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FEDERAL UNIVERSITY OF AMAZONAS
FACULTY OF PHYSICAL EDUCATION AND PHYSIOTHERAPY
POSTGRADUATE PROGRAM IN HUMAN MOVEMENT SCIENCES

EVALUATION OF THE ISOKINETIC STRENGTH OF THE INTERNAL AND EXTERNAL ROTATOR, FLEXOR, AND EXTENSOR MUSCLES OF THE SHOULDERS IN DIFFERENT GROUPS OF AQUATIC ACTIVITY PRACTITIONERS

NEICE BAHIA CARNEIRO

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Academic dissertation submitted to the Postgraduate Program in Human Movement Sciences at the Federal University of Amazonas, with the purpose of obtaining a master's degree in Human Movement Sciences, in the area of Biodynamics of Human Movement.

Supervisor: Professor Dra. Kelly de Jesus

Co-supervisor: Professor Dr. Marcos Franken

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Approved on January 10th, 2024.

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Dedicated to my mother, Sebastiana Justo Bahia.

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Learning is the only thing that the mind never tires of, is never afraid of and never regrets.

Leonardo Da Vinci

LIST OF FIGURES

LIST OF TABLES

RESUMO

A força muscular é uma das características biomecânicas determinantes do desempenho em um ambiente hidrodinâmico e a avaliação desta variável é um procedimento comum dentro de um programa de treinamento. Esta dissertação foi dividida em dois artigos, os quais tiveram os seguintes objetivos: (i) Analisar os efeitos da técnica de crawl ventral utilizada por diferentes grupos de praticantes de atividades aquáticas sobre a força isocinética da articulação do ombro dos músculos rotadores internos e externos, flexores e extensores; (ii) Analisar o efeito de duas velocidades angulares nas estruturas de rede da força isocinética do ombro e das atividades aquáticas. Em cada estudo, participaram 27 praticantes da natação competitiva (n = 7), águas abertas (n = 7), triatlo (n = 7) e polo aquático (n = 6). Em ambos os artigos a avaliação foi feita usando um dinamômetro isocinético *Biodex System* 4.0 (*Biodex Medical Systems, Shirley, NY, EUA*) com ações concêntricas máximas nos movimentos de rotação interna e externa, flexão e extensão dos ombros nas velocidades angulares de 60 e 180°/s (três e 20 repetições, respectivamente). No primeiro estudo foram analisadas as variáveis pico de torque (N·m), trabalho total (J), coeficiente de variação (%), razão de equilíbrio convencional (RE/RI, FL/EX) (%) e índice de fadiga (%). No segundo, foram utilizadas as variáveis isocinéticas (pico de torque (N·m) e trabalho total (J)) dos membros preferido e não preferido e as atividades aquáticas (natação, águas abertas, triatlo e polo aquático). Para atender ao primeiro objetivo (estudo 1) utilizou-se o teste equivalente não paramétrico de *Kruskal-Wallis*, onde o teste *post-hoc* verificou as diferenças (p < 0,05) entre os grupos por meio de comparações pareadas entre natação competitiva vs. águas abertas vs. triatlo e polo aquático. Para atender ao segundo objetivo (estudo 2), foi utilizada a técnica *Network Analysis Machine Learning* para verificar as múltiplas relações simultâneas entre as variáveis de força isocinética e as atividades aquáticas, por meio de três medidas de centralidade em escores z: *expected influence, closeness centrality* e *strength centrality*. O primeiro estudo mostrou que os praticantes de águas abertas apresentaram valores de força isocinética inferiores aos de polo aquático para rotação interna do ombro direito (trabalho total a 60°/s; p = 0,033, ES = -0,251, e pico de torque a 180°/s; p = 0,036, ES = -0,250) e flexão do ombro esquerdo (pico de torque p = 0,041, ES = -0,248 e trabalho total; p = 0,047, ES = -0,246), ambos a 60°/s. A técnica de crawl ventral utilizada por diferentes grupos de praticantes de atividades aquáticas pareceu influenciar a resposta da força isocinética. Ao compreender que estas variáveis podem afetar o desempenho, treinadores dessas atividades aquáticas podem identificar estratégias de treino para prevenir lesões. O segundo estudo mostrou que, ao mudar a velocidade angular, as variáveis mais proeminentes nas estruturas da rede também mudaram no que diz respeito aos parâmetros de centralidade. O trabalho total de rotação externa do lado não preferido assumiu posição central na velocidade angular 60°/s. A variável atividades aquáticas apresentou um posicionamento periférico em ambas as velocidades angulares. Se a velocidade angular de 180°/s for considerada a mais próxima das características específicas das atividades aquáticas aqui representadas, o trabalho total de rotação interna (1,000) e o pico de torque de extensão (0,959), ambos do lado preferencial, apresentaram grande influência no desempenho dessas atividades aquáticas.

Palavras-chave: biomecânica, dinamômetro isocinético, desempenho, atividades aquáticas, parâmetros de centralidade.

ABSTRACT

Muscular strength is a determining biomechanical feature of performance in a hydrodynamic environment and its assessment is a common procedure within a training program. This academic dissertation was divided into two articles, which had the following aims: (i) to analyze the effects of front crawl technique used by different groups of aquatic activity practitioners on the isokinetic shoulder joint strength of the internal and external rotator, flexor, and extensor muscles; (ii) to analyze the effect of two angular velocities on the network structures of shoulder isokinetic strength and aquatic activities. Twenty-seven practitioners of competitive swimming (n = 7), open water (n = 7), triathlon (n = 7) and water polo (n = 6) participated in each study. In both articles, the evaluation was carried out using a Biodex System 4.0 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) with maximum concentric actions in the movements of internal and external rotation, flexion and extension of the shoulders at angular speeds of 60 and 180°/s (three and 20 repetitions, respectively). In the first study, the variables peak torque (N·m), total work (J), coefficient of variation (%), ER/IR ratio and FL/EX ratio (%) and fatigue index (%) were analyzed. In the second, the isokinetic variables (peak torque (N·m) and total work (J)) of the preferred and non-preferred side and aquatic activities (swimming, open water, triathlon and water polo) were used. For the first aim (study 1), the equivalent non-parametric Kruskal-Wallis test was used. The post-hoc test verified differences ($p < 0.05$) between groups through paired comparisons between competitive swimming vs. open water vs. triathlon and water polo**.** For the second aim (study 2)**,** the Network Analysis Machine Learning technique was used to verify the multiple simultaneous relationships between isokinetic strength variables and aquatic activities, using three centrality measures in z scores: expected influence, closeness centrality, and strength centrality. The first study showed that, open water practitioners showed lower values of isokinetic strength than water polo for right shoulder internal rotation (total work at 60°/s; $p = 0.033$, ES = -0.251, and peak torque at 180°/s; $p = 0.036$, ES = -0.250) and left shoulder flexion (peak torque $p = 0.041$, ES = -0.248 and total work; $p = 0.047$, ES = -0.246), both at 60°/s. The front crawl technique used by different groups of aquatic activity practitioners seemed to influence isokinetic strength response on dry land. By learning that these variables might affect performance, coaches of these aquatic activities can identify training strategies to prevent injuries. The second study showed that, by changing the angular velocity, the most prominent variables in the network structures also change concerning the centrality parameters. The total external rotation work of the non-preferred side took a central position at the angular velocity of 60°/s. The variable “aquatic activities” showed a peripheral positioning at both angular velocities. If the angular velocity of 180°/s is considered the closest to the specific features of the aquatic activities represented here, the total work of internal rotation (1.000) and peak torque of extension (0.959), both on the preferred side, showed great influence on performance of these aquatic activities.

Keywords: biomechanics, isokinetic dynamometer, performance, aquatic activities, centrality parameters.

SUMMARY

1. GENERAL INTRODUCTION

Muscular strength is a determining biomechanical feature of performance in a hydrodynamic environment and its assessment is a common procedure within a training program (Tourny-Chollet; Seifert; Chollet, 2009; Batalha *et al.*, 2018; Carvalho *et al.*, 2019). Although biomechanical assessments are carried out using specific methods, it has been identified that the forces produced on dry land are related to the ability to apply force in water (Carvalho *et al.*, 2019; Wiażewicz; Eider, 2021). Even though the hydrodynamic position and angular velocity of movement are specific to competitive swimming, open water, triathlon, and water polo, the analysis of upper limb isokinetic strength is useful in training intervention for providing reliable and valid data from isokinetic torque values (Carvalho *et al.*, 2019; Tan *et al.*, 2021). In addition, it allows monitoring variables related to performance such as peak torque, total work, conventional balance ratio, and fatigue index (Batalha *et al.*, 2018; Carvalho *et al.*, 2019; Wiażewicz; Eider, 2021), in line with the aim of this study.

In competitive swimming, open water, triathlon, and water polo, practitioners use the front crawl technique (Figueiredo *et al.*, 2013; King *et al.*, 2022) to overcome the hydrodynamic drag force during stroke (Tourny-Chollet; Seifert; Chollet, 2009; McLaine *et al.*, 2018). However, practitioners of these aquatic activities have different demands on the shoulder joint, such as swimming with the head below and above water (de Jesus *et al.*, 2012), kinematic features regarding the length and strokes frequency (Tan; Polglaze; Dawson, 2009; de Jesus *et al.*, 2012; Seifert; Chollet; Bardy, 2004), including throwing actions in water polo. Thus, changes in muscle strength are likely to occur, as we investigated in our first study by analyzing the effects of the front crawl technique on the isokinetic strength of the shoulder joint when used by different groups of aquatic activity practitioners. Therefore, potential effects and their causes must be investigated and understood, as these demands require high upper limb forces and can affect performance (Seifert; Chollet; Bardy, 2004; Batalha *et al.*, 2015; Psycharakis; Coleman, 2023).

On this subject, bilateral force asymmetries are pointed out as factors that influence performance by increasing active drag and intra-cycle speed variations, reducing the ability to produce propulsive forces (Sanders *et al*., 2011). On this variable, partial results involving swimmers were presented at the XIVth International Symposium of Biomechanics and Medicine in Swimming in Leipzig/Germany in 2023 (Appendix E). The effects induced by muscle fatigue in the shoulder joint are also a performance limiting factor (Batalha *et al.*, 2018; King *et al.*, 2022). In addition, practitioners of the front crawl technique are also subject to developing agonist-antagonist muscle imbalances due to the excessive use of the upper limbs, both in swimming training and in throwing in water polo, whose relationship with pain and injury must be investigated (Batalha *et al.*, 2018; Mota; Ribeiro, 2012). Therefore, both coaches and practitioners of these aquatic activities can be benefited from the diagnosis of these causes. In this regard, we sought to investigate the " Correlation between training volume and muscle imbalances in swimmers" (Appendix B). As well as whether "Does the volume of aquatic training influence conventional balance ratios in swimmers who perform strength training on dry land?" (Appendix C). The results were, respectively, presented at the I International Congress of Human Movement Sciences, Manaus - AM and at the XX Brazilian Congress of Biomechanics, Bauru - SP.

Complementarily, variables that predict performance must be identified for high sporting results to be achieved (Olivier; Daussin, 2018; de Jesus *et al*., 2019). In this respect, the tethered swimming test has shown that peak torque of flexion/extension is associated with swimmers' performance (Carvalho *et al*., 2019). In water polo, total work and peak torque of shoulder extensors are predictors in the sprint swimming (25 m), while the peak torque of internal rotators are predictors in throwing velocity (Olivier; Daussin, 2018). Identifying performance predictor variables is critical for controlling and monitoring training (Olivier; Daussin, 2018; de Jesus *et al*., 2019) and can be strengthened by correlation analysis of multivariate datasets to better understand the phenomena impacting performance. Therefore, in our second study, we propose to analyze the effect of two angular velocities on the network structures of isokinetic shoulder strength and aquatic activities (competitive swimming, open water, triathlon, and water polo).

Network analysis allows identifying relationships between variables and their importance and influence on the estimated network structures (Hevey, 2018), which is useful for training program intervention (Fiori *et al.*, 2022; Vasques *et al.*, 2023). In addition, it verifies the multiple simultaneous relationships in a complex system, formed by the centrality parameters, which will determine the variables most susceptible to intervention (Epskamp *et al.*, 2012). It is therefore important to assess strength levels periodically throughout training routines, as well as to investigate the correlation between multivariate datasets so that researchers, coaches, and aquatic activity practitioners can understand the phenomena that affect performance. Thereby, this study raises the following questions: What is the effect of practicing different aquatic activities on the isokinetic strength of the internal and external rotator, flexor, and extensor muscles of the shoulders in practitioners of the front crawl technique? Does the change in angular velocity reflect the interactions between isokinetic variables and different aquatic activities in the network structures formed?

2. OBJECTIVES

2.1. GENERAL OBJECTIVE

- To evaluate the isokinetic strength of the internal and external rotator, flexor and extensor muscles of the shoulders in swimming, open water, triathlon and water polo practitioners who use the front crawl technique.

2.2. SPECIFIC OBJECTIVES

- To compare peak torque, total work, coefficient of variation, conventional balance ratio (ER/IR, FL/EX) and fatigue index in the movements of internal and external rotation, flexion and extension of the shoulders between different groups of aquatic activity practitioners at angular velocities of 60 and 180°/s;
- To analyze whether the practice of different aquatic activities influences the isokinetic strength of the internal and external rotator, flexor and extensor muscles of the shoulders in swimming, open water, triathlon and water polo practitioners who use the front crawl technique;
- To estimate the network structures of the variables of peak torque and total work in the movements of external and internal rotation, flexion and extension of the shoulders at angular velocities of 60 and 180°/s in swimmers, open water swimmers, triathletes and water polo players;
- To identify the relationships between isokinetic variables and different aquatic activities in network structures with two angular velocities.

3. HYPOTHESES

The following hypotheses were formulated for the following studies:

(i) There are differences in isokinetic torques (peak torque and total work), ER/IR ratio and fatigue index.

(ii) The change in angular velocity influences the values of the centrality parameters in the estimated network structures.

4. RESULTS

4.1. STUDY 1

Effects of front crawl technique used by different groups of aquatic activity practitioners on shoulder strength

Abstract

This study aimed to analyze the effects of front crawl technique used by different groups of aquatic activity practitioners on the isokinetic shoulder joint strength of the internal and external rotator, flexor, and extensor muscles. The participants were divided into four groups of aquatic activities: competitive swimming (n = 7) open water (n = 7), triathlon (n = 7), and water polo (n = 6). Concentric actions at 60°/s (three repetitions) and 180°/s (20 repetitions) were measured using isokinetic dynamometry. We assessed peak torque, total work, coefficient of variation, fatigue index, external/internal ratio, and flexion/extension ratio of the right and left shoulders in internal and external rotation, flexion, and extension. The open water showed lower values of isokinetic strength than water polo for right shoulder internal rotation (total work at 60°/s; $p = 0.033$, ES = -0.251, and peak torque at 180°/s; $p = 0.036$, ES = -0.250) and left shoulder flexion (peak torque $p = 0.041$, ES = -0.248 and total work; $p = 0.047$, ES = -0.246), both at 60°/s. The front crawl technique used by different groups of aquatic activity practitioners seems to influence isokinetic strength response on dry land. By learning that these variables might affect performance, coaches can identify training strategies to help practitioners achieve better sporting results.

Keywords: biomechanics, isokinetic strength, aquatic activities, athletic performance

Introduction

Biomechanical characteristics, such as muscle force production, are performance determinants in a specific hydrodynamic environment and are commonly assessed (Tourny-Chollet *et al*., 2009; Carvalho *et al*., 2019). Although biomechanical evaluations are performed through specific tests, dryland testing allows the monitoring of a larger number of performance-related variables, such as peak torque and total work (Carvalho *et al*., 2019; Wiażewicz; Eider, 2021). Isokinetic shoulder strength measurements can be considered valid up to 180°/s, as individuals take time to reach the desired velocity. Furthermore, in concentric contractions at high velocities there are "torque overshoots" that should not be considered when calculating the peak torque (Mayer *et al.*, 2001). Studies aimed to measure the shoulder rotator isokinetic strength applied two angular velocities, where 60 and 180°/s are the most used in the swimmer's population (Batalha *et al*., 2015; Wiażewicz; Eider, 2021). These angular velocities represented a decrease (60°/s), used for constructing strength ratios from a clinical point-of-view, and an increase (180°/s), like in the swimming technique (Carvalho *et al.*, 2019; Wiażewicz; Eider, 2021).

