdot min^{-1}$ seems to promote a symmetric motion during the both exercises; (v) the relative peak of force reached ~68% of the force in dry-land condition; and (vi) a higher variation of the relative peak of force was found at lower cadences.

Several efforts have been conducted to increase the accuracy of the force assessment in water. With this in mind, there was an attempt to acquire variables in an ecological environment and in motor actions that are near and/or observed in a real context. While previous studies tried this kind of approach in competitive sports such as swimming (e.g. Bartolomeu et al., 2018), the knowledge of force production during water fitness exercises was somewhat scarce (Chapter 2). In order to fulfil that gap in the literature, this work aimed to analyse and to compare the behaviour of the forces and symmetries into an incremental protocol for a static (horizontal adduction) and a dynamic (rocking horse) water fitness exercises.

An increase in the propulsive peak force is reached at higher cadences. The musical cadence of 150 $b \cdot min^{-1}$ in young subjects showed higher values (~50 N) in PF for both exercises (Chapter 3). This suggests that at a maximum velocity and a higher segmental frequency the PF will be higher, as reported by Becker and Havriluk (2006) while assessing the horizontal adduction in swimmers (Chapter 3). However, in-water asymmetries can be more pronounced in different musical cadences and lead to muscular imbalances or deficits in strength during some activities (Sanders, Thow, & Fairweather, 2011). Indeed, the 135 $b \cdot min^{-1}$ was the only musical cadence that showed a symmetric motion in both exercises. The remaining cadences induced an asymmetric motion in both exercises. This is an important issue from a technical and planning point of view. The water fitness professionals need to pay attention to this phenomenon in order to induce some harmony while working strength and to avoid some kind of overuse injuries in their participants. At this point, the horizontal adduction was the one that elicited a symmetric motion at most of the cadences and can be considered the most suitable exercise to build up strength at some part of the session. (Chapter 4). Furthermore, the musical cadence of 135 $b \cdot min^{-1}$ seems to elicit the optimal relative peak of force (Chapter 5) without compromising the motion pattern (optimal symmetry) in both exercises (Chapter 4).

Chapter 7. Conclusions

The main findings of this work highlight the importance to assess propulsive forces in several water fitness exercises, as a way to contribute for an optimal strength development. So, water fitness professionals should pay major attention to the effect of musical cadence and prescribe the exercises properly when attempting to build the session for muscular conditioning. The overall conclusions are the following:

i. increasing musical cadence promotes an increase in propulsive force production by the upper-limbs in water fitness exercises;

ii. faster cadences elicited a similar exertion pattern for propulsive force in horizontal adduction and rocking horse;

iii. the horizontal adduction demonstrated higher values of propulsive peak force during an incremental protocol;

iv. the dominant and non-dominant upper-limb showed a similar exertion into the same cadence for both exercises;

v. the musical cadence of 135 $b \cdot min^{-1}$ presented a symmetric motion and an optimal relative peak force without compromising the motion pattern during the both exercises;

vi. the relative peak of force of the maximum force in dry-land reached values above 50% at faster musical cadence in young health water fitness participants;

vii. slower cadences promote a higher peak of force variation.

Chapter 8. Suggestions for future research

The research interest related to water fitness programs has increasing in the las couple of decades. However, still remains a lack of knowledge in biomechanical testing aiming to understand the acute and chronic responses and adaptations, namely in using a kinetic approach. Thus, in order to fulfill some gap in the literature, it seems important to consider the following research:

i. compare the effect of musical cadence in propulsive force between genders and different age groups;

ii. analyze the propulsive forces using different basic water fitness exercises and to assess to upper and lower-limbs´ contributions.

iii. analyze the effect of an muscular conditioning program in symmetry and in the rate of force production;

iv. assess to the influence of anthropometric, kinematic and kinetic variables regarding the gender on water fitness programs.

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Apendix I. Written informed consent for the participation

UNIVERSIDADE DE COIMBRA
FACULDADE DE CIÊNCIAS DO DESPORTO E EDUCAÇÃO FÍSICA

ANÁLISE CINÉTICA DE EXERCÍCIOS BASE DE HIDROGINÁSTICA: ADUÇÃO HORIZONTAL E CAVALO-MARINHO

Desde já agradecemos por ter demostrado interesse em participar. Este estudo surge no âmbito da elaboração da dissertação da discente Catarina Maria Simões da Costa Santos, afeta ao 2º Ciclo de Estudos em Biocinética, da Faculdade de Ciências do Desporto e Educação Física, da Universidade de Coimbra. O estudo é orientado pelo Professor Doutor Luís Manuel Pinto Lopes Rama, da Faculdade de Ciências do Desporto e Educação Física, da Universidade de Coimbra e coorientado pelo Professor Doutor Mário Jorge de Oliveira Costa, da Escola Superior de Educação, Comunicação e Desporto, do Instituto Politécnico da Guarda.

