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ISOKINETIC ASSESSMENT OF SWIMMERS' SHOULDERS: BENEFITS AND LIMITATIONS, MAGNITUDE AND DIRECTION ASYMMETRIES AND, NETWORK ANALYSIS

Manaus

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YVES SIMÕES DOS SANTOS

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Thesis submitted to the Postgraduate Program in Human Movement Sciences at the Federal University of Amazonas to obtain a Master's Degree in Human Movement Sciences.

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ISOKINETIC ASSESSMENT OF SWIMMERS' SHOULDERS: BENEFITS AND LIMITATIONS, MAGNITUDE AND DIRECTION ASYMMETRIES AND, NETWORK ANALYSIS

O presente trabalho em nível de mestrado foi avaliado e aprovado pela banca examinadora composta pelos seguintes membros:

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Universidade Federal do Amazonas

Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de Mestre em Ciências do Movimento Humano.

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Coordenação do Programa de Pós-Graduação em Ciências do Movimento Humano

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Profª. Dra. Karla de Jesus

Orientadora

Manaus, 2023

Dedico este trabalho à minha mãe (*in memoriam*).

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RESUMO

Esta dissertação foi divida em três estudos, os quais tiveram como objetivo: a) indicar os benefícios e limitações dos resultados dos testes isocinéticos para o desempenho dos principais movimentos da articulação do ombro em nadadores, considerando os diferentes níveis competitivos, técnicas de nado, distâncias de prova e sexo; b) comparar a magnitude e determinar a consistência das assimetrias isocinéticas do pico de torque entre as velocidades angulares de 60 e 180°/s nos movimentos articulares do ombro de rotação interna e externa, flexão e extensão; c) investigar as relações complexas e simultâneas entre os *World Aquatic points* (desempenho) e os parâmetros do teste isocinético (pico de torque e trabalho total) dos movimentos de rotação interna e externa, flexão e extensão do complexo do ombro, através de uma análise de redes, e comparar o pico de torque e trabalho total entre os lados preferidos e não preferidos dos ombros de nadadores de competitivos. Para o primeiro objetivo (estudo 1) foi realizado um estudo de revisão sistemática, seguindo as recomendações do PRISMA. Para determinar a magnitude e consistência da direção das assimetrias isocinéticas do pico de torque (estudo 2), foram avaliados 21 nadadores competitivos na técnica de nado crawl, no qual foram analisados os torques isocinéticos de rotação interna e externa, flexão e extensão dos ombros obtidas pelo dinamômetro isocinético. No estudo 3 participaram 23 nadadores homens competitivos e as redes formadas para analisar as múltiplas relações utilizaram o World Aquatic points (variável de desempenho), pico de torque e trabalho total dos movimentos de rotação interna e externa, flexão e extensão dos ombros na velocidade de 180°/s. Análises estatísticas utilizadas no estudo foram: estudo 2 – Para normalidade foi utilizado o teste de *Shapiro-Wilk*, para comparar a magnitude das assimetrias entre as velocidades de 60 e 180°/s foi utilizado o teste T para amostras dependentes e para determinar a consistência das assimetrias nas velocidades de 60 e 180°/s foi utilizado o coeficiente de Kappa; estudo 3: foi utilizada a técnica de análise de redes de aprendizagem automática para investigar as relações simultâneas entres o World Aquatic points e valores de pico de torque e trabalho total dos movimentos de rotação interna e externa, flexão e extensão e os parâmetros isocinéticos entre os membros superiores preferido e não preferido foram comparados utilizando o teste t para amostras dependentes. Em todos os testes foi considerado o nível de significância de 5% (p < 0,05). Os resultados do estudo 1 indicaram que os principais benefícios nas análises isocinéticas dos ombros em nadadores estão na investigação clínica e relações com a performance de nado, e as principais limitações estão no posicionamento do nadador no equipamento. No estudo 2, os resultados mostraram maior magnitude das assimetrias em rotação interna (p = 0,007; ES: -1,38 a -0,13) e flexão (p = 0,008; ES: -1,30 a -0,06) realizadas a 60°/s. Os níveis de concordância da direção das assimetrias entre as velocidades angulares foram razoáveis a substanciais (Kappa: 0,40 a 0,69). Para o estudo 3, foi identificado através da análise de redes, que o membro não preferido apresentou relações complexas entre as variáveis do estudo e na comparação, o trabalho total de rotação externa foi maior (p = 0,028; ES = -0,24) para o lado preferido. A partir da revisão sistemática conclui-se que a utilização do dinamómetro isocinético permite verificar os níveis de força, resistência, razão de equilíbrio e assimetrias entre nadadores de diferentes técnicas, ajudando a analisar e monitorizar as condições clínicas das articulações do ombro dos nadadores. Em relação a comparação da magnitude e determinação das assimetrias (estudo 2), pode-se concluir a compreensão das assimetrias musculares permite o desenvolvimento de programas de treino específicos para corrigir os desequilíbrios de força e otimizar as técnicas de natação. Para o estudo 3, a aplicação de força pelo lado não preferido, devido as dificuldades individuais do nadador, parece representar uma janela para aumentar o desempenho de nado. Os resultados encontrados podem ajudar pesquisadores, treinadores e atletas na tomada de decisão na escolha das avaliações e na individualização dos resultados encontrados. Essas informações são cruciais para a qualidade e interpretação dos testes, além de auxiliar os nadadores quanto à condição clínica do ombro e níveis de assimetrias.