In front crawl swimming, the propulsion of the stroke depends on the hydrodynamic drag force generated mainly by the upper limbs, with movements of internal rotation, extension, and adduction to overcome active drag (Figueiredo *et al*., 2013; McLaine *et al*., 2018). However, it is important to consider the changes in muscle strength due to the pace imposed by the swimming speed. In water polo, the front crawl technique is performed with the head out of the water and sprint swimming, implying shorter stroke length and high stroke frequency (Tan *et al*., 2009; de Jesus *et al*., 2012). Pool swimmers use two main pacing strategies: (i) shorter stroke length and high stroke frequency; or (ii) longer stroke length and lower stroke frequency (Seifert; Chollet; Bardy, 2004). Open water swimmers and triathletes adopt behind drafting as an effective tactic in terms of muscle fatigue and swimming efficiency, swimming with a longer stroke length and lower stroke frequency (Zacca *et al*., 2020; Rodríguez *et al*., 2021; Puce *et al*., 2022). According to (Kwok *et al.*, 2021), the higher the swimming speed increases, the force the greater applied in the propulsive phases.

Based on the above specific biomechanical characteristics, swimming training can have effects on isokinetic shoulder strength. The values reported correspond to

80 and 90 km per week, respectively, for open water and pool swimmers (Pink; Tibone, 2000; Baldassarre *et al*., 2019), while for triathletes and water polo players the literature reports 2.5 and 4 hours per week, respectively (Annett *et al*., 2000; Egermann *et al*., 2003). This indicates a higher volume of training dedicated to swimming for pool swimmers and a lower volume of training for triathletes. Furthermore, it has been shown that a macrocycle of training in the front crawl technique strengthens the internal rotator muscles more than the external rotator muscles, causing agonist-antagonist muscle imbalances that may be associated with future injuries (Batalha *et al.*, 2015). Given the repetitive nature of upper limb actions, it is also relevant the role of muscle fatigue, since it is associated with pain and injury (King *et al.*, 2022).

With regard to this subject, a recent study (King *et al.*, 2022) showed that water polo players achieved higher peak torque in internal rotation than swimmers and the control group but had lower endurance as a result of induced fatigue. In addition, water polo players and swimmers showed different activation patterns of the internal rotator muscles of the shoulder (King *et al.*, 2022). Therefore, the strength variables that affect performance, such as muscle imbalances (by peak torque) and muscle fatigue (by work performed in the first and last thirds of the test) in the shoulder joint can be measured and are commonly used in studies with swimmers and water polo players (Batalha *et al*., 2015; Olivier; Daussin, 2018; King *et al*., 2022). These variables also lack measurement in the aquatic activities of open water and triathlon, and although they involve different aquatic activities, both use the front crawl technique in competitions. Thus, they are probably exposed to the same risk factors due to the use of the upper limb, requiring attention to better control and monitor training, which is demanded in high-level sports performance.

Training demands on the shoulder joints differ between practitioners of different aquatic activities, such as technical patterns like the front crawl technique with the head under and above the water, as well as kinematic characteristics involving stroke length and frequency. Therefore, changes in muscle strength might occur, thus highlighting the importance of investigating possible effects during the isokinetic test and understanding their causes. Although the hydrodynamic position and the angular velocity of the movement are specific among competitive swimmers, open water swimmers, triathlon swimmers and water polo players, the isokinetic dynamometer provides objective and valid data on upper limb strength that can be decisive in sports performance. Therefore, the aim of this study was to analyze the effects of the front crawl technique used by different groups of aquatic activity practitioners on the isokinetic shoulder joint strength of the internal and external rotator, flexor, and extensor muscles. We formulated the following hypothesis: (i) there will be differences in peak torque, RE/RI ratio, and fatigue index.

Methods

Participants

Twenty-seven practitioners, six females (age: 32 ± 15 years old; body mass: 58.4 ± 4.1 kg; height: 1.63 m ± 0.05; arm span: 1.65 ± 0.06 m) and twenty-one males (age: 28 ± 13 years old; body mass: 74.2 ± 13.6 kg; height: 1.76 ± 0.07 m; arm span: 1.79 ± 0.07 m), of different aquatic activities were divided into four groups: competitive swimming (n = 7), open water (n = 7), triathlon (n = 7), and water polo (n = 6). Table 1 shows the main baseline characteristics of the participants. The following inclusion criteria were set: (i) individuals aged 15 years old or above (Batalha *et al.*, 2015); (ii) use of the front crawl as the main swimming technique (Keiner *et al.*, 2018); (iii) regular training for competitions over the last three years (Lawsirirat; Chaisumrej, 2017); (iv) a minimum training frequency of three times a week (Mota; Ribeiro, 2012), and as exclusion criteria: (iv) having a clinical history of upper limb disorders (Batalha *et al.*, 2015). The participants were instructed not to train 24 hours before the tests (Vasques *et al.*, 2023). All procedures were performed in accordance with the ethical standards and the study was approved by the Research Ethics Committee of the Federal University of Amazonas (CAAE: 79527917.5.0000.5020). All participants and legal guardians of those under the age of 18 years old were informed about the objectives, assessment procedures, risks, and benefits. In addition, they all signed a written informed consent.

Table 1 **–** Median (Mdn) and interquartile range (IQR) values of the baseline characteristics of the participants using the front crawl technique in competitive swimming (CS), open water (OW), triathlon (TR), and water polo (WP).

	CS (n = 7)	**OW (n = 7)**	**TR (n = 7)**	**WP (n = 6)**
	Mdn ± IQR	**Mdn ± IQR**	**Mdn ± IQR**	**Mdn ± IQR**
Age (years)	20.00 ± 6.00	27.00 ± 27.00	47.00 ± 19.00	26.00 ± 8.00

Body mass (kg)	64.90 ± 8.60	65.20 ± 25.20	82.00 ± 32.30	83.80 ± 20.35
Height (m)	1.70 ± 0.13	1.66 ± 0.16	1.75 ± 0.13	1.77 ± 0.16
Arm span (m)	1.77 ± 0.16	1.75 ± 0.14	1.80 ± 0.17	1.79 ± 0.20
Weekly volume of swimming training (h)	9.00 ± 7.50	12.00 ± 6.50	6.25 ± 9.00	5.25 ± 7.88
Training background (years)	11.00 ± 10.00	7.00 ± 4.00	5.00 ± 8.00	14.00 ± 8.25

Isokinetic Assessment

We performed the isokinetic assessment using an isokinetic dynamometer (Biodex 4 Multi-Joint System, New York) in the shoulder joint internal and external rotation, flexion, and extension. The familiarization process consisted of two repetitions in each joint movement and angular velocities of 60 and 180°/s (Batalha *et al.*, 2015) (Wiażewicz; Eider, 2021). The participant was positioned in the seated isokinetic dynamometric chair (Figure 1, A and B panels) for the shoulder joint internal and external rotation, with a 90° range of motion in shoulder abduction and elbow flexion, respectively (Batalha *et al.*, 2015). For the shoulder joint flexion and extension, the participant was positioned with a forearm supination similar to hand positioning during swimming (Figure 1, C and D panels) (Carvalho *et al.*, 2019).

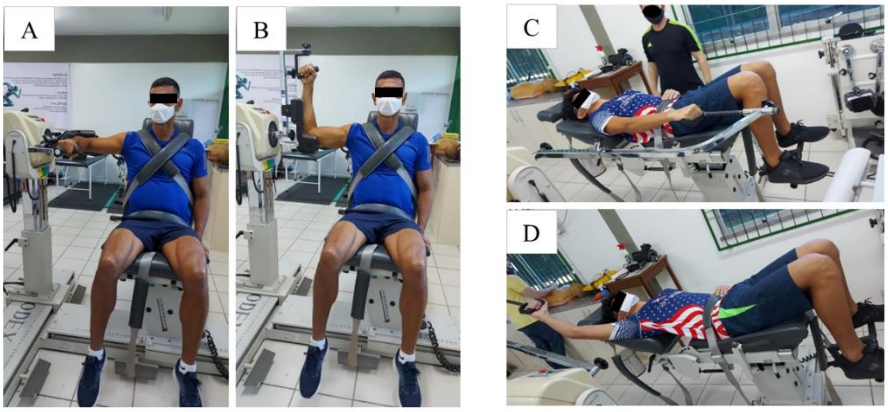

Figure 1 – A and B panels: external and internal rotation, respectively; C and D panels: flexion and extension, respectively.

We adopted a protocol for isokinetic strength assessment of the internal and external rotators (Batalha *et al.*, 2015), and another for the flexor and extensor muscles (Wiażewicz; Eider, 2021). In both protocols, a goniometer was used to align the shoulder joint with the mechanical axis of the equipment. The participants were stabilized using a pelvic belt to avoid compensation with body movement (Batalha *et al.*, 2015). The following two protocols were used to assess the shoulder joint movements: (i) three maximum concentric repetitions of internal and external rotation and flexion, and extension at 60°/s angular velocity, in addition to (ii) 20 maximum concentric repetitions of internal and external rotation and flexion, and extension at 180°/s angular velocity. We provided a two-min rest between angular velocities, five-min to change body side, and 10 min at movement changes. Throughout the repetitions, the participants were verbally encouraged to perform with maximum effort (Batalha *et al*., 2015; Wiażewicz; Eider, 2021).

Data Collection

The variables were analyzed for the right and left shoulders and the values were recorded and accessed from the report provided by the isokinetic dynamometer for peak torque (N·m), total work (J), coefficient of variation (%), fatigue index (%), and conventional ratio (%) in internal and external rotation and flexion and extension movements.

Peak torque (N·m) is a variable applied to characterize muscle strength values, defined as the maximum torque produced by the joint over the entire range of motion (Perrin, 1993). Total work (J) is defined as the sum of the work performed in all test repetitions (Kannus, 1994). The coefficient of variation (%) is applied to establish the test reliability in the variables (Hopkins, 2000), whose acceptable value must be less than or equal to 15% in isokinetic testing and data interpretation (Wiażewicz; Eider, 2016). Fatigue index (%) is a variable determined by the ratio of the difference in work performed in the first and last thirds of the test from a larger number of repetitions, where negative values indicate an increase in work production in the last third compared with the first third, and positive values represent a decline (Van de Velde *et al.*, 2011), defined by the equation proposed by Özçakar et al. (Özçakar *et al.*, 2005), as follows:

$$IF\ (\%) = [(W1 - W2) / W1] \times 100 \quad (1)$$

The ER/IR and FL/EX ratios are variables that allow accessing muscle balance values between antagonists/agonists, associating them with possible injury risks (Ellenbecker; Davies, 2000). They are calculated by the following equations:

$$[(ER / IR) \times 100] \tag{2}$$

$$[(FL / EX) \times 100] \tag{3}$$

Statistical Analysis

We performed a sample power calculation (one-way ANOVA) on the G*Power 3.1 statistical software at a 95% confidence level and a 5% margin of error. A sample size of six participants per aquatic activities was estimated. The Shapiro-Wilk test verified the data normality ($p > 0.05$), with results presented by descriptive statistics (median and interquartile range). The Levene test analyzed the assumption of homogeneity, with the variables presenting non-normal distribution. The equivalent non-parametric Kruskal-Wallis test was used. The post-hoc test verified differences ($p < 0.05$) between groups through paired comparisons between competitive swimming vs. open water vs. triathlon and water polo. The ordinal eta-squared equation calculated the effect size, as follows: $\eta^2[H] = \frac{H-k+1}{N-k}$, interpreted as 0 - 0.09 (trivial), 0.1 - 0.29 (small), 0.3 - 0.49 (medium), 0.5 - 0.69 (large), and ≥ 0.7 (very large).

Results

The comparison revealed differences only between two groups of the different aquatic activities assessed, showing that isokinetic strength was greater in water polo players than in open water swimmers at both angular velocities.

Figure 2 shows the median and interquartile range values the following differences in isokinetic strength for the right shoulder: total work of internal rotation at 60°/s ($p = 0.033$; ES = -0.251) (C panel) and the peak torque of internal rotation at 180°/s ($p = 0.036$; ES = -0.250) (B panel). As to the left shoulder, the differences referred to the peak torque of flexion ($p = 0.041$; ES = -0.248) (A panel), and total work of flexion ($p = 0.047$; ES = -0.246), both at 60°/s (C panel).

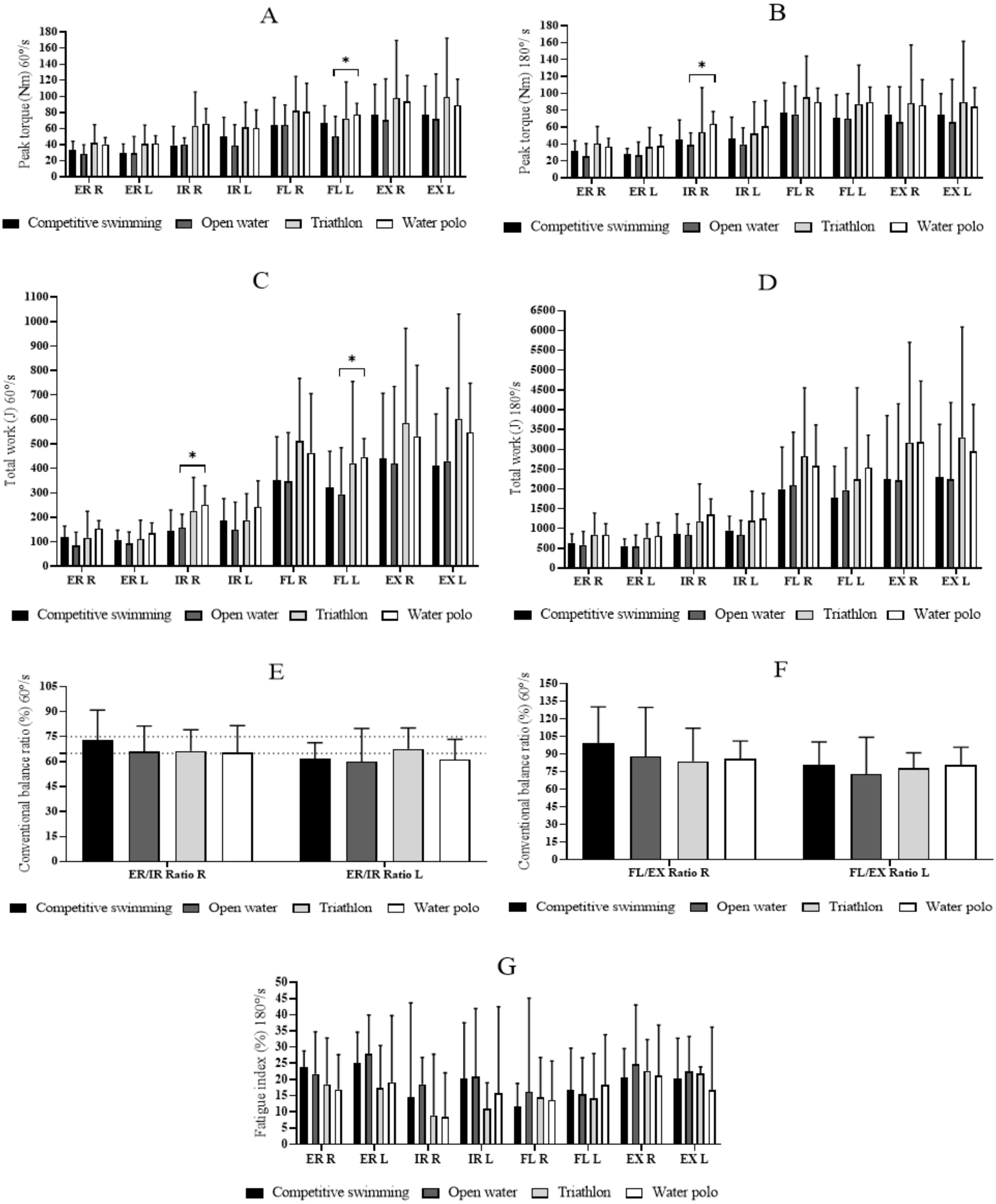

Figure 2 – Values of the median and interquartile range for isokinetic variables peak torque (A and B), total work (C and D), ER / IR (E) and FL / EX (F) ratios, and fatigue index (G) in the internal (IR) and external rotation (ER) and flexion (FL) and extension (EX) movements of the right (R) and left (L) shoulders at 60 and 180º/ s angular velocities. Ratio normative values (66 – 75%). *Significance value ($p < 0.05$).