O objetivo do estudo é o de avaliar a produção de força propulsiva e o índice de simetria dos membros superiores durante a execução de dois exercícios típicos de hidroginástica: adução horizontal e cavalo-marinho, em diferentes cadências musicais. Será aplicado um protocolo incremental por patamares de 1 minuto, nas cadências de 105, 120, 135 e 150 batimentos por minuto, perfazendo o tempo total de quatro minutos de exercitação. O estudo envolve a recolha de dados relativos à composição corporal e antropometria, forças produzidas em meio aquático (força máxima) e em meio terrestre (força máxima isométrica). Adicionalmente, determinar-se-á a magnitude relativa de intensidade de execução em cada uma das cadências tendo em conta o valor de força máxima obtida em condição terrestre durante a adução horizontal.

A decisão em participar é totalmente voluntária, ressaltando que a participação no estudo não acarreta qualquer custo, nem implica qualquer risco decorrente da realização do protocolo de avaliação. Mais se informa que não existirá qualquer tipo de desvantagem se decidir não participar ou abandonar o estudo em qualquer momento. Este estudo segue os princípios da Declaração de Helsínquia e da Convenção de Oviedo para experimentos em humanos.

Os dados recolhidos serão confidenciais, somente a equipa de investigação terá acesso aos mesmos que serão recolhidos em formato de total anonimato. Os resultados deste estudo poderão ser publicados, sem qualquer identificação de forma individualizada dos participantes, sendo que *a posterior* da sua apresentação serão destruídos. Se tiver alguma questão inerente ao estudo não hesite contactar para *************@sapo.pt** ou **91*********.

____

(Assinatura)

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO PARA A PARTICIPAÇÃO EM ESTUDOS DE INVESTIGAÇÃO

(de acordo com a Declaração de Helsínquia e a Convenção de Oviedo)

Li cuidadosamente a folha informativa relativa a este projeto e reconheço na íntegra os procedimentos de investigação inerentes ao objeto de estudo, bem como o que envolve a minha participação. Todas as questões ou dúvidas foram esclarecidas de forma satisfatória. Neste seguimento, compreendi que:

1. A participação é voluntária, sendo livre de abandonar o estudo a qualquer momento;
2. Não se prevê qualquer tipo de vantagem e/ou desvantagem, custos e riscos durante a exercitação do protocolo;
3. Os dados recolhidos serão destruídos após o término do estudo e respetiva apresentação;
4. Os resultados poderão ser publicados mas o anonimato será preservado.
5. No caso de uma descoberta acidental que possa contribuir para a prevenção, diagnóstico e tratamento de qualquer doença existente ou futura, por favor assinale o procedimento que deseja ser adotado:
    a. ser informado diretamente sobre as descobertas clínicas ☐
    b. não ser informado sobre as descobertas clínicas ☐
    c. deixar a decisão a cargo do seu médico de família, que para o efeito será contactado pela equipa investigadora ☐

Assim, declaro que aceito participar neste estudo

______________________________________ ____/_____/________

(Assinatura) (Data)

ID	

Apendix II. Publications

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a. Kinetic Analysis of Water Fitness Exercises: Contributions for Strength Development.

Catarina C. Santos[1], Luís M. Rama[1,2], Daniel A. Marinho[3,4], Tiago M. Barbosa[4,5,6], Mário J. Costa[4,7]

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Environmental Research and Public Health

MDPI

Article

Kinetic Analysis of Water Fitness Exercises: Contributions for Strength Development