Palavras-chave: Lesões; Performance; Concordância; Assimetrias; Redes complexas.

ABSTRACT

This thesis was divided into three studies, which aimed to: a) indicate the benefits and limitations of isokinetic test results for the performance of the main shoulder joint movements in swimmers, considering the different competitive levels, swimming techniques, race distances and gender; b) compare the magnitude and determine the consistency of isokinetic peak torque asymmetries between the angular velocities of 60 and 180°/s in the shoulder joint movements of internal and external rotation, flexion and extension; c) to investigate the complex and simultaneous relationships between the World Aquatic points (performance) and the parameters of the isokinetic test (peak torque and total work) of the shoulder movements of internal and external rotation, flexion and extension, by means of a network analysis, and to compare the peak torque and total work between the preferred and non-preferred sides of the shoulders of competitive swimmers. For the first objective (study 1), a systematic review study was carried out, following the PRISMA recommendations. To determine the magnitude and consistency of the direction of isokinetic peak torque asymmetries (study 2), 21 competitive crawl swimmers were evaluated, in which the isokinetic torques of internal and external rotation, flexion and extension of the shoulders obtained by the isokinetic dynamometer were analyzed. In study 3, 23 competitive male swimmers took part and the networks formed to analyze the multiple relationships used the World Aquatic points (performance variable), peak torque and total work of the internal and external rotation movements, shoulder flexion and extension at a speed of 180°/s. Statistical analyses used in the study were: study 2 - The Shapiro-Wilk test was used for normality, the T-test for dependent samples was used to compare the magnitude of the asymmetries between the speeds of 60 and 180°/s and the Kappa coefficient was used to determine the consistency of the asymmetries between the speeds of 60 and 180°/s; study 3: The automatic learning network analysis technique was used to investigate the simultaneous relationships between the World Aquatic points and peak torque values and total work of the internal and external rotation, flexion and extension movements and the isokinetic parameters between the preferred and non-preferred upper limbs were compared using the t-test for dependent samples. A significance level of 5% ($p < 0.05$) was considered in all tests. The results of study 1 indicated that the main benefits of shoulder isokinetic analysis in swimmers are in clinical research and relationships with swimming performance, and the main limitations are in the positioning of the swimmer on the equipment. In study 2, the results showed greater magnitude of asymmetries in internal rotation ($p = 0.007$; ES: -1.38 to -0.13) and flexion ($p = 0.008$; ES: -1.30 to -0.06) performed at 60°/s. The levels of agreement in the direction of the asymmetries between the angular velocities were reasonable to substantial (Kappa: 0.40 to 0.69). For study 3, we identified through network analysis that the non-preferred limb showed complex relationships between the study variables and in the comparison, the total external rotation work was greater ($p = 0.028$; ES = -0.24) for the preferred side. From the systematic review it can be concluded that the use of the isokinetic dynamometer makes it possible to check the levels of strength, endurance, balance ratio and asymmetries between swimmers of different techniques, helping to analyze and monitor the clinical conditions of swimmers' shoulder joints. Regarding the comparison of the magnitude and determination of asymmetries (study 2), it can be concluded that understanding muscle asymmetries allows the development of specific training programs to correct strength imbalances and optimize swimming techniques. For study 3, the application of force on the non-preferred side, due to the swimmer's individual difficulties, seems to represent a window to increase swimming performance. The results found can help researchers, coaches and athletes make decisions on the choice of assessments and the individualization of the results found. This information is crucial for the quality and interpretation of the tests, as well as helping swimmers to determine the clinical condition of the shoulder and levels of asymmetry.