Discussion

This study aimed to analyze the effects of front crawl technique used by different groups of aquatic activity practitioners on the isokinetic shoulder joint strength of the internal and external rotator, flexor, and extensor muscles. The results showed higher values of isokinetic strength for the water polo when compared with the open water. Our findings confirmed the hypothesis of differences in the peak torque variable between different aquatic activities since the front crawl technique is performed differently (e.g., swimming speed, stroke length, stroke frequency, front crawl with head underwater, and front crawl with head above water), suggesting a distinct demand for upper limbs strength.

The torque of the internal rotator muscles has been shown to be higher during the catch and pull phases, thus demonstrating that the demand is very high on the rotator muscles of the shoulder joints in the propulsive phase of the stroke, requiring powerful movements of internal rotation and adduction (Tourny-Chollet; Seifert; Chollet, 2009). Our data showed differences in the right shoulder for the variables of total work at 60°/s (158.00 ± 54.90 vs. 250.85 ± 78.53) and peak torque at 180°/s (38.90 ± 14.30 vs. 63.85 ± 14.65), both in the internal rotation movement, between open water and water polo, respectively (Figure 2**,** B and C panels). Water polo players showed to have higher pre-fatigue torque values (26.71) of internal rotators when compared with swimmers (22.82) and the control group (20.86) (King *et al*., 2022). Electromyographic data (Gaudet; Tremblay; Begon, 2017) showed that the pectoralis, latissimus dorsi, and subscapularis muscles were moderately strong to strongly active during the internal rotation movement (~40 **-** 85% of maximal voluntary activity) in the front crawl technique, providing support for our findings.

In the water polo, the front crawl technique with the head above the water showed to imply a short stroke length and a high stroke frequency (de Jesus *et al.*, 2012). This position increases the cross-sectional area of the body, promoting greater hydrodynamic resistance (de Jesus *et al.*, 2012), and hence greater application of upper limb force. In the stroke frequency with the front crawl head above water (1.09 + 0,08 Hz) and leading the ball (1.18 + 0.08 Hz) (de Jesus *et al.*, 2012) strongly require the internal rotation movements of the shoulder joint (Elliott, 1993). In open water, during the propulsive phases of the strokes in the front crawl technique, elite swimmers swim (10 km) with longer stroke lengths, and consequently, lower levels of stroke frequency with 35–37 cycles/min in the first half of the race, increasing by up to 39 cycles/min in the second half (Rodríguez *et al.*, 2021).

Distinct characteristics such as increased and decreased stroke frequency in open water (Zacca *et al*., 2020; Rodríguez et al., 2021), suggest a change in strength. The intermittent nature of water polo, such as predominantly ballistics movements, including sprint swimming, jumping, and especially throwing (Tan *et al*., 2009; Nekooei *et al*., 2019), reinforcing the idea of greater application of force by the shoulder joint as a function of speed. Swimming speed and muscle strength are highly correlated, thus faster speeds demand greater muscle strength (Kwok *et al.*, 2021). Therefore, each of these aquatic activities requires the glenohumeral joint to apply distinct muscular strength, both in the propulsive phases of the front crawl technique strokes (Figueiredo *et al.*, 2013) and throwing actions (Nekooei *et al.*, 2019). This might explain the difference in isokinetic strength between these aquatic activities found in our study as the water polo players had higher the isokinetic strength values than the open water swimmers (Figure 2).

Our study found differences in left shoulder flexion between open water and water polo (Figure 2**,** A and C panels) for the variables peak torque (50.30 ± 24.90 vs. 77.35 ± 14.08) and total work (294.10 ± 190.20 vs. 446.05 ± 75.47) respectively, both at 60°/s. The literature reports that extensor muscles are strong contributors to the production of propulsive forces in front crawl technique strokes (McLaine *et al.*, 2018). Furthermore, another study (Olivier; Daussin, 2018) showed that the extension peak torque (r = -0.63; p = 0.006) was a performance predictor in 25 m swimming in water polo players, while the extension total work (r = 0.6921; p = 0.0126) showed a high correlation with performance in swimmers (Wiażewicz; Eider, 2021). Although we found no differences in the variables peak torque and total work (60°/s), the practitioners of the different aquatic activities achieved higher extension values (Figure 2), corroborating Wiażewicz and Eider (2016).

In the first half of the pull phase in the front crawl technique, force is generated as the shoulder moves in extension, adduction, and internal rotation (McLaine *et al.*, 2018). While the rotator cuff muscles act as stabilizers in forces produced by the extensor muscles of the shoulder, the axioscapular muscles rotate and stabilize the scapula against destabilizing forces produced by the extensor muscles and rotator cuff, showing the relevance of these muscles for force production and stabilization of the shoulder joint, with the extensors acting in propulsion (McLaine *et al.*, 2018). Therefore, both the front crawl technique and the throwing actions strongly require the internal rotator muscles of the shoulder joint (Olivier; Daussin, 2018), as well as the adductors and extensors. These differences can be explained by the demand on the upper limbs, as water polo performance involves repetitive passes and throws, in addition to besides the front crawl technique with the head out of the water (Olivier; Daussin, 2018).

Our study involved the calculation of the ER/IR ratio (Figure 2, E panel) and no differences were found; however, low values were identified for the right shoulder in open water (65.95 ± 15.45 %) and water polo (65.33 ± 16.29 %), in addition to the left shoulder in competitive swimming (61.92 ± 9.40 %), open water (60.06 ± 19.85 %), and water polo (61.15 ± 12.27 %). According to Ellenbecker and Davies (2000), the normality for the muscle balance should range from 66 to 75 %, with different values indicating muscle imbalances, where low rates are associated with potential injury risks. Regarding this, during swimming training, front crawl swimmers need to exert upper limb strength, overloading the shoulder joint and contributing to potential muscular imbalances (Batalha *et al*., 2015). The nature of water polo makes players one-sided by focusing on improving the preferred upper limb needed in throws, exposing them to injury risk factors (Nekooei *et al*., 2019).

We acknowledge a few limitations of our study, such as the low level of sport proficiency of the participants, the volume of swimming training, which can be considered low compared with the literature, as well as dry land strength training reported by only a few participants. The conclusions did not take into account possible differences between the sexes. These factors may have influenced the results of the variables analyzed. Future studies should take these limitations into account since different aquatic activities have their own particularities and therefore specific demands on the shoulder joint.

Conclusion

This study showed lower values of isokinetic force for the open water compared with the water polo in the variables of peak torque and total work, both in the internal rotation and flexion movements. This result indicates that the front crawl technique used by different groups of aquatic activity practitioners seems to influence the isokinetic strength performance, suggesting that the upper limb force production may differ according to the biomechanical patterns adopted. This finding suggests the existence of different behaviors of muscle strength application in the upper limbs depending on the specificity of the aquatic activities, with different demands for the shoulder joint muscles. This study also found muscle balance ratios outside the normative values, although with no differences between the groups. However, these findings might also help identify possible injury risks by adding land-based preventive strength exercises to the training program to strengthen external rotator muscles and shoulder joint stabilizers. Our data can help the respective coaches provide values for variables that influence sports performance and establish interventions in the training program that adapt to the demands imposed by each of these aquatic activities.

4.3. STUDY 2

Effect of two angular velocities on isokinetic shoulder evaluation: a network analysis applied to different practitioners of the front crawl technique

Abstract

Purpose: This study analyzed the effect of two angular velocities on the network structures of shoulder isokinetic strength and aquatic activities. **Methods:** Twenty-seven practitioners (six female and 21 male) of swimming (n = 7), open water (n = 7), triathlon (n = 7), and water polo (n = 6) participated in the study. Concentric actions at 60°/s (three repetitions) and 180°/s (20 repetitions) were measured using an isokinetic dynamometer. Peak torque and total work of the shoulders in internal and external rotation, flexion, and extension movements were assessed. To demonstrate the relationships and influence between the variables, we used three measures of centrality, in z scores: expected influence, closeness centrality and strength centrality. **Results:** By changing the angular velocity, the most prominent variables in the network structures also change concerning the centrality parameters. The total external rotation work of the non-preferred side took a central position at the angular velocity of 60°/s. The variable "aquatic activities" showed a peripheral positioning at both angular velocities. If the angular velocity of 180°/s is considered the closest to the specific features of the aquatic activities represented here, the total work of internal rotation (1.000) and peak torque of extension (0.959), both on the preferred side, showed great influence on performance of these aquatic activities. **Conclusion:** These elements deserve special attention from coaches, physical trainers, and practitioners because they strongly contribute to throws, the production of propulsive forces in front crawl technique, as well as to shoulder stabilization and control, thus being susceptible to intervention in training programs.

Keywords: performance, aquatic activities, isokinetic strength, centrality parameters.

Introduction

Isokinetic evaluation is an objective tool to investigate muscle torque that has brought important contributions to sports performance and clinical conditions of the shoulder joint (Tourny-Chollet *et al*., 2009; Batalha *et al*., 2018). During the isokinetic test, muscle torque decreases with increasing angular velocity, and such a decline is attributed to different patterns of neuromuscular activation (Baltzopoulos; Brodie, 1989) that occur according to the movement velocity (Gaudet; Tremblay; Begon, 2017). For example, greater forces production should occur at lower speeds (i.e., low angular velocity) (Baltzopoulos; Brodie, 1989). Other studies have used a low angular velocity to characterize variables indicative of pain and injury, and a high angular velocity, like in competitive performance (Gaudet; Tremblay; Begon, 2017; Batalha *et al.*, 2018). In swimming it is common to use 60 and 180°/s (Batalha *et al*., 2015; Wiażewicz; Eider, 2021), but such a pattern has not appeared for water polo players (Mota; Ribeiro, 2012; Olivier; Daussin, 2018). Despite the importance of this evaluation in open water and triathlon, we found no research studies involving isokinetic assessment.

Concerning performance, the front crawl technique are frequently used by swimmers (pool and open water swimming and triathletes) and water polo players in competitions and training (King *et al.*, 2022), where internal rotation, adduction, and extension movements of the shoulder joint are required in each stroke (McLaine *et al.*, 2018). However, in water polo, the front crawl technique is executed with arms elevated above the water and the athlete's head out of the water (Tan *et al*., 2009; de Jesus *et a*l., 2012). These technical requirements demand high upper limb strengths that influence performance (Batalha *et al.*, 2015), mainly the capacity to generate propulsive forces during the stroke (Seifert *et al*., 2004; Batalha *et al*., 2015; Psycharakis; Coleman, 2023), thus requiring periodic assessment of strength levels throughout training routines.

As suggested, the identification of performance predictor variables is critical for controlling and monitoring training (de Jesus *et al.*, 2019). In this regard, it has been demonstrated that peak flexion/extension torque is associated with performance in tethered swimming (Carvalho *et al.*, 2019). In water polo, total work and peak torque of shoulder extensors were predictors in the sprint swimming (25 m), while the peak torque of internal rotators were predictors in throwing velocity (Olivier; Daussin, 2018). These studies demonstrate the use of isokinetic variables in predicting performance. However, often the results may not confirm theoretically expected correlations, compromising the understanding of existing relationships (Vasques *et al.*, 2023). Thus it is important that researchers, coaches, and practitioners investigate the correlation between multivariate datasets to understand the phenomena that impact performance through network analysis (Fiori *et al*., 2022; Vasques *et al*., 2023).

Compared to regression analysis, network analysis does not eliminate any variables from the model due to multicollinearity issues, thus allowing to identify the pattern of relationships between variables, providing information on their importance and influence within the network structures (Hevey, 2018), which is useful for training program intervention (Fiori *et al.*, 2022). In addition, it checks the multiple simultaneous relationships in a complex system, formed by the centrality parameters, which will determine the variables most susceptible to intervention (Epskamp *et al.*, 2012). Therefore, this study aimed to analyze the effect of two angular velocities on the estimated network structures of shoulder isokinetic strength and aquatic activities (swimming, open water, triathlon, and water polo). Our hypothesis was that the change in angular velocity influences the values of the centrality parameters in the estimated network structures.

Materials and methods

Participants

Twenty-seven (six females and 21 males) practitioners from the swimming, open water, triathlon, and water polo participated in the study. Table 2 shows the main baseline characteristics of the participants. The following inclusion criteria were set: (i) aged 15 years old or above (Batalha *et al.*, 2018); (ii) regular training for competitions over the last three years (Lawsirirat; Chaisumrej, 2017); and (iii) a minimum training frequency of three times a week (Mota; Ribeiro, 2012). In turn, the following exclusion criterion was considered: (iv) clinical history of upper limb disorders (Batalha *et al.*, 2018). The study was approved by the local Institutional Ethics Committee and followed the Declaration of Helsinki. All participants and legal guardians of those under the age of 18 years old were informed about the objectives, assessment procedures, risks, and benefits. In addition, they all signed the written informed consent.

Table 2 – Mean and standard deviation (SD) values of the baseline characteristics of age (years), body mass (kg), height (m), and arm span (m) of the participants

	Swimming (n = 7)	**Open water (n = 7)**	**Triathlon (n = 7)**	**Water polo (n = 6)**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Age (years)	22.00 ± 9.00	32.00 ± 15.00	45.00 ± 8.00	27.00 ± 4.00
Body mass (kg)	65.90 ± 4.88	67.41 ± 11.88	79.17 ± 20.90	80.37 ± 11.25
Height (m)	1.71 ± 0.06	1.70 ± 0.09	1.71 ± 0.10	1.79 ± 0.08
Arm span (m)	1.77 ± 0.07	1.72 ± 0.08	1.75 ± 0.10	1.83 ± 0.10

Procedures

Each participant was invited to attend the lab on a specific day and time. Initially, a questionnaire was applied to identify each participant's main information, such as aquatic activities, training volume (h), and training background (years). Next, the participants answered the Dutch Handedness Questionnaire (Van Strien, 2003) for hand-side preference. The results of the laterality questionnaire were used to define the preferred and non-preferred upper limbs. The anthropometric measurements of body mass, height, and arm span were recorded.

Isokinetic assessment

The isokinetic assessment was performed using an isokinetic dynamometer (Biodex 4 Multi-Joint System, New York) in the shoulder joint internal and external rotation, flexion, and extension. The familiarization process consisted of two repetitions in each joint movement and angular velocities of 60 and 180°/s (Batalha *et al.*, 2018). The participant was positioned in the seated isokinetic dynamometric chair for the shoulder joint external and internal rotation (Figure 3**,** A panel), respectively), with a 90° range of motion in shoulder abduction and elbow flexion, respectively (Batalha *et al.*, 2018). For the shoulder joint flexion and extension, the participant was positioned in the dynamometer chair with forearm supination similar to hand positioning during swimming (Figure 3**,** B panel; (Carvalho *et al.*, 2019). The right shoulder joint was assessed first and then the left.

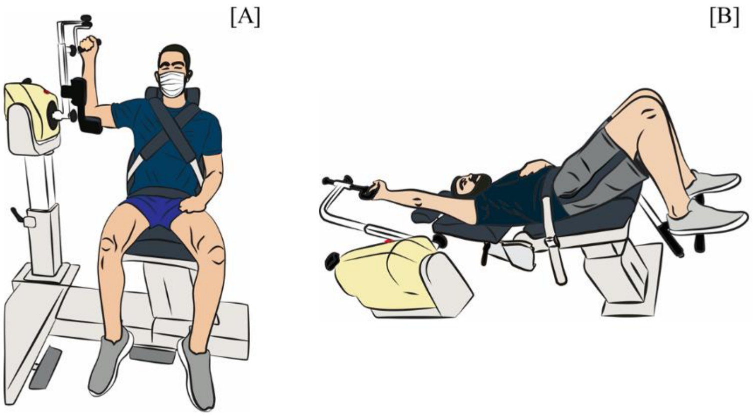

Figure 3 – A and B panels: external and internal rotation, flexion, and extension, respectively.