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Abstract: The evaluation of propulsive forces in water allows the selection of the most appropriate strategies to develop strength during water fitness sessions. The aim of this study was threefold: (i) to analyze the rate of force production; (ii) to analyze the rate of force variation; and (iii) to compare limbs' symmetry in two water fitness exercises. Twenty-two young health subjects (age: 21.23 ± 1.51 years old, body mass: 67.04 ± 9.31 kg, and height: 166.36 ± 8.01 cm) performed incremental protocols of horizontal adduction (HA) and rocking horse (RH_{add}), from 105 until 150 $b \cdot min^{-1}$. Data acquisition required an isokinetic dynamometer and a differential pressure system that allowed the assessment of (a) isometric peak force of dominant upper limb ($IsometricF_D$); (b) propulsive peak force of dominant upper limb ($PropulsiveF_D$); and (c) propulsive peak force of nondominant upper limb ($PropulsiveF_{ND}$). Significant differences were found in the rate of force production ($RateF_D$) between the majority cadences in both exercises. The $RateF_D$ reached ~68% of the force in dry-land conditions, and lower cadences promoted a higher rate of force variation (ΔForce). Most actions were asymmetric, except for the HA at 135 $b \cdot min^{-1}$. In conclusion, the musical cadence of 135 $b \cdot min^{-1}$ seems to elicit a desired rate of force production with a symmetric motion in both exercises.

Keywords: water exercise; propulsive force; isometric force; asymmetries; cadence

1. Introduction

Aquatic activities related to health and well-being promotion increased remarkably in popularity and adherence in the past decades. There is a wide variety of water programs focusing on fitness [1], performance [2], rehabilitation [3], and therapy [4]. The increasing interest is attributed to the potential benefits of water programs, as reported in the literature [5]. Other potential benefits mentioned include (i) the reduced effect of body weight; (ii) the reduced impact in specific joints (e.g., a decreased ground reaction force); (iii) the reduced muscle pain; (iv) an improved blood flow due to hydrostatic pressure; (v) a three-dimensional body motion and; and (vi) higher social development and commitment.

b. Comparison of propulsive forces between two head-out water exercises.

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Comparison of propulsive forces between two head-out water exercises

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ABSTRACT

The aim of this study was to analyse and compare the propulsive force between two basic head-out water exercises. Twenty-nine young healthy participants (age: 21.7 ± 1.9 years-old, body mass: 68.5 ± 10.8 kg, height: 168.2 ± 9.6 cm) performed an incremental protocol for each exercise (horizontal adduction and rocking horse) from 105 beats per minute (b·min-1) until 150 b·min-1 with increments of 15 b·min-1 every 30 seconds. Data acquisition required a differential pressure system to obtain propulsive forces in upper limbs', especially the peak force for the dominant member (DPeakF) and non-dominant member (NDPeakF). Force values from both exercises were higher in DPeakF and NDPeakF even when increasing the music cadence and higher forces were found in HAAdd. Differences ($p \leq 0.05$) were found when comparing two exercises at lower music cadences. The main conclusion is that there are significantly differences between two basic head-out water exercises at lower cadences. **Keywords**: Water exercises; Music cadence; Propulsive forces.

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c. Assessment of upper-limbs' symmetry in water fitness exercises.

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d. Efeito da cadência musical na força propulsiva num exercício base de hidroginástica.

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Efeito da cadência musical na força propulsiva num exercício base de hidroginástica

Catarina C. Santos[1], Luís P. Rama[1], Raul F. Bartolomeu[2], Tiago M. Barbosa[3,4], Mário J. Costa[5]

RESUMO | *ABSTRACT*

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INTRODUÇÃO

O estudo da força em exercícios básicos de hidroginástica é escasso. Das evidências existentes apenas se reportam valores em exercícios verticais à máxima velocidade de execução (1). O objetivo deste estudo foi analisar o efeito de diferentes cadências musicais na força propulsiva durante a execução de um exercício base de hidroginástica.

MÉTODOS

Catorze participantes (22,20 ± 1,94 anos de idade; 66,45 ± 12,79 kg de massa corporal; 168,6 ± 12,01 cm de estatura) foram sujeitos a um protocolo incremental com candências de 105, 120, 135 e 150 batimentos por minuto (bmp), ao ritmo de execução "tempo de água", durante a realização de um exercício base com duas fases: adução (AdHoriz) e abdução (AbdHoriz) horizontal dos membros superiores, no plano do ombro. Para análise das forças propulsivas recorreu-se a um sistema de monitorização (Aquanex 4.1, Swimming Technology Research, USA), possibilitando a aquisição de valores de força máxima do membro dominante (FmáxD, N) e não dominante (FmáxND, N). Confirmados os pressupostos, foi realizada a análise comparativa (Wilcoxon) com uma significância assumida de $p \leq 0{,}05$.