Keywords: Injuries; Performance; Agreement; Asymmetries; Complex networks.

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SUMMARY

1. INTRODUCTION

The shoulder is a complex joint whose movements depend on interdependent joints: glenohumeral, clavicular sternum, acromioclavicular and thoracic scapula (Tovin, 2006). The muscles that cross these joints act synergistically to generate movement and maintain stability at the same time, so several functions are related to the same muscle group. In addition, the scapulohumeral rhythm allows for a large range of movement of the humerus in relation to the trunk (Olivier; Quintin; Rogez, 2008; Tovin, 2006). The characteristics and capabilities of the shoulder and its muscles are essential for swimming performance, as approximately 90% of the propulsion generated in crawl swimming depends on the upper limbs (Deschodt; Arsac; Rouard, 1999; Silveira *et al.*, 2017) and the swimmer needs to generate propulsive forces to overcome drag (Toussaint et al., 2000).

In addition, athletes who practice sports characterized by movements that raise the upper limbs above the level of the head, such as swimming, perform shoulder movements with high speed and extreme range of motion, making them more prone to injury (Feijen *et al.*, 2020b). In swimming in particular, muscular imbalances appear in swimmers' shoulders not only over several years of practice, but also after a single competitive season (Batalha *et al.*, 2015b), with the occurrence of injuries estimated at 23 to 38% (Chase *et al.*, 2013; Walker *et al.*, 2012).

Also, although swimming is considered a symmetrical sport, previous studies have not guaranteed the symmetry of forces between the sides of the body (Alberty *et al.*, 2009; Tourny-Chollet; Seifert; Chollet, 2009). High-performance swimmers need to apply propulsive forces between the sides of the body to minimize resistive drag during swimming(Carvalho *et al.*, 2019). Physical asymmetries can result in greater effort on one side of the body compared to the other, reducing the swimmer's ability to produce propulsive forces (Sanders; Thow; Fairweather, 2011). The front crawl technique involves alternating bilateral coordination (Nikodelis; Kollias; Hatzitaki, 2005) and studies indicate that there are asymmetries in kinetics (Dos Santos *et al.*, 2013; Morouço *et al.*, 2015), arm coordination (Alberty *et al.*, 2009; Seifert; Chollet; Allard, 2005), shoulder and hip rotations (Psycharakis; Sanders, 2008). The main causes may be related to lateral dominance, the occurrence of injuries, the development of fatigue and swimming technique (Sanders; Thow; Fairweather, 2011).

However, asymmetry refers to the difference in performance or function between limbs and has been a popular line of research in recent years (Bishop *et al.*, 2017, 2018a). Research has reported asymmetries in the isokinetic parameters of the shoulder musculature in athletes from individual and team sports such as cricket (Oliver; Lala; Gillion, 2020), tennis (Brito *et al.*, 2022), volleyball (Hadzic *et al.*, 2014) and swimming (Tourny-Chollet; Seifert; Chollet, 2009). Recently, the analysis of the direction of asymmetries has been encouraged, making it possible to analyze which limb is favored by the asymmetry (Bishop *et al.*, 2017, 2018a). The direction of asymmetries can vary in different tasks or between assessments carried out on different days, thus justifying the relevance of exploring the consistency of the favored limb over time to monitor the progression of asymmetries (Bishop *et al.*, 2018a, 2018b).