A protocol was used to assess the isokinetic strength of the internal and external rotators (Batalha *et al.*, 2018) and another for the flexor and extensor muscles (Wiażewicz; Eider, 2021). In both protocols, a goniometer was used to align the shoulder joint with the mechanical axis of the equipment. The participants were stabilized with a pelvic belt to avoid compensation with body movement (Batalha *et al.*, 2018). The following two protocols were used to assess the shoulder joint movements: (i) three maximum concentric repetitions of internal and external rotation and flexion and extension at 60°/s angular velocity and (ii) 20 maximum concentric repetitions of internal and external rotation and flexion and extension at 180°/s angular velocity. Two-min of rest between angular velocities, five-min to change body side, and 10 min at movement changes were provided. During all repetitions, the participants were verbally encouraged to perform with maximum effort (Wiażewicz; Eider, 2021).

Data collection

The variables were analyzed for the right and left shoulders. The values were recorded and accessed from the report provided by the isokinetic dynamometer for peak torque (N·m) and total work (J) in internal and external rotation, flexion, and extension movements. The peak torque is defined as the maximum torque produced by the joint over the entire range of motion (Perrin, 1993), while total work is the sum of the work performed in all test repetitions (Kannus, 1994).

Statistical analysis

Data distribution was verified using the Shapiro-Wilk test. Descriptive statistics was calculated with mean, standard deviation, and mean 95% confidence intervals. The Network Analysis Machine Learning technique was used (Epskamp *et al.*, 2012) to verify the multiple simultaneous relationships among isokinetic strength variables (peak torque and total work) and aquatic activities (swimming, open water, triathlon, and water polo). This analysis considers a complex system formed among the analysis parameters. Thus, centrality measures were generated to learn the role of each variable in the system. For a better understanding of the centrality of each variable, the values were transformed into a z-score. The following three measures were used in this study (Epskamp *et al.*, 2012):

(i) Expected Influence: estimated from the magnitude of negative and positive edges that connect a node to others.

(ii) Closeness Centrality: determined from the inverse of the distances from one node to all others.

(iii) Strength Centrality: the sum of all the weights of the paths that connect one node to the others.

Thus, to avoid eliminating variables, two networks were framed and analyzed: one for 60°/s and another for 180°/s angular velocities, both with the preferred and non-preferred upper limb. Regarding centrality measures, the more distant from zero, the greater relevance of the variable within the system. To carry out the analysis, we adopted a cutoff point of 0.900 to indicate the relevance of each parameter in the identified networks. In this study, the random field model “pairwise Markov” was used to improve the accuracy of the partial correlation network. In both networks, the variables were numbered from one to 17, where: number one represented the aquatic activities group (pool and open water swimming, triathlon, and water polo); the even numbers (two to 16) indicated the right and left isokinetic peak torque variables; and the odd numbers (three to 17) represented the total work on both sides of the shoulder joint. The estimation algorithm used assumes the highest-order iteration of the true graph. The algorithm includes an L1 penalty (regularized neighborhood regression). Regularization is achieved by a minus absolute selection and contraction operator that controls model dispersion (Friedman; Hastie; Tibshirani, 2008).

The Extended Information Bayesian Criterion (EBIC) was used (more conservative to select the Lambda from the regularization parameter). EBIC uses a hyperparameter (y) that determines how much EBIC selects sparse models (Chen; Chen, 2008; Foygel; Drton, 2010). The value is usually set between 0 and 0.5. Higher values indicate more parsimonious models with fewer edges. A value closer to 0 indicates an estimate with more edges. A y-value of 0.25 is potentially a useful value for exploratory networks, which was used herein (Foygel; Drton, 2010). The fit function returns the estimated parameters to a weighted and unweighted adjacency matrix. Positive and negative relationships in the network are expressed in blue and in red, respectively. The thickness and intensity of the colors represent the magnitude of the associations. We used the JASP program version 0.17.2.0 for all analyses and building of the networks.

Results

Table 3 shows the values of mean, standard deviation, and 95% confidence interval of the isokinetic variables of peak torque and total work of the preferred and non-preferred sides at angular velocities 60 and 180°/s.

Table 3 **–** Values of mean, standard deviation (SD), and confidence interval (95% CI) of the variables isokinetic in the angular velocities 60 and 180°/s

Angular velocity 60°/s			**Angular velocity 180°/s**		
Variable	**Mean ± SD**	**95% CI**	**Variable**	**Mean ± SD**	**95% CI**
PT IR P (N·m)	48.31 ± 16.11	[41.94 – 54.68]	PT IR P (N·m)	49.40 ± 16.64	[42.82 – 55.98]
TW IR P (J)	176.00 ± 64.10	[150.64 – 201.36]	TW IR P (J)	1008.43 ± 369.69	[862.19 – 1154.63]
PT IR NP (N·m)	50.60 ± 15.53	[44.46 – 56.75]	PT IR NP (N·m)	50.67 ± 17.22	[43.86 – 57.48]
TW IR NP (J)	186.09 ± 61.91	[161.60 – 210.58]	TW IR NP (J)	1059.03 ± 381.99	[907.92 – 1210.13]
PT ER P (N·m)	33.02 ± 9.86	[29.12 – 36.92]	PT ER P (N·m)	30.71 ± 8.95	[27.17 – 34.25]
TW ER P (J)	116.53 ± 37.07	[101.87 – 131.20]	TW ER P (J)	662.81 ± 202.77	[582.59 – 743.02]
PT ER NP (N·m)	32.42 ± 9.70	[28.57 – 36.24]	PT ER NP (N·m)	30.80 ± 9.83	[26.91 – 34.69]
TW ER NP (J)	113.96 ± 34.27	[100.41 – 127.52]	TW ER NP (J)	638.74 ± 206.72	[556.96 – 720.52]
PT FL P (N·m)	69.49 ± 19.00	[61.97 – 77.00]	PT FL P (N·m)	78.17 ± 19.92	[70.29 – 86.05]
TW FL P (J)	395.73 ± 128.02	[345.09 – 446.38]	TW FL P (J)	2226.32 ± 744.45	[1931.83 – 2520.82]
PT FL NP (N·m)	66.06 ± 17.80	[59.01 – 73.10]	PT FL NP (N·m)	74.43 ± 18.01	[67.31 – 81.55]
TW FL NP (J)	368.17 ± 116.70	[322.00 – 414.33]	TW FL NP (J)	2096.59 ± 767.43	[1793.00 – 2400.17]

PT EX P (N·m)	82.06 ± 28.11	[70.94 – 93.18]	PT EX P(N·m)	74.91 ± 22.67	[65.94 – 83.88]
TW EX P (J)	477.19 ± 166.90	[411.16 – 543.21]	TW EX P (J)	2586.34 ± 1009.93	[2186.83 – 2985.86]
PT EX NP (N·m)	82.79 ± 26.21	[72.42 – 93.15]	PT EX NP (N·m)	76.94 ± 23.24	[67.75 – 86.14]
TW EX NP (J)	486.19 ± 162.27	[422.00 – 550.38]	TW EX NP (J)	2656.94 ± 972.50	[2272.23 – 3041.65]

Peak torque (PT), total work (TW), internal rotation (IR), external rotation (ER), flexion (FL), extension (EX), preferred (P), and non-preferred (NP).

Figures 4 and 5 illustrate the network plots generated for the 60 and 180º/s angular velocities from the isokinetic variables of peak torque, total work, and aquatic activities, in the movements of internal rotation and external rotation, flexion, and extension of the preferred and non-preferred sides. Blue and red edges indicate positive and negative relationships, respectively. The thickness of the edges represents the strength of the interaction between the variables. In the 60°/s network (Figure 4) we observed that variables peak torque and total work of external rotation of the non-preferred side assume more central positions, especially total work of external rotation of the non-preferred. We can also identify a more isolated interconnected cluster formed between peak torque and total work of extension of the preferred side, and peak torque and total work of extension of the non-preferred side. In addition, we found a strong interaction on the preferred side between peak torque and total work of internal rotation, as well as between peak torque and total work of flexion.

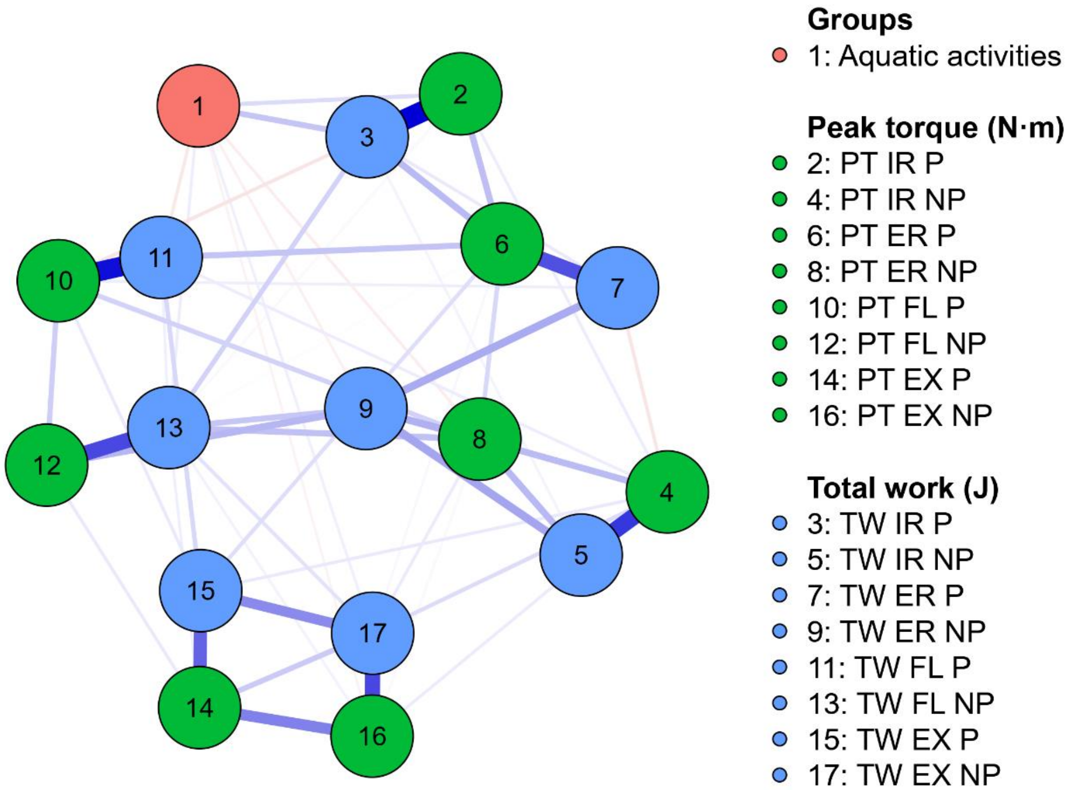

Figure 4 **–** Network plots at angular velocity 60°/s of the the isokinetic variables and aquatic activities. Peak torque (PT), total work (TW), internal rotation (IR), external rotation (ER), flexion (FL), extension (EX), preferred (P), and non-preferred (NP).

In the 180°/s network (Figure 5), it becomes difficult to identify a more central variable. In this network structure, the total work of external rotation of the non-preferred side assumes a peripheral position. Furthermore, there seem to be four more defined clusters between peak torque of flexion of the preferred side and total work of flexion of the non-preferred side; peak torque of extension of the preferred side and total work of extension of the non-preferred side; aquatic activities and total work of internal rotation of the preferred side; and peak torque of internal rotation and total work of external rotation, both of the non-preferred side. Stronger interactions were identified for the preferred side between the variables: peak torque and total work of internal rotation, as well as peak torque and total work of external rotation, while for the non-preferred side, between peak torque and total work of internal rotation.

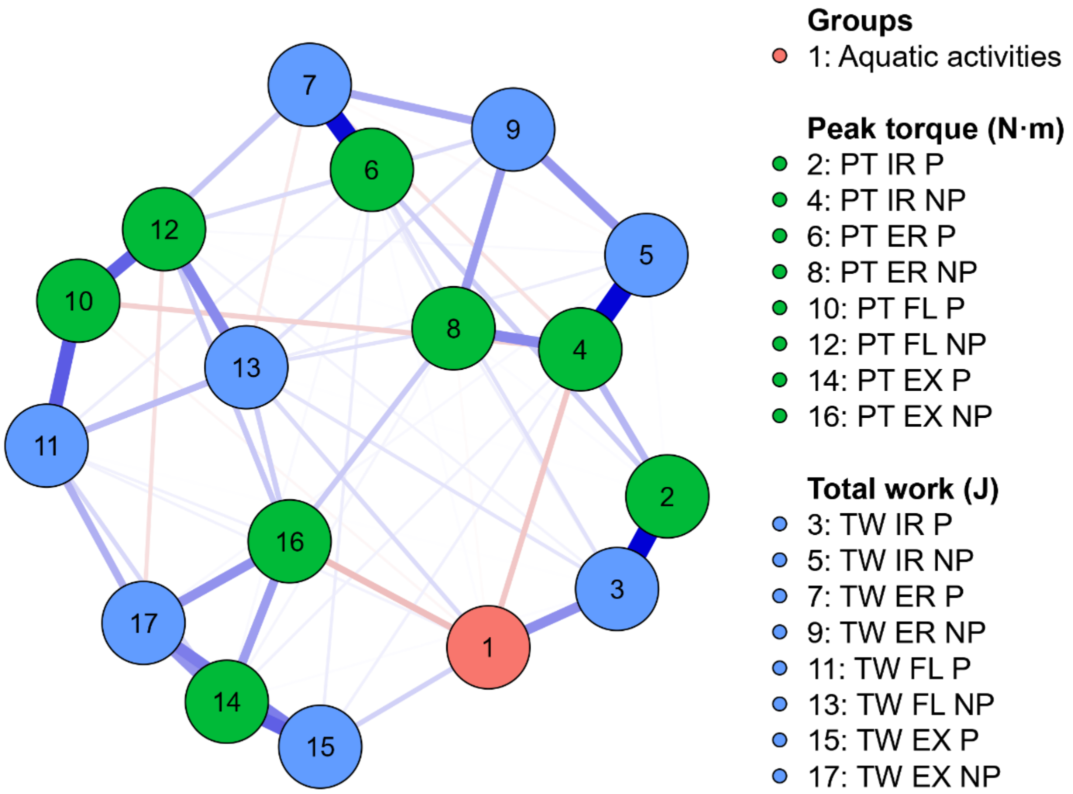

Figure 5 – Network plots at angular velocity 180°/s of the isokinetic variables and aquatic activities. Peak torque (PT), total work (TW), internal rotation (IR), external rotation (ER), flexion (FL), extension (EX), preferred (P), and non-preferred (NP).

Table 4 shows the centrality measures for the isokinetic variables and aquatic activities for networks 60 and 180°/s. In the 60°/s network, we highlight the following variables for the preferred side: peak torque of external rotation (Closeness Centrality, Strength Centrality, and Expected Influence), total work of internal rotation (Strength Centrality and Expected Influence), and total work of external rotation (Closeness Centrality). For the non-preferred side, we found the following variables: total work of flexion (Closeness Centrality, Strength Centrality, and Expected Influence) and total work of extension (Strength Centrality and Expected Influence). In the 180°/s network, we highlighted the "aquatic activities" variable (Closeness Centrality), in addition to the following isokinetic variables for the preferred side: peak torque of flexion (Closeness Centrality), peak torque of extension (Expected Influence), total work of internal rotation (Expected Influence), and total work of flexion (Closeness Centrality). For the non-preferred side, the most prominent variables were peak torque of internal rotation (Closeness Centrality and Strength Centrality), peak torque of external rotation

(Closeness Centrality), peak torque of flexion and extension (Closeness Centrality), and total work of internal rotation (Closeness Centrality).