RESULTADOS

Tabela 1

Análise comparativa dos valores de força (N) entre o membro dominante e membro não dominante na mesma cadência

Adução horizontal				Abdução horizontal			
Cadência (bpm)	Variáveis	Média±DP	*p*	Cadência (bpm)	Variáveis	Média±DP	*p*
105	FmáxD [N]	29,98±11,95	0,73	105	FmáxD [N]	10,11±2,09	0,03
	FmáxND [N]	29,00±8,73			FmáxND [N]	9,16±2,21	
120	FmáxD [N]	37,85±14,47	0,22	120	FmáxD [N]	10,41±2,23	0,05
	FmáxND [N]	35,55±10,91			FmáxND [N]	9,79±2,01	
135	FmáxD [N]	41,93±14,59	0,93	135	FmáxD [N]	10,94±2,13	0,16
	FmáxND [N]	40,81±11,59			FmáxND [N]	10,18±2,20	
150	FmáxD [N]	46,40±13,39	0,56	150	FmáxD [N]	11,61±1,56	0,04
	FmáxND [N]	46,80±12,64			FmáxND [N]	10,75±1,30	

FmáxD, força máxima dominante; FmáxND, força máxima não dominante; bpm, batimentos por minuto; DP, desvio-padrão; N, Newton

Tabela 2

Análise comparativa dos valores de força (N) do membro dominante e membro não dominante a diferentes cadências

Adução horizontal							
Membro dominante				Membro não dominante			
Cadências (bpm)	Variáveis	Média ± DP	*p*	Cadência (bpm)	Variáveis	Média ± DP	*p*
105-120	FmáxD [N]	29,98 ± 11,95	0,001	105-120	FmáxND [N]	29,00 ± 8,73	0,002
	FmáxD [N]	37,85 ± 14,47			FmáxND [N]	35,55 ± 10,91	
	% AForça D	19,43 ± 10,93			% AForça ND	18,35 ± 13,65	
120-135	FmáxD [N]	37,85 ± 14,47	0,006	120-135	FmáxND [N]	35,55 ± 10,91	0,009
	FmáxD [N]	41,93 ± 14,59			FmáxND [N]	40,81 ± 11,59	
	% AForça D	9,43 ± 10,42			% AForça ND	12,14 ± 12,95	
135-150	FmáxD [N]	41,93 ± 14,59	0,02	135-150	FmáxND [N]	40,81 ± 11,59	0,01
	FmáxD [N]	46,40 ± 13,39			FmáxND [N]	46,80 ± 12,64	
	% AForça D	9,96 ± 13,83			% AForça ND	12,26 ± 13,99	

FmáxD, força máxima dominante; FmáxND, força máxima não dominante; % AForça, percentagem de aumento de força; bpm, batimentos por minuto; DP, desvio-padrão; N, Newton.

Tabela 3

Análise comparativa dos valores de força (N) do membro dominante e membro não dominante a diferentes cadências

Abdução horizontal							
Membro dominante				Membro não dominante			
Cadências (bpm)	Variáveis	Média ± DP	*p*	Cadência (bpm)	Variáveis	Média ± DP	*p*
105-120	FmáxD [N]	10,11 ± 2,09	0,15	105-120	FmáxND [N]	9,16 ± 2,21	0,026
	FmáxD [N]	10,41 ± 2,23			FmáxND [N]	9,79 ± 2,01	
	% AForça D	0,99 ± 22,89			% AForça ND	5,89 ± 17,53	
120-135	FmáxD [N]	10,41 ± 2,23	0,19	120-135	FmáxND [N]	9,79 ± 2,01	0,36
	FmáxD [N]	10,94 ± 2,13			FmáxND [N]	10,18 ± 2,20	
	% AForça D	3,14 ± 23,23			% AForça ND	0,76 ± 24,10	
135-150	FmáxD [N]	10,94 ± 2,13	0,016	135-150	FmáxND [N]	10,18 ± 2,20	0,23
	FmáxD [N]	11,61 ± 1,56			FmáxND [N]	10,75 ± 1,30	
	% AForça D	7,21 ± 10,21			% AForça ND	6,27 ± 13,86	

FmáxD, força máxima dominante; FmáxND, força máxima não dominante; % AForça, percentagem de aumento de força; bpm, batimentos por minuto; DP, desvio-padrão; N, Newton.

DISCUSSÃO

Os resultados demostram que quando comparados os dois membros à mesma cadência as forças produzidas apenas diferem na AbdHoriz, o que hipoteticamente sugere a presença de assimetrias nessa fase, que pode ser devido a um menor controlo motor e/ou fragilidade dos músculos posteriores. Por outro lado, quando comparada a força entre cadências verifica-se um aumento da força e uma tendência para manutenção na % AForça a cadências mais elevadas.

REFERÊNCIAS

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