For these analyses, the isokinetic dynamometer is commonly used (Batalha *et al.*, 2018, 2020), showing moderate to high reliability, with intraclass correlation values of 0.69 to 0.92 (Meeteren; Roebroeck; Stam, 2002) and 0.77 to 0.86 (Frisiello *et al.*, 1994) in test and retest measurements for isokinetic strength assessments of the shoulder joint. Research on this subject dates back to the 1990s (Beach; Whitney; Dickoff-Hoffman, 1992; McMaster; Long; Caiozzo, 1992). The main objective of researchers has been to verify muscle imbalances (Batalha *et al.*, 2012), strength asymmetries between the upper limbs (Carvalho *et al.*, 2019; Tourny-Chollet; Seifert; Chollet, 2009), correlation of results with other research instruments (Carvalho *et al.*, 2019) and correlation with swimming performance (Tan et al., 2021; Wiazewicz; Eider, 2021).

The investigation of isokinetic parameters between shoulder muscles play an important role in joint stability analyses (Cools *et al.*, 2002; Drigny *et al.*, 2020) and injury prevention (Batalha *et al.*, 2012; Vargas *et al.*, 2021). However, few studies have attempted to correlate isokinetic parameters with swimming performance (Tan *et al.*, 2021; Wiazewicz; Eider, 2021). In view of these issues, this thesis proposed some research questions: What are the main benefits and limitations of isokinetic analysis in swimmers' shoulders? Are there isokinetic torque asymmetries in the shoulder joint of competitive crawl swimmers? Are there differences in the magnitude and direction of isokinetic torque asymmetries in internal and external rotation, flexion and extension movements at different angular velocities (60 vs. 180°/s)? Using network analysis, are there correlations between isokinetic parameters and a performance variable (World Aquatic points) in competitive swimmers?

2. OBJETIVES

2.1. STUDY 1

General Objetive

To investigate the benefits and limitations of isokinetic test in shoulders of swimmers.

Specific objetives

- To identify, through a systematic review, the main protocols used for swimmers of different genders, competitive levels, ages and swimming techniques;

- Analyze the quality of the studies, based on the National Institutes of Health/National Heart, Lung, and Blood Institute (NHLBI) tool;

- To describe the main limitations of isokinetic analysis in swimmers' shoulders.

2.2. STUDY 2

General Objetive

To evaluate the magnitude and direction of isokinetic torque asymmetries at different angular velocities (60 vs. 180°/s) in the internal and external rotation, flexion and extension movements of the shoulders of competitive swimmers.

Specific objetives

- Compare the magnitude of isokinetic peak torque (PT) asymmetries between the angular velocities of 60 and 180°/s in the shoulder joint movements of internal (IR) and external rotations (ER), flexion (FL), and extension (EX);

- Determine the consistency of the direction of inter-limb asymmetries in the shoulder joint movements of IR, ER, FL, and EX at angular velocities of 60 and 180°/s.

2.3. STUDY 3

General objetives

To investigate the relationship between isokinetic parameters (peak torque and total work) at 180°/s in internal and external rotation, flexion and extension movements with World Aquatic points (performance).

Specific objetives

- Investigate the complex and simultaneous relationships between the World Aquatics points (performance) and the isokinetic test parameters, throug a network analysis;

- Compare the isokinetic parameters between the preferred and non-preferred sides of the shoulders of competitive swimmers.

3. HYPOTHESES

3.1. STUDY 1

- There's no hypothesis for this study.

3.2. STUDY 2

- Both the magnitude and direction of asymmetries are specific for each shoulder angular velocity and joint movement.

3.3. STUDY 3

- The network analysis would show strong relationships between the isokinetic variables and the World Aquatics points for both upper limp sides;

- The isokinetic parameters would not differ between the sides of the shoulders in the group of competitive swimmers.

4. RESULTS

The results section has been divided into three parts, which correspond to the studies carried out (1 to 3), in accordance with the established objectives. Table 1 shows the title of the articles resulting from this thesis, the journal in which they were published or submitted, and the Qualis specification.

Table 1. Articles developed in this thesis.

Articles title	Journal	Qualis
Benefits and limitations of isokinetic force assessments in swimmer's shoulders: A systematic review.	Journal of Bodywork and Movement Therapies (accepted)	A2
Magnitude and direction of shoulder torque asymmetries between different angular velocities in competitive swimmers.	Sports Biomechanics (submitted)	A3
Complex relationships between shoulder joint isokinetic parameters and performance in swimmers: a network analysis