Table 4 – Centrality measures of isokinetic variables and aquatic activities at angular velocities 60 and 180°/s

Network – Angular velocity 60°/s				Network – Angular velocity 180°/s			
Variable	**Closeness**	**Strength**	**Expected influence**	**Variable**	**Closeness**	**Strength**	**Expected influence**
Aquatic activities	0.541	0.387	0.136	Aquatic activities	0.922	0.586	0.162
PT IR P (N·m)	0.754	0.781	0.833	PT IR P (N·m)	0.867	0.650	0.846
TW IR P (J)	0.789	1.000	0.951	TW IR P (J)	0.850	0.768	1.000
PT IR NP (N·m)	0.793	0.830	0.777	PT IR NP (N·m)	0.990	1.000	0.715
TW IR NP (J)	0.821	0.800	0.780	TW IR NP (J)	0.905	0.689	0.880
PT ER P (N·m)	1.000	0.928	0.991	PT ER P (N·m)	0.804	0.666	0.867
TW ER P (J)	0.952	0.665	0.600	TW ER P (J)	0.872	0.779	0.766
PT ER NP (N·m)	0.834	0.797	0.850	PT ER NP (N·m)	0.950	0.581	0.737
TW ER NP (J)	0.890	0.816	0.812	TW ER NP (J)	0.893	0.611	0.795
PT FL P (N·m)	0.868	0.823	0.761	PT FL P (N·m)	0.991	0.736	0.712
TW FL P (J)	0.898	0.811	0.768	TW FL P (J)	0.914	0.669	0.871
PT FL NP (N·m)	0.885	0.672	0.717	PT FL NP (N·m)	0.900	0.708	0.779
TW FL NP (J)	0.900	0.906	0.968	TW FL NP (J)	0.810	0.677	0.779
PT EX P (N·m)	0.663	0.767	0.819	PT EX P (N·m)	0.799	0.737	0.959
TW EX P (J)	0.737	0.797	0.851	TW EX P (J)	0.776	0.622	0.810
PT EX NP (N·m)	0.646	0.736	0.739	PT EX NP (N·m)	1.000	0.754	0.690
TW EX NP (J)	0.723	0.937	1.000	TW EX NP (J)	0.891	0.785	0.879

Peak torque (PT), total work (TW), internal rotation (IR), external rotation (ER), flexion (FL), extension (EX), preferred (P), non-preferred (NP).

Discussion

This study aimed to analyze the effect of two angular velocities on the estimated network structures of shoulder isokinetic strength and aquatic activities (swimming, open water, triathlon, and water polo). The results showed that by changing the angular velocity, the variables that are most prominent within the network structures also change concerning the centrality parameters. Our findings confirm the hypothesis that the change in angular velocity influences the values of the centrality parameters in the estimated network structure. Even though all participants in this study belong to aquatic activities that perform the front crawl technique, some differences must be considered. Sprint swimmers and water polo players tend to achieve higher angular velocities in their practices than long-distance swimmers (pool and open water) and triathletes. This can be explained by the higher intensity actions of swimming, such as the high stroke frequency of sprint swimmers (Seifert; Chollet; Bardy, 2004), as well as the explosive actions of water polo players, including speed swimming, block, wrestle, burst and throwing (Tan *et al*., 2009).

This study estimated networks for two angular velocities. Our findings showed that the total work of external rotation on the non-preferred side assumed a more central position only at the angular velocity of 60°/s (Figure 4). This suggests that this variable assumes an important role that is fundamental in actions in which the strength of the upper limbs predominate, since at this angular velocity it is possible to reach higher levels of muscle strength (Carvalho *et al.*, 2019). As for the external rotation of the shoulders, it has been demonstrated that the middle and posterior deltoid, upper, middle, and lower trapezius, supraspinatus, and infraspinatus muscles are highly active (41-71% of maximal voluntary activity), acting in controlling the movements (Gaudet; Tremblay; Begon, 2017). Therefore, this information seems to be useful, especially for sprint swimmers and water polo players, since the strength of the external rotator muscles is needed to slow down the movements of the internal rotators (Mota; Ribeiro, 2012) both in the front crawl technique and throwing actions (specifically in water polo).

Our results revealed that the “aquatic activities” variable showed a peripheral positioning in both angular velocities, indicating no influence on the networks. In addition, we also identified a strong interaction for the preferred side between the following variables: peak torque and total work of internal rotation, as well as peak torque and total work of flexion. These findings suggest that these pairs of variables influence each other, corroborating the literature, which reports that during the propulsive phases of swimming and throwing actions in water polo, strength is mainly demanded from the internal rotator muscles (Yanai; Hay, 2000; Olivier; Daussin, 2018). Associated with this, there is the participation of the pectoralis major and latissimus dorsi muscles acting with greater activation in internal rotation movements (45-85% of maximal voluntary activity) (Gaudet; Tremblay; Begon, 2017). In contrast, the flexors act as antagonists (McLaine *et al.*, 2018), slowing down the movements of the internal rotators (Mota; Ribeiro, 2012).

In the 180°/s network (Figure 5), we found no central variable. However, stronger interactions were found for the preferred side among the following variables: peak torque and total work of internal rotation, peak torque and total work of external rotation. In turn, for the non-preferred side, we found such interactions between peak torque and total work of internal rotation. These variables are associated with performance, where peak torque of internal rotation (r = -0.65; p = 0.009) and total work (r = -0.76; p = 0.001), respectively, were able to predict performance in throwing velocity and in 25 m swimming in water polo (Olivier; Daussin, 2018). These findings have provided important contributions to muscle strength in isokinetic conditions, especially when the angular velocity used is like the velocity of a specific modality (Carvalho *et al.*, 2019).

Also concerning the isokinetic variables, even though the importance of the variable peak torque of the shoulder rotator muscles and its practical application in the training program are known (Mota; Ribeiro, 2012; Batalha *et al.*, 2018), we highlight the relevance of the total work in the internal and external rotation movements, specifically at this angular velocity, since it allows determining variables that affect performance, such as muscle fatigue (Batalha *et al.*, 2018). Therefore, at higher velocities, while achieving lower levels of strength, there is a predominance of muscular resistance (Batalha *et al.*, 2018). This suggests that the prominent variables of this network may be interesting in intervention, especially in long-distance swimmers (swimming and open water) and triathlon, aquatic activities which require resistance to muscle fatigue (Bentley *et al.*, 2002; Batalha *et al*., 2018; Rodríguez *et al*., 2021).

The network analysis revealed that by changing the angular velocity, the variables that are most prominent within the network structures also change concerning the centrality parameters (Table 4). This can be explained by the influence of angular velocity on muscle recruitment, as shown, changed from 60 to 240°/s (Gaudet; Tremblay; Begon, 2017). In the 60°/s network, the variables of total work of internal rotation on the preferred side and total work of extension on the non-preferred side stood out in the parameters “Strength Centrality” and “Expected Influence”. Respectively, it represents the importance of these variables by their stronger relationships and influence, making practical interventions focused on the most influential variables feasible (Hevey, 2018). The peak torque of external rotation on the preferred side and the total work of flexion on the non-preferred side stand out in all the parameters. The total work of external rotation on the preferred side stands out only in “Closeness Centrality”, indicating that it can be affected quickly by the interventions and make changes in network structure. This reinforces the role of internal rotation and extension movements, essential in the propulsive phases of the front crawl technique, in addition to external rotation and flexion, acting in stabilization and slowdown in swim strokes (Mota; Ribeiro, 2012; McLaine *et al.*, 2018).

In the 180°/s network, among the variables highlighted and centrality parameters analyzed (Table 4), total work of internal rotation and peak torque of extension variables, both from the preferred side, stood out in the “Expected Influence” parameter. This result indicates that these variables are targets for direct intervention. Therefore, if the angular velocity at 180º/s is considered the closest to the specificities of the aquatic activities represented herein, coaches, physical trainers, and practitioners should pay more attention to the total work of internal rotation and peak torque of extension, both on the preferred side. Since the movements of internal rotation and extension are used by swimmers in the front crawl technique in the propulsive phases, they overload the shoulder joint and contributes to potential muscle imbalances (Batalha *et al.*, 2015). In addition, the exposure to a macrocycle of swimming training is enough to trigger muscle imbalances, inducing pain and risk of injury (Batalha *et al.*, 2015).

During the front crawl technique, upper limb strength is needed to overcome the active drag in the propulsive stroke phases (Figueiredo *et al.*, 2013; Psycharakis; Coleman, 2023), requiring internal rotation, adduction, and extension movements, which are performed by the pectoral, latissimus dorsi, and subscapularis muscles, all strongly contributing to this technique (Yanai; Hay, 2000). The external rotator and flexor muscles are important in stabilizing the shoulder joint to counterbalance the force produced by their agonists (McLaine *et al.*, 2018). However, open water swimmers and triathletes swim at longer stroke length and lower levels of stroke frequency (Bentley *et al.*, 2002; Rodríguez *et al.*, 2021), as in long-distance pool swimmers (Seifert; Chollet; Bardy, 2004), unlike sprinter swimmers and water polo players, whose stroke frequency is higher than the stroke length (Seifert; Chollet; Bardy, 2004; de Jesus *et al.*, 2012). Furthermore, water polo players perform three styles of front crawl technique: front crawl with head under water, front crawl with head above water, and front crawl when leading the ball (de Jesus *et al.*, 2012), demanding high forces from the shoulder joints.

The biomechanical characteristics involving the general kinematics of swimming (e.g., stroke length and stroke frequency) and different styles of the front crawl (e.g., front crawl with head under water, front crawl with head above water, in addition to throwing actions in water polo) of the aquatic activities represented in our study require different adaptations of the shoulder joint. Thus, they might influence the force production during the isokinetic test and consequently, the values of peak torque and total work. Therefore, the analysis of the interactions between the variables in our study allowed us to identify that once manipulated, the isokinetic variables can impact the structure of training, in addition to defining practical intervention strategies best suited to the performance of pool and open water swimmers, triathletes, and water polo players.

It is important to recognize some limitations of our study, such as the synthetic sample, considered a relevant aspect in network analyses. A larger sample size would be ideal as it would indicate greater precision in estimating the analyzed parameters, as well as greater statistical power. A larger sample size would also allow estimating networks controlling for aquatic activities. Another limitation is the use of the isokinetic dynamometer which it is not accessible to all coaches. Perhaps further studies could develop network analyses using equipment closer to the reality of the aquatic activities represented here, such as the load cell. However, our study provided indications of variables that should be paid attention to by coaches, physical trainers, and practitioners in training sessions.

The network analysis showed that the most prominent centrality parameters were altered when the angular velocity changed from 60 to 180°/s. If the angular velocity at 180º/s is considered as the closest to the specificities of the aquatic activities represented here, coaches, physical trainers, and practitioners should pay more attention to the total work of internal rotation and the peak torque of extension, both on the preferential. These variables that are accessed from the isokinetic test and linked to swimming performance during internal rotation and extension movements strongly contribute to throws and the production of propulsive forces in front crawl technique, particularly the dominant upper limb. The isokinetic test allowed accessing variables that can be manipulated and are subject to intervention in water and dry land training programs, thus helping optimize the sport performance of pool and open water swimmers, triathletes, and water polo players.

5. GENERAL DISCUSSION

It has been proposed that strength is a determining biomechanical feature in performance (Carvalho *et al.*, 2019; Tan *et al*., 2021). Therefore, studies have assessed upper limb strength in front crawl practitioners to improve performance in aquatic activities (Batalha *et al*., 2015; Oliver; Daussin, 2018). In our studies, we assess the biomechanical parameters by measuring isokinetic strength in different groups of aquatic activity practitioners. This type of assessment has been applied to swimmers (Tourny-Chollet, Seifert; Chollet, 2009; Carvalho *et al.*, 2019) and water polo players (Mota; Ribeiro, 2012; Oliver; Daussin, 2018). Research in open water (Rodríguez *et al*., 2021) and triathlon (Bentley *et al*., 2002) has focused on analyzing the effects of age and gender on performance, as well as physiological variables that can affect performance.

Our first study showed that open-water swimmers had lower values in the isokinetic test than water polo players. The literature reports that during training, practitioners of these activities are subjected to high volumes of repetitive exercises (Baldassarre *et al*., 2017; Annett *et al*., 2000), which require high upper limb strength (Batalha *et al*., 2018). These strength demands on the shoulder joint can be explained by the greater contribution of the upper limbs in producing propulsive forces during stroke (Seifert; Chollet; Bardy, 2004; Psycharakis; Coleman, 2023). Nor should we forget that water polo players, in addition to swimming the front crawl technique, require high muscle strength in the upper limbs to perform the throws (Olivier; Daussin, 2018).

In general, overcoming active drag requires powerful movements of rotation, adduction, and extension of the shoulder joint in each stroke (Tourny-Chollet *et al*., 2009; McLaine *et al*., 2018). Thus, it is expected that these muscle groups are stronger not only in hydrodynamic conditions but also in dry land tests, as previously demonstrated (Batalha *et al*., 2018; Mota; Ribeiro, 2012; Wiażewicz; Eider; 2016) and confirmed in our studies for the isokinetic torque of internal rotation movements. However, the external rotation force has the function of controlling the glenohumeral joint during swimming (McMaster *et al*., 1998) and throwing actions in water polo, and must be strong enough to slow down the movement of the internal rotators (Mota; Ribeiro, 2012). Therefore, coaches need to pay attention to external rotation strength since low values might indicate imbalances between the agonist-antagonist muscles, thus being a potential risk of pain and injury (Batalha *et al*., 2018). Compensatory exercises for external rotators outside the water are suggested for the training program (Batalha *et al*., 2015; Batalha *et al*., 2020). On this subject, one of our partial results sought to identify the correlation between training volume and muscle imbalances in swimmers (Appendix B). We also investigated whether the volume of aquatic training influences conventional balance ratios in swimmers who do strength training on land (Appendix C), but no differences were found in either investigation.

Practitioners of the different aquatic activities had higher extension values, corroborating the findings of Wiażewicz and Eider (2016). As reported, the extensor muscles play a role in producing propulsive forces in the front crawl technique (McLaine *et al*., 2018), being related to performance in swimmers (Wiażewicz; Eider, 2021), as well as 25m swimming performance in water polo players (Olivier; Daussin, 2018). Our first study showed differences in flexion movements between open water and water polo. Knowing that the agonist muscles (internal rotators, adductors, and extensors) are strong contributors to propulsion during the front crawl technique (Tourny-Chollet *et al*., 2009; McLaine *et al*., 2018), we can understand that the antagonist muscles (i.e., external rotators, abductors and flexors) stabilize the scapula and decelerate the forces produced by the agonist muscles (McLaine *et al.*, 2018). These results can be justified by as water polo performance involving repetitive passes and throws, as well as the front crawl technique with the head out of the water (Olivier; Daussin, 2018), requiring greater strength from the shoulder joint.

Our second study sought to investigate the relationships between isokinetic variables and aquatic activities in the estimated network structures. The variable total work of external rotation on the non-preferred side assumed a central position at an angular velocity of 60°/s, suggesting that it is important in actions requiring high upper limb forces due to the greater force production at lower angular velocities (Baltzopoulos; Brodie, 1989). We also identified a strong interaction for the preferred side between the pairs of variables: peak torque and total work of internal rotation and peak torque and total work of flexion, both showing mutual influence. Sprint swimmers and water polo players perform high-intensity swimming, demanding high levels of strength, especially from the internal rotator muscles during the propulsive phases of swimming and throwing in water polo (Yanai; Hay, 2000; Olivier; Daussin, 2018). Therefore, they need the external rotator and flexor muscles to slow down the movements of the antagonist muscles (Mota; Ribeiro, 2012; McLaine *et al*., 2018).

On the 180°/s grid, strong interactions were found between the variables peak torque and total work of internal rotation, and peak torque and total work of external rotation, for the preferred side, and peak torque and total work of internal rotation, for the non-preferred side. Although peak torque is commonly used in isokinetic assessments in swimming (Batalha *et al*., 2015) and water polo (Oliver; Daussin, 2018), total work at high angular velocity allows us to determine variables that affect performance, such as muscle fatigue (Batalha *et al*., 2018). Considering that muscular resistance predominates at higher angular velocities (Batalha *et al*., 2018), these findings suggest that the prominent variables of this network may be useful in the intervention of aquatic activities that require resistance to muscular fatigue, such as swimming (long distance), open water, and triathlon (Bentley *et al*., 2002; Batalha *et al*., 2018; Rodríguez *et al*., 2021).

Regarding the centrality parameters, in the 60°/s grid, the variables total work of internal rotation on the preferred side and total work of extension on the non-preferred side stood out in the “Strength Centrality” and “Expected Influence” parameters, showing strong relationships and influence of these variables and indicating that they are amenable to practical interventions (Hevey, 2018). Peak torque of external rotation on the preferred side and total work of flexion on the non-preferred side stood out in all parameters. The total work of external rotation stood out only in “Closeness Centrality”, indicating that it can be affected quickly by interventions and cause changes to the network structure. These findings reinforce the role of internal rotation and extension movements in the propulsive phases of the front crawl technique, as well as external rotation and flexion during stabilization and deceleration in the stroke and throw in water polo (Mota; Ribeiro, 2012; McLaine *et al*., 2018).

In the 180°/s net, total internal rotation work and peak extension torque, both on the preferred side, were prominent in the "Expected Influence" parameter, suggesting that these variables are targets for direct intervention. In this case, if we consider that the angular velocity at 180º/s is the closest to the performance speed of the aquatic activities in this study, the total work of internal rotation and peak torque of extension, both on the preferred side, deserve special attention. As reported, the repetition of these movements during the front crawl technique (as well as in the throwing actions in water polo) overloads the shoulder joint and, as previously demonstrated, a macrocycle of swimming training is enough to trigger muscle imbalances, thus strongly contributing to pain and risk of injury (Batalha *et al*., 2015). In addition, bilateral force asymmetries have been identified as factors that influence performance, as they can increase active drag and intra-cycle speed variations, affecting the production of propulsive forces (Sanders et al., 2011). We therefore sought to analyze the relationship between the classification of FINA points and the symmetry index of isokinetic torque in swimmers (Appendix E). The results showed no association. Although it has been reported that the application of symmetrical force influences swimming performance, this effect was not observed in our study.

6. FINAL CONSIDERATIONS

The comparison of isokinetic strength variables showed results that suggest differences in upper limb force production. These findings may have been influenced by the biomechanical patterns adopted by different groups of aquatic activity practitioners during the front crawl technique, such as in open water and water polo. The different behaviors during the application of shoulder muscle strength may result from the specificities of each aquatic activity, mainly due to the muscular demands in the propulsive phases of the stroke. Although there were no differences between groups, this study also found muscle imbalance values. This reinforces the importance of considering conventional balance ratios on an individual basis, as these findings can help identify potential risks of pain and injury. As such, we should suggest preventive ground-based strength exercises within the training program to strengthen the external rotator muscles and promote muscle strength balance in the shoulder joint.

The network analysis showed that by changing the angular velocity from 60 to 180°/s, the centrality parameters that stand out most in the estimated networks also change. This suggests that changes in speed influence muscle strength levels, which might be useful in prescribing training in swimming, open water, triathlon, and water polo – all aquatic activities requiring different speeds in competitive performance involving the kinematics of the front crawl technique. Therefore, if the angular velocity of 180º/s is considered the closest to the performance velocity of these aquatic activities, attention should be paid to the total work of internal rotation and the peak torque of extension, both on the preferred side. Internal and external rotation movements are directly linked to the production of propulsive forces during stroke in the front crawl technique, as well as in the throwing actions of water polo players.

Despite not reproducing the hydrodynamic position during the front crawl technique, the isokinetic test provides reliable and valid data on variables that can be manipulated. Therefore, they can also be targeted for intervention in training programs both in the water and on dry land, helping coaches and practitioners optimize sporting performance in each of the aquatic activities represented here.

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8. REFERENCES

BALTZOPOULOS, Vasilios; BRODIE, D.A. Isokinetic dynamometry: applications and limitations. **Sport Medicine**, [*s. l.*], v. 8, n. 2, p. 101–116, 1989.

BATALHA, Nuno *et al.* Does a land-based compensatory strength-training programme influences the rotator cuff balance of young competitive swimmers?. **European Journal of Sport Science**, [*s. l.*], v. 15, n. 8, p. 764–772, 2015.

BATALHA, Nuno *et al.* Does a water-training macrocycle really create imbalances in swimmers' shoulder rotator muscles? **European Journal of Sport Science**, [*s. l.*], v. 15, n. 2, p. 167–172, 2015. Disponível em: http://dx.doi.org/10.1080/17461391.2014.908957.

BATALHA, Nuno *et al.* The effectiveness of land and water based resistance training on shoulder rotator cuff strength and balance of youth swimmers. **Journal of Human Kinetics**, [*s. l.*], v. 62, n. 1, p. 91–102, 2018. Disponível em: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6006528/.

BENTLEY, David J. *et al.* Specific aspects of contemporary triathlon: implications for physiological analysis and performance. **Sports Medicine**, [*s. l.*], v. 32, n. 6, p. 345–359, 2002.

CARVALHO, Diogo D. *et al.* In-water and on-land swimmers' symmetry and force production. **International Journal of Environmental Research and Public Health**, [*s. l.*], v. 16, n. 24, p. 1–9, 2019. Disponível em: https://www.mdpi.com/1660-4601/16/24/5018.

CHEN, Jiahua; CHEN, Zehua. Extended Bayesian information criteria for model selection with large model spaces. **Biometrika**, [*s. l.*], v. 95, n. 3, p. 759–771, 2008.

DE JESUS, Karla *et al.* Kinematic analysis of three water polo front crawl styles. **Journal of Sports Sciences**, [*s. l.*], v. 30, n. 7, p. 715–723, 2012.

DE JESUS, Kelly *et al.* Predicting centre of mass horizontal speed in low to severe swimming intensities with linear and non-linear models. **Journal of Sports Sciences**, [*s. l.*], v. 37, n. 13, p. 1512–1520, 2019. Disponível em: https://doi.org/10.1080/02640414.2019.1574949.

EGERMANN, M. *et al.* Analysis of injuries in long-distance triathletes. **International Journal of Sports Medicine**, [*s. l.*], v. 24, n. 4, p. 271–276, 2003.

ELLENBECKER, Todd S.; DAVIES, George J. The application of isokinetics in testing and rehabilitation of the shoulder complex. **Journal of Athletic Training**, [*s. l.*], v. 35, n. 3, p. 338–350, 2000.

ELLIOTT, Jacqueline. Shoulder pain and flexibility in elite water polo players. **Physiotherapy (United Kingdom)**, [*s. l.*], v. 79, n. 10, p. 693–697, 1993. Disponível em: http://dx.doi.org/10.1016/S0031-9406(10)60004-1.

EPSKAMP, Sacha *et al.* Qgraph: network visualizations of relationships in psychometric data. **Journal of Statistical Software**, [*s. l.*], v. 48, n. April, 2012.

FIGUEIREDO, P. *et al.* Kinematic and electromyographic changes during 200 m front crawl at race pace. **International Journal of Sports Medicine**, [*s. l.*], v. 34, n. 1, p. 49–55, 2013.

FIORI, Júlia Mello *et al.* The impact of a swimming training season on anthropometrics, maturation, and kinematics in 12-year-old and under age-group swimmers: a network analysis. **Frontiers in Sports and Active Living**, [*s. l.*], v. 4, n. February, p. 1–10, 2022.

FOYGEL, Rina; DRTON, Mathias. Extended Bayesian information criteria for Gaussian graphical models. **Advances in Neural Information Processing Systems 23: 24th Annual Conference on Neural Information Processing Systems 2010, NIPS 2010**, [*s. l.*], v. 30, n. November, p. 1–14, 2010.

FRIEDMAN, Jerome; HASTIE, Trevor; TIBSHIRANI, Robert. Sparse inverse covariance estimation with the graphical lasso. **Biostatistics**, [*s. l.*], v. 9, n. 3, p. 432–441, 2008.

GAUDET, Sylvain; TREMBLAY, Jonathan; BEGON, Mickael. Muscle recruitment patterns of the subscapularis, serratus anterior and other shoulder girdle muscles during isokinetic internal and external rotations. **Journal of Sports Sciences**, [*s. l.*], v. 36, n. 9, p. 985–993, 2017. Disponível em: https://doi.org/10.1080/02640414.2017.1347697.

HEVEY, David. Network analysis: a brief overview and tutorial. **Health Psychology and Behavioral Medicine**, [*s. l.*], v. 6, n. 1, p. 301–328, 2018.

HOPKINS, Will G. Measures of reliability in sports medicine and science. **Sports Medicine**, [*s. l.*], v. 30, n. 5, p. 375–381, 2000.

KANNUS, P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. **International Journal of Sports Medicine**, [*s. l.*], v. 15, p. 11–18, 1994.

KEINER, Michael *et al.* Influence of maximal strength on in-water and dry-land performance in young water polo players. **Journal ofStrength and Conditioning Research**, [*s. l.*], v. 00, n. 00, p. 1–7, 2018.

KING, Savannah *et al.* Changes in muscle activation during and after a shoulder-fatiguing task: a comparison of elite female swimmers and water polo players. **Frontiers in Sports and Active Living**, [*s. l.*], v. 4, n. July, p. 1–12, 2022.

KWOK, Wan Yu *et al.* A systematic review and meta-analysis: biomechanical evaluation of the effectiveness of strength and conditioning training programs on front crawl swimming performance. **©Journal of Sports Science and Medicine**, [*s. l.*], v. 20, n. October, p. 564–585, 2021.

LAWSIRIRAT, Chaipat; CHAISUMREJ, Pattraporn. Comparison of isokinetic strengths and energy systems between short and middle distance swimmers. **Journal of Physical Education and Sport**, [*s. l.*], v. 17, n. 3, p. 960–963, 2017. Disponível em: https://efsupit.ro/images/stories/17august2017/art147.pdf.

MAYER, F. *et al.* Diagnostics with isokinetic devices in shoulder measurements -

potentials and limits. **Isokinetics and Exercise Science**, [*s. l.*], v. 9, n. 1, p. 19–25, 2001.

MCLAINE, Sally J. *et al.* Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers?. **Journal of Science and Medicine in Sport**, [*s. l.*], v. 22, n. 5, p. 516–520, 2018.

MOTA, Nuno; RIBEIRO, Fernando. Association between shoulder proprioception and muscle strength in water polo players. **Isokinetics and Exercise Science**, [*s. l.*], v. 20, n. 1, p. 17–21, 2012.

NEKOOEI, Pooya *et al.* Anatomical shoulder movement strength imbalance among water polo overhead athletes. **International Journal of Kinesiology and Sports Science**, [*s. l.*], v. 7, n. 2, p. 15–20, 2019.

OLIVIER, Nicolas; DAUSSIN, Frédéric N. Relationships between isokinetic shoulder evaluation and fitness characteristics of elite french female water-polo players. **Journal of Human Kinetics**, [*s. l.*], v. 64, n. 1, p. 5–11, 2018. Disponível em: https://www.sciendo.com/article/10.1515/hukin-2017-0181.

ÖZÇAKAR, Levent *et al.* Quantification of the weakness and fatigue in thoracic outlet syndrome with isokinetic measurements. **British Journal of Sports Medicine**, [*s. l.*], v. 39, n. 3, p. 178–181, 2005.

PERRIN, David H. **Isokinetic exercise and assessment**. [*S. l.*]: Champaign, IL: Human Kinetics, 1993.

PINK, Marilyn M; TIBONE, James E. The painful shoulder in the throwing athlete. **Orthopedic Clinics of North America**, [*s. l.*], v. 31, n. 2, p. 247–261, 2000.

PSYCHARAKIS, Stelios G.; COLEMAN, Simon G. S. Which phases of the stroke cycle are propulsive in front crawl swimming?. **Research Quarterly for Exercise and Sport**, [*s. l.*], 2023.

PUCE, Luca *et al.* Muscle fatigue and swimming efficiency in behind and lateral drafting. **Frontiers in Physiology**, [*s. l.*], v. 13, n. March, 2022.

RODRÍGUEZ, Luis *et al.* Stroking rates of open water swimmers during the 2019 FINA world swimming championships. **International Journal of Environmental Research and Public Health**, [*s. l.*], v. 18, n. 13, p. 6850, 2021.

SANDERS, Ross H; THOW, Jacqueline; FAIRWEATHER, Malcolm. Asymmetries in Swimming: Where Do They Come from? **Journal Swimming Research**. [S. l.: s. n.], 2011.

SEIFERT, L.; CHOLLET, D.; BARDY, B. G. Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. **Journal of Sports Sciences**, [*s. l.*], v. 22, n. 7, p. 651–660, 2004.

TAN, Julian Q.J. *et al.* The transfer of dry-land strength and power into thrust in competitive swimming. **Sports Biomechanics**, [*s. l.*], v. 00, n. 00, p. 1–12, 2021. Disponível em: https://doi.org/10.1080/14763141.2020.1869815.

TAN, Frankie; POLGLAZE, Ted; DAWSON, Brian. Activity profiles and physical demands of elite women's water polo match play. **Journal of Sports Sciences**, [*s. l.*], v. 27, n. 10, p. 1095–1104, 2009.

TOURNY-CHOLLET, C.; SEIFERT, L.; CHOLLET, D. Effect of force symmetry on coordination in crawl. **International Journal of Sports Medicine**, [*s. l.*], v. 30, n. 3, p. 182–187, 2009.

VAN DE VELDE, Annemie *et al.* Scapular-muscle performance: two training programs in adolescent swimmers. **Journal of Athletic Training**, [*s. l.*], v. 46, n. 2, p. 160–167, 2011.

VAN STRIEN, J. W. **The dutch handedness questionnaire**. [*S. l.: s. n.*], 2003. Disponível em: https://ep.eur.nl/retrieve/1742/PSY011.pdf.

VASQUES, Dieisson M *et al.* Antropometría, posición táctica, parámetros de rendimiento y experiencia en waterpolo: análisis de redes. **Apunts Educación Física y Deportes**, [*s. l.*], v. 152, n. 2º trimestre (abril-junio), p. 62–69, 2023.

WIAŻEWICZ, Aleksander; EIDER, Jerzy. Assessment of shoulder joint strength disproportion of masters swimmers. **Central European Journal of Sport Sciences and Medicine**, [*s. l.*], v. 16, n. 4, p. 85–90, 2016. Disponível em: http://psjd.icm.edu.pl/psjd/element/bwmeta1.element.psjd-3316fd91-e9be-4467-b848-b79edb2e5e40.

WIAŻEWICZ, Aleksander; EIDER, Jerzy. The relationship between swimming performance and isokinetic shoulder strength of elite swimmers. **Human Movement**, [*s. l.*], v. 22, n. 4, p. 10–19, 2021.

YANAI, Toshimasa; HAY, James G. Shoulder impingement in front-crawl swimming: II. analysis of stroking technique. **Medicine and Science in Sports and Exercise**, [*s. l.*], v. 32, n. December 1998, p. 30–40, 2000.

ZACCA, Rodrigo *et al.* 5 km front crawl in pool and open water swimming: breath-by-breath energy expenditure and kinematic analysis. **European Journal of Applied Physiology**, [*s. l.*], v. 120, n. 9, p. 2005–2018, 2020.

9. APPENDIXES

APPENDIX A

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COMPARISON OF ISOKINETIC FORCE OF THE INTERNAL AND EXTERNAL ROTATORS OF THE SHOULDERS BETWEEN SWIMMERS OF ALTERNATE AND SIMULTANEOUS TECHNIQUES

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The aim of this study was to compare the peak torque and the strength ratio between the external and internal swimmers' right and left shoulder rotators between alternate and simultaneous swimming techniques. Sixteen competitive swimmers (3 females and 13 males) were divided equally into two groups, alternate and simultaneous swimming techniques. The experimental protocol consisted of three maximum concentric repetitions of internal rotation and external rotation of the shoulder at an angular velocity of 60°/s and twenty repetitions at a velocity of 180°/s, with a two minutes interval between speeds and four minutes in the change of laterality of the upper limbs on a Biodex isokinetic dynamometer (Biodex System 4.0, Biodex Corp., Shirley, NY, EUA).The peak torque and the strength ratio between the external and internal swimmers' right and left shoulder rotators were measured. No difference was obtained between swimming techniques for peak torque and the strength ratio between the external and internal swimmers' right and left shoulder rotators ($p > 0.05$), except for the right shoulder internal rotation at 180º/s (alternate: 44.13 ± 11.58; simultaneous: 56.25 ± 8.83; $p < 0.05$). Based on our results, peak torque and the strength ratio between the external and internal swimmers' right and left shoulder rotators do not seem to be influenced by the athlete's predominant swimming technique, with alternate (front crawl and backstroke) or simultaneous (breast and butterfly) strokes. The main findings of this study show that the balance relationships between the ER/IR rotators of the shoulders do not seem to be differentiated by the alternate and simultaneous swimming techniques. However, observing only the PT/IR at a speed of 180°/s of the right shoulders, there was a significant difference between the groups and, therefore, the ER/IR balance ratio was at the maximum limit of normality. Regardless of the specialization of the swimming technique, that is, alternate or simultaneous, swimmers can present imbalances in the internal and external rotators of the shoulders, which reveal the need for compensatory strength training focused on the rotator muscles of the shoulder.

KEYWORDS: Dynamometry, upper limbs, swimming, performance, injury.

INTRODUCTION: Competitive swimming performance is influenced by factors such as anthropometry, body composition and upper limb strength (Lawsirirat & Chaisumrej, 2017). Swimmers usually perform a daily training routine that requires high shoulder joint loads, since the propulsive force is generated mainly by the upper limbs (Batalha et al., 2020). The propulsive force of the upper limbs in cyclical movements has a significant contribution from the internal rotation (IR) and external rotation (ER) muscles of the shoulder (Wiazerwicz & Eider, 2021), and the IR tend to be stronger when compared to the ER (Batalha et al., 2021). al., 2014).

These strength imbalances in the rotator muscles of the shoulder, along with the training season, can trigger chronic injuries to the strength responses of the upper limbs (Batalha et al., 2013). Studies mention that the ER and IR muscles, associated with imbalance and injuries in swimmers, were evaluated mainly in concentric and eccentric contractions, where there are functional and conventional reasons between the strengths of the ER and IR to indicate probable injury risks due to muscle imbalance. However, the functional relationship, performed with eccentric peak torque (PT)/RE contractions, is considered more adequate to assess the dynamic stability of the glenohumeral joint, while the conventional relationship, performed with concentric contractions of ER and RI, is indicated. for injury prevention (Drigny et al., 2020), where the ER:IR ratio should be between 0.66 and 0.75 (Ellenbecker & Davies, 2000).

In this sense, it is understood that the measurement of maximum strength levels in the upper limbs of swimmers is necessary considering that the internal rotators of the shoulder are the muscles that act directly on the propulsive force, precisely in the concentric contractions of the arms. Batalha et al., 2014).
According to Secchi et al. (2015) alternating (i.e. crawl and backstroke) and simultaneous (i.e. breaststroke and butterfly) swimming techniques may act differently on the shoulder propulsion muscles and require different strength training to improve performance and prevent injuries. The aim of this study was to compare the PT of the RI and ER muscles and the balance ratio between the rotators (ER/IR) of the right and left shoulders of swimmers between alternating and simultaneous swimming techniques. It was hypothesized that the alternating and simultaneous swimming technique groups do not differ in relation to the muscular balance ratio (RE/RI), however, the PT of the RE and RI movements may present significant differences between the groups.

METHODS: Sixteen competitive swimmers (3 females and 13 males) with a minimum of eight hours of training per week were divided equally into two groups: alternating (front crawl and backstroke) and simultaneous (breast and butterfly) swimming technique groups (G1 and G2 respectively), according to Table 1. To be included in the study, swimmers had to be free of shoulder injuries and had been training and competing in the last 3 years. For the selection of groups, the swimmers included in the study informed their main competitive events. The experimental procedures were approved by the local Ethics Committee and were in accordance with the Declaration of Helsinki of 1975. All participants and their respective guardians (when under 18 years of age) were instructed on the objectives and possible difficulties in implementing the protocols, after who signed the consent form.

Table 1: Means and standard deviations (SD) of the anthropometric characteristics of the participants differentiated by groups (G1= Alternate; G2= Simultaneous) and sex.

	G1 (Males): Means ± SD	G1: (Females) Means ± SD	G2 (Males): Means ± SD	G2 (Females): Means ± SD
1. Age	21.50 ± 7.23	18.00 ± 2.83	19.14 ± 3.02	22.00 ± *
2.Body Mass (kg)	65.57 ± 4.04	60.85 ± 1.48	66.70 ± 9.61	52.30 ± *
3. Stature (cm)	173.8 ± 5.41	165.5 ± 0.71	172.24 ± 7.01	160.50 ± *
4. Arm Span (cm)	178.78 ± 5.79	170.25 ± 0.35	176.89 ± 4.52	163.40 ± *

*** There is no SD in G2 (Females) as there is only one woman in the group.**

An isokinetic dynamometer Biodex (Biodex System 4.0 Biodex Corp., Shirley, NY, EUA) properly calibrated was used to assess the isokinetic shoulder IR and ER force profile. The participants were placed in a seated and stabilized position in an isokinetic chair, aligning the evaluated shoulder joint with the dynamometer axis (cf. manufacturer's recommendations). Each swimmer performed three maximum concentric repetitions of IR and ER of the shoulder at an angular velocity of 60°/s and twenty repetitions at a velocity of 180°/s, with passive intervals of two minutes between speeds and four minutes in the change of laterality of the upper limbs (Batalha et al., 2020). The force ratio between the right and left shoulder of the ER and IR swimmers was calculated [(ER/IR) x100] (Cingel et al., 2007).
Data normality was tested using the Shapiro-Wilk test. Descriptive statistics were performed using means and standard deviations (SD). Comparisons between groups alternate vs. simultaneous were performed using the t-test for independent samples. The significance level was set at 0.05. Effect size (ES) was calculated using Cohen's *d* and classified as trivial (0 - 0.19), small (0.20 - 0.49), medium (0.50 - 0.79) and large (> 0.80; Cohen, 1988). Calculations were performed using the software IBM SPSS *Statistics Base* 23.0.

RESULTS: Descriptive statistics (mean and SD) for isokinetic force values at 60°/s and 180°/s and respective comparisons between alternate and simultaneous swimming techniques for right and left shoulder are show in Table 2.

Table 2: Mean ± Standard deviations (SD) of the external (ER) and internal (IR) right and left shoulder rotators peak torque (PT) and the strength ratio between the ER and IR swimmers' right and left shoulder rotators (ER/IR) for alternate and simultaneous swimming techniques, *p*-value and effect size (ES).

		Variables				
Shouder Side	Swimming Techniques	PT/ER (60°/s)	PT/IR (60º/s)	PT/ER (180º/s)	PT/IR (180º/s)	Ratio ER/IR
Right Shoulder	Alternate	30,13 ± 4,91	41,50 ± 11,07	33,38 ± 8,26	44,13 ± 11,58	0,75 ± 0,12
	Simultaneous	38,00 ± 14,58	52,50 ± 11,92	34,75 ± 4,37	56,25 ± 8,83	0,75 ± 0,36
	p	0,170	0,076	0,684	0,034*	0,978
	ES	-0,724	-0,956	-0,208	-1,178	-0,015
Left Shoulder	Alternate	27,75 ± 4,53	42,13 ± 8,94	29,13 ± 3,56	45,63 ± 7,69	0,67 ± 0,08
	Simultaneous	31,25 ± 7,05	48,75 ± 12,84	32,63 ± 4,69	51,38 ± 11,48	0,65 ± 0,09
	p	0,257	0,251	0,115	0,259	0,723
	ES	-0,591	-0,599	-0,841	-0,589	-0,235

*Significant difference ($p < 0,05$).

DISCUSSION: The results showed that there is a difference in the PT value of the RI at 180°/s of the right shoulder (p = 0.034) between the alternating and simultaneous swimming techniques. Probably the swimmers evaluated have the right arm as the dominant limb and, therefore, greater proficiency on the right side, which justifies the PT/IR of the right shoulder being stronger when compared to the left shoulder. For this reason, the ER/IR balance ratio on the right side presented higher values compared to the left shoulder. It is recommended that PT/ER values be at least ⅔ of PT/IR to avoid injury (Drigny et al., 2020). Differences were also observed between the PT means in both the RI and the RE performed at 60°/s and 180°/s, where the means were higher in the right shoulders in both groups.

As in the study by Lawsirirat and Chaisumrej (2017), where short and medium-distance swimmers obtained differences in PT only in the right shoulder and ankle extensors, as they had a similar training structure. It is believed that there were no further differences in our study for this same reason.

There is only one study that compared shoulder muscle strength between alternating and simultaneous swimming techniques (Secchi et al., 2015), which observed that there was no difference in muscle strength in the adductor, abductor, and ER and IR muscles of the shoulders. However, this study used the protocol of 5 repetitions at 60º/s and 20 repetitions at 300º/s, and the literature indicates that angular velocities above 180º/s are not properly indicated due to excess torque that can make the PT calculation difficult. (Mayer et al., 2001).

The present study was not able to reveal differences in the isokinetic strength profile of alternating and simultaneous upper limbs as well as the previous study (Secchi et al., 2015), which may be due to the use of alternating swimming techniques even by specialized swimmers in swimming techniques simultaneous.

A swimming training macrocycle is sufficient to produce muscle imbalances between the shoulder rotators, as there is a significant increase in RI strength without a proportional increase in ER strength, which can lead to joint injuries and dysfunctions (Batalha et al., 2013; Batalha et al. al.2014). In the present study, the values of the ER/IR ratio are at the upper limit of normality, which seems to be due to the higher qualitative PT of the right shoulder of the RI muscle group. Further studies should consider a sufficient sample size with different training levels (ie from age group to elite) to separately analyze the influence of each swimming technique on the isokinetic strength profile.

CONCLUSION: The main findings of this study show that the balance relationships between the ER/IR rotators of the shoulders do not seem to be differentiated by the alternate and simultaneous swimming techniques. However, observing only the PT/IR at a speed of 180°/s of the right shoulders, there was a significant difference between the groups and, therefore, the ER/IR balance ratio was at the maximum limit of normality. Regardless of the specialization of the swimming technique, that is, alternate or simultaneous, swimmers can present imbalances in the internal and external rotators of the shoulders, which reveal the need for compensatory strength training focused on the rotator muscles of the shoulder.

REFERENCES

Batalha, N. M., Raimundo, A. M., Tomas-Carus, P., Barbosa, T. M., & Silva, A. J. (2013). Shoulder rotator cuff balance, strength, and endurance in young swimmers during a competitive season. *Journal of Strength and Conditioning Research, 27*(9), 2562–2568. https://doi.org/10.1519/JSC.0b013e31827fd849

Batalha, N., Marmeleira, J., Garrido, N., & Silva, A. J. (2014). Does a water-training macrocycle really create imbalances in swimmers' shoulder rotator muscles? *European Journal of Sport Science, 15*(2), 167–172. https://doi.org/10.1080/17461391.2014.908957

Batalha, N., Paixão, C., Silva, A. J., Costa, M. J., Mullen, J., & Barbosa, T. M. (2020). The effectiveness of a dry-land shoulder rotators strength training program in injury prevention in competitive swimmers. *Journal of Human Kinetics, 71*(1), 11–20. https://doi.org/10.2478/hukin-2019-0093

Carvalho, D. D., Soares, S., Zacca, R., Marinho, D. A., Silva, J., Pyne, D. B., Vilas-Boas, J. p., & Fernandes, R. J. (2019). In-water and on-land swimmers' symmetry and force production. *International Journal of Environmental Research and Public Health, 16*(24), 1–9. https://doi.org/doi:10.3390/ijerph16245018

Cingel, R. van., Kleinrensink, G. J., Mulder, P., Bie, R. de., & Kuipers, H. (2007). Isokinetic strength values, conventional ratio and dynamic control ratio of shoulder rotator muscles in elite badminton players. *Isokinetics and Exercise Science, 15*(4), 287–293. https://doi.org/10.3233/ies-2007-0285

Cohen J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed). Hillsdale, NJ: Lawrence Erlbaum.

Collado-Mateo, D., Dominguez-Muñoz, F. J., Batalha, N., Parraça, J., Tomas-Carus, P., & Adsuar, J. C. (2018). Test-retest reliability of isokinetic arm strength measurements in competitive swimmers. *Journal of Human Kinetics, 65*(1), 5–11. https://doi.org/10.2478/hukin-2018-0035

Ellenbecker, T., & Roetert, E. P. (2003). Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. Journal of Science and Medicine in Sport, 6(1), 63–70. https://doi.org/10.1016/S1440-2440(03)80009-9

Lawsirirat, C., & Chaisumrej, P. (2017). Comparison of isokinetic strengths and energy systems between short and middle distance swimmers. *Journal of Physical Education and Sport, 17*(3), 960–963. https://doi.org/10.7752/jpes.2017.s3147

Mayer, F., Horstmann, T., Baurle, W., Grau, S., Handel, M., & Dickhuth, H. H. (2001). Diagnostics with isokinetic devices in shoulder measurements - potentials and limits. *Isokinetics and Exercise Science, 9*(1), 19–25. https://doi.org/10.3233/ies-2001-0059

Secchi, L. L. B., Brech, G. C., & Greve, J. M. D. (2015). Isokinetic dynamometry on the internal rotator and adductor muscles of the swimmers' shoulders: no differences between asymmetrical and symmetrical swimming strokes. *Medical Express, 2*(2), 1–5. https://doi.org/10.5935/medicalexpress.2015.02.02

Wiazerwicz, A., & Eider, J. (2021). The relationship between swimming performance and isokinetic shoulder strength of elite swimmers. *Human Movement, 22*(4), 10–19. https://doi.org/doi.org/10.5114/hm.2021.103285

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APPENDIX B

CORRELAÇÃO ENTRE VOLUME DE TREINO E DESEQUILÍBRIOS MUSCULARES EM NADADORES

CORRELATION BETWEEN TRAINING VOLUME AND MUSCLE IMBALANCES IN SWIMMERS

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RESUMO

Na natação competitiva os músculos rotadores do ombro desempenham um papel fundamental na produção de forças propulsivas e estão expostos a desequilíbrios musculares em virtude dos movimentos articulares repetitivos. O objetivo do estudo foi correlacionar a razão de equilíbrio muscular dos rotadores dos ombros com o volume de treino semanal em nadadores. Foram avaliados 31 nadadores (idade 26,13 ± 11,72 anos; massa corporal 65,20 ± 12,26 kg; estatura 173,0 ± 6,54 cm; envergadura 177,5 ± 5,68 cm) divididos em dois grupos, G1 (n=12) com o volume de treino entre 9000 e 20000 m/semana; G2 (n=19) entre 21000 e 31000 m/semana. Utilizou-se um dinamômetro isocinético (*Biodex 4 Multi-Joint System, New York*) para acessar o pico de torque (PT) (N.m) de rotação externa (RE) e interna (RI) dos ombros com 3 repetições máximas na velocidade angular de 60º/s, no modo concêntrico. Utilizou-se um questionário de caracterização da amostra na coleta de informação da variável volume de treino. A razão de equilíbrio muscular foi determinada pela equação: PT RE/ PT RI, com valores normativos entre 0,66 e 0,75. Consideraram-se os valores de *Kolmogorov-Smirnov* para normalidade dos dados com $p < 0,05$. Os coeficientes de Correlação de *Spearman* para dados não paramétricos foram utilizados para verificar a associação entre volume de treino e razão de equilíbrio do ombro direito e esquerdo. A mediana, o intervalo interquartil para G1 e G2 e a correlação respectivamente, foram: volume de treino (12000,00 ± 6000,00 m e 24000,00 ± 6000,00 m); razão de equilíbrio do ombro direito (0,70 ± 0,17 e 0,68 ± 0,17; r= - 0,156 e p=0,40) razão de equilíbrio do ombro esquerdo (0,61 ± 0,09 e 0,66 ± 0,19; r= 0,043 e p=0,82). Os resultados não apresentaram correlação entre as variáveis analisadas, que talvez tenham sido influenciados pelo número da amostra ou volume de treino, pois pode ter sido insuficiente para causar efeitos de desequilíbrio muscular nos nadadores. Diante do achado, é necessária investigação, considerando o nível competitivo, diferentes volumes semanais de treino e outras variáveis de desempenho entre nadadores, não apenas em um período específico, mas ao longo de uma temporada competitiva.

Palavra-chave: natação, força muscular, articulação do ombro.

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APPENDIX C

XX CBBauru 2023

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O volume de treino aquático influencia as razões de equilíbrio convencional em nadadores que realizam treinamento de força em terra?

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Contextualização: Os músculos rotadores internos desempenham um papel crucial na produção de forças propulsivas durante o nado, tornando-os suscetíveis a desequilíbrios musculares agonista-antagonista em virtude da exposição ao treinamento de natação (BATALHA et al., 2018). Programas de treinamento de força em terra são recomendados, pois auxiliam na redução das diferenças de produção de força, promovendo equilíbrio entre as ações dos músculos rotadores da articulação ombro (BATALHA et al., 2015).

Objetivo: Verificar se a razão de equilíbrio convencional dos músculos rotadores da articulação do ombro de nadadores está associada ao volume de treino aquático semanal quando controlada pelo treinamento de força em terra.

Material e métodos: Doze nadadores (10 homens e duas mulheres), sendo seis nadadores que realizavam treinamento de força em terra (idade: 19,17 ± 3,87 anos; massa corporal: 62,12 ± 5,25 kg; estatura: 172,10 ± 7,80 cm; envergadura: 175,37 ± 8,34 cm) e seis que não realizavam (idade: 32,83 ± 17,15 anos; massa corporal: 71,05 ± 9,81 kg; estatura: 171,63 ± 6,19 cm; envergadura: 176,20 ± 4,43 cm) foram avaliados. O participante foi posicionado sentado, fixado nas regiões do tronco e pelve na cadeira do dinamômetro isocinético Biodex System 4.0 (Biodex Medical Systems, Shirley, NY, EUA), com amplitude de 90° em abdução de ombro e flexão de cotovelo. O protocolo consistiu em três repetições concêntricas máximas de rotação externa e interna dos ombros na velocidade angular de 60°/s, com cinco minutos de intervalo na mudança de lateralidade. A correlação parcial para dados paramétricos ($p < 0,05$) foi feita através do software estatístico SPSS 22.0.

Resultados: A correlação parcial mostrou que o volume de treino aquático semanal (24500,00 ± 9120,42 m) não influenciou as razões de equilíbrio convencional dos ombros direito (71,42 ± 9,87 %) e esquerdo (67,11 ± 10,63 %) quando controlada pelo treinamento de força em terra ($p > 0,05$) (Tabela 1).

Tabela 1: Correlação entre as variáveis volume de treino aquático semanal (m) e razões de equilíbrio convencional-REC (%) nos movimentos de rotação externa e interna na velocidade angular de 60°/s.

	Ombro direito REC (%)	Ombro esquerdo REC (%)
Volume de treino aquático semanal (m)	-0,422	0,020
p	0,196	0,954

Conclusões: Os achados mostraram não haver associação entre o volume de treino aquático e razões de equilíbrio convencional entre os músculos agonista-antagonista em nadadores que realizam e que não realizam treinamento de força em terra. Considerou-se como limitação o tamanho da amostra, pois pode ter sido insuficiente para identificar tais associações. Vale salientar que os treinadores podem utilizar avaliações isocinéticas periódicas, incluindo a variável em questão, pois os resultados auxiliam na identificação de possíveis riscos de dor e surgimento de lesão, e associada ao monitoramento do treino de força em terra, ajudam na redução dos desequilíbrios musculares na articulação do ombro em nadadores.

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Referências bibliográficas:

BATALHA, N. et al. Does a land-based compensatory strength-training programme influences the rotator cuff balance of young competitive swimmers? **European Journal of Sport Science**, v. 15, n. 8, p. 764–772, 2015.

BATALHA, N. et al. The effectiveness of land and water based resistance training on shoulder rotator cuff strength and balance of youth swimmers. **Journal of Human Kinetics**, v. 62, n. 1, p. 91–102, 2018.

APPENDIX D

XX CBBauru 2023

Comparação da simetria de força nos flexores e extensores dos ombros entre nadadores de técnicas de nado alternadas e simultâneas

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Contextualização: Na natação, a aplicação de força simétrica entre os membros superiores, auxiliam na redução da força de arrasto, promovendo um alinhamento corporal durante o nado, tanto em técnicas de nado alternadas (crawl e costas) quanto em simultâneas (peito e borboleta). **Objetivo:** Comparar o índice de simetria dos flexores e extensores dos ombros nas velocidades de 60 e 180°/s entre nadadores especialistas em técnicas alternadas e simultâneas. **Material e métodos:** Dezesseis nadadores (13 homens e três mulheres) participaram do estudo, divididos em: técnicas alternadas (n= 8) e simultâneas (n= 8). As características foram, respectivamente: 18,50 ± 2,13 vs. 19,87 ± 3,94 anos de idade, 63,18 ± 3,62 vs. 65,18 ± 10,13kg de massa corporal, 170,25 ± 7,16 vs. 170,35 ± 5,87cm de estatura e 174,96 ± 6,69 vs. 175,70 ± 5,95cm de envergadura. Para avaliação do índice de simetria dos flexores e extensores dos ombros, utilizou-se o dinamômetro isocinético (BIODEX SYSTEM 4, Biodex Corp., Shirley, NY, EUA), onde o pico de torque (PT) foi inserido na equação proposta por Robinson, Herzog e Nigg (1981). Os participantes executaram três repetições concêntricas a 60°/s e 20 repetições a 180°/s com dois minutos de intervalo entre as velocidades e cinco entre lateralidade (WIAZEWICZ; EIDER, 2021). A normalidade foi verificada pelo teste de *Shapiro-Wilk*, a comparação dos grupos através do teste *t* para amostras independentes ($p < 0,05$) e o tamanho de efeito pelo *g* de Hedges. As análises foram realizadas pelo software estatístico SPSS 22.0. **Resultados:** Os valores de índice de simetria mostraram diferença entre os grupos para o movimento de extensão a 180°/s (Tabela 1), onde o grupo de técnicas alternadas apresentou tendência a maiores PT para o membro superior não preferido (> 0) ao contrário do grupo de técnicas simultâneas, onde apresentaram maior PT para o membro preferido (< 0). O tamanho de efeito teve como classificação "forte" (> 0,8) para a variável índice de simetria de extensão a 180°/s. **Conclusões:** Os grupos apresentaram valores de simetria de força entre os membros superiores (entre -10 e 10 %). No entanto, nadadores de técnicas alternadas obtiveram valores próximos ao limite da normalidade, sugerindo ser devido às ações especificas das técnicas de nado, como alternância de membros superiores e rolamento ao longo do eixo longitudinal. Sugere-se que análises individuais de magnitude e direção das simetrias sejam feitas a fim de direcionar estratégias de treinamento e reabilitação.

Referências bibliográficas:

1. ROBINSON R. O.; HERZOG W.; NIGG B. M. Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. **Journal of Manipulative and Physiological Therapeutics**. v. 10, n. 4, p. 172-6, 1987. PMID: 2958572.
2. WIAŻEWICZ, A.; EIDER, J. The relationship between swimming performance and isokinetic shoulder strength of elite swimmers. **Human Movement,** v. 22, n. 4, p. 10–19, 2021.

APPENDIX E

CORRELATION BETWEEN FINA POINTS AND ISOKINETIC TORQUE SYMMETRY INDEX OF THE SHOULDER JOINT IN SWIMMERS

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INTRODUCTION

The front crawl technique is considered the fastest and most frequently used technique in swimming training (Tourny-Chollet, Seifert, & Chollet, 2009) being characterized by upper limb cycles with propulsive and non-propulsive phases (Chollet, Chalies, & Chatard, 2000). However, despite the cyclical nature of this swimming technique, the symmetry of propulsive forces cannot be affirmed (Formosa, Sayers, & Burkett, 2013). One of the causes of asymmetry that affects propulsion are the differences in bilateral forces that cause three effects: 1) on the rotational balance of the body, causing misalignment; 2) the smaller contribution of the weaker side in the production of propulsive forces; and 3) fatigue due to the attempt to maintain swimming speed causing the stronger side to apply greater force to compensate for the weaker side (Sanders, 2013).
It has been reported that the application of symmetrical force between the right and left sides of the body is a factor that influences swimming performance by improving body alignment, reducing active drag, and decreasing intra-cycle velocity variations (Sanders, Thow, & Fairweather, 2011). However, swimmers can develop bilateral force asymmetries as a result of various factors (e.g., injuries, technique development, preferred breathing side, among others), reducing their ability to produce propulsive forces (Sanders et al., 2011). Investigating performance factors, such as the symmetry index, is critical to understanding bilateral strength in swimmers. Therefore, the aim was to analyze the relationship between FINA points classification and the symmetry index (SI) of isokinetic torque in internal rotation (IR), external rotation (ER), flexion (FL), and extension (EX) movements of the shoulders in swimmers, hypothesizing that FINA points influences isokinetic torque symmetry.

METHODS

According to the Dutch Handedness Questionnaire (Van Strien, 2003) for hand side preference, 15 swimmers (12 males and 3 females; age: 21.0 ± 7.0 years old; body mass: 66.0 ± 9.1 kg; height: 1.70 ± 0.06 m; arm span: 1.75 ± 0.07 m) were classified concerning lateral upper limb preference as strongly lateralized right- handed person (13) and strongly lateralized left-handed person (two). Like in Dalamitros et al. (2021), the score calculation was based on the swimming race specialty of each athlete according to 2021 world records in long pool. Based on the competitive level classification criteria of McKay et al. (2022), all selected swimmers were classified as trained/developed athletes (tier 2). The participants were positioned and stabilized in the trunk and pelvis regions on the Biodex System 4.0 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, EUA). The protocol involved 20 maximal concentric repetitions in the movements of IR, ER, FL, and EX of the shoulders, with five minutes for changing body side, and 10 minutes at change of motion. An angular velocity of 180°/s was selected for resembling the velocity applied during the swim cycles. The SI (%) was accessed from the isokinetic variable peak torque (Nm), defined by the equation proposed by Herzog et al. (1989): SI (%) = [Preferred upper limb – Non-preferred upper limb / 0.5 (Preferred upper limb + Non-preferred upper limb)] x 100. The symmetry index allows characterizing the strength differences between the contralateral limbs (Evershed, Burkett, & Mellifont, 2014) where values −10% < SI < 10% reveal symmetry, while SI < −10% and SI > 10% indicate asymmetry (Herzog et al., 1989). This study was approved by the Institutional Ethics Committee and followed the Declaration of Helsinki on human research. All participants and legal guardians of those under the age of 18 years old were informed about the objectives, assessment procedures, risks, and benefits. In addition, they all signed written informed consent. Normality was checked by the Shapiro-Wilk test and assumption of homoscedasticity by the linear regression test. Bivariate correlation was performed by analyzing Spearman's ρ (Rho) correlation coefficient on the IBM SPSS 22.0 statistical software.

RESULTS

No relationships ($p > 0.05$) were found between FINA points classification vs. SI IR (ρ = - 0.288;), vs. SI ER (ρ = - 0.440), vs. SI FL (ρ = 0.050), and vs. SI EX (ρ = - 0.220), as shown in Figure 1. We also found no relationships ($p > 0.05$) when using only males between the variables: FINA points vs. SI IR (ρ = - 0.532;), vs. SI ER (ρ = - 0.562), vs. SI FL (ρ = 0.431), and vs. SI EX (ρ = - 0.225).

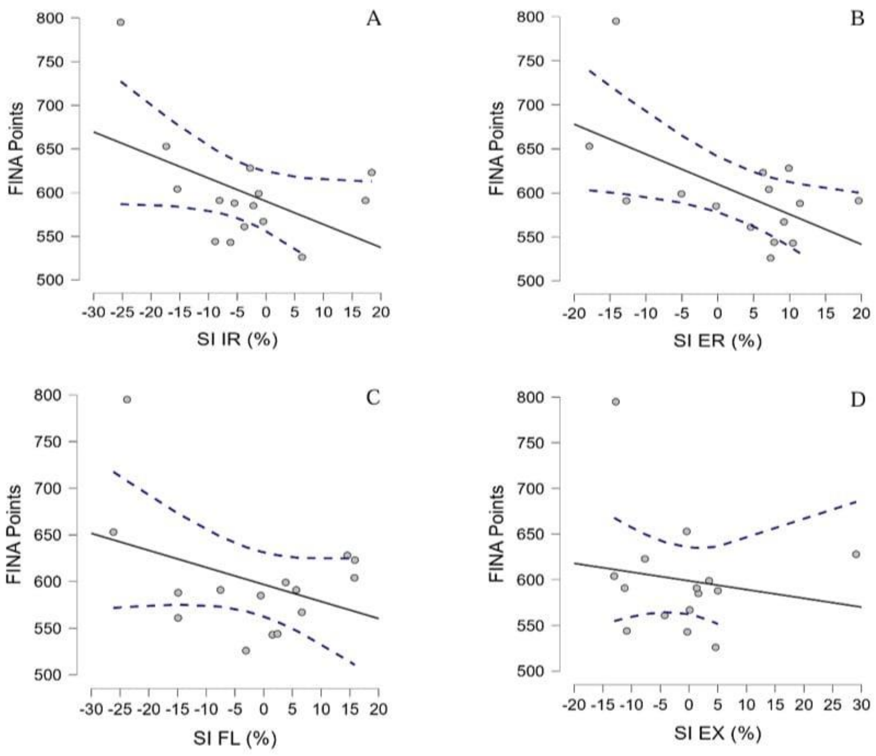

Figure 1: Correlation values between the FINA points and symmetry index (SI) variables of internal (IR) and external rotation (ER), flexion (FL), and extension (EX) of the shoulders at angular velocity 180°/s.

DISCUSSION

This study aimed this to analyze the relationship between the classification of FINA points and symmetry index of isokinetic torque in IR, ER, FL, and EX movements of the shoulders in swimmers. The results showed no association between FINA points and SI ($p > 0.05$), thus rejecting the hypothesis that FINA points influence isokinetic torque symmetry, possibily due to the little specificity of the isokinetic dynamometer with swimming.
Asymmetries occur continuously in swimming, specifically in the front crawl technique, due to the alternating nature of the stroke cycle, and can affect both endurance and propulsion, which, together with the physiological capacity of the swimmer, are the main determinants of performance (Sanders, 2013). Asymmetries affecting propulsion include unequal contributions from the right and left upper and lower limbs due to bilateral force differences (Sanders et al., 2011; Sanders, 2013). Previous studies have shown that elite swimmers, with FINA points 900 (Formosa et al., 2013), as well as swimmers of different competitive levels (Morouço et al., 2015), showed strength asymmetry in video analysis and tethered swimming tests, respectively. Our findings revealed that SI does not seem to influence the performance swimmers. According to Morouço et al. (2015), higher values of force asymmetry (SI > 10%) did not lead to worse performance but produced a significant effect on it. The authors point out that, to some extent, force asymmetry may not be critical to achieve high swimming speed.
Although it has been reported that the application of symmetrical force influences swimming performance because the propulsive forces are generated mainly by the upper limbs, specifically in the front crawl technique, such an effect was not observed in our study. This finding can be explained using isokinetic variables. The isokinetic dynamometer may not be applied specifically for performance analysis in swimming due to its little specificity for this modality. However, it has shown important contributions to competitive swimming.

REFERENCES

Chollet, D., Chalies, S., & Chatard, J. C. (2000). A new index of coordination for the crawl: description and usefulness. *International Journal of Sports Medicine*, *21*(1), 54–59. https://doi.org/10.1055/s-2000-8855

Evershed, J., Burkett, B., & Mellifont, R. (2014). Musculoskeletal screening to detect asymmetry in swimming. *Physical Therapy in Sport*, *15*(1), 33–38. https://doi.org/10.1016/j.ptsp.2013.02.002

Formosa, D. P., Sayers, M. G. L., & Burkett, B. (2013). Front-crawl stroke-coordination and symmetry: a comparison between timing and net drag force protocols. *Journal of Sports Sciences*, *31*(7), 759–766. https://doi.org/10.1080/02640414.2012.750004

Herzog, W., Nigg, B. M., & Read, L. (1989). Asymmetries in ground reaction force. *Medicine and Science in Sport and Exercise*, *21*(1), 110–114.

Morouço, P. G., Marinho, D. A., Fernandes, R. J., & Marques, M. C. (2015). Quantification of upper limb kinetic asymmetries in front crawl swimming. *Human Movement Science*, *40*, 185–192. https://doi.org/10.1016/j.humov.2014.12.012

Sanders, R. H. (2013). How do asymmetries affect swimming performance? *J. Swimming Research*, *21*(January 2013), 1.

Sanders, R. H., Thow, J., & Fairweather, M. (2011). Asymmetries in swimming: where do they come from ? *Journal of Swimming Research*, *18*(September), 1–11.

Tourny-Chollet, C., Seifert, L., & Chollet, D. (2009). Effect of force symmetry on coordination in crawl. *International Journal of Sports Medicine*, *30*(3), 182–187. https://doi.org/10.1055/s-0028-1104581

Van Strien, J. W. (2003). The dutch handedness questionnaire. Retrieved from https://ep.eur.nl/retrieve/1742/PSY011.pdf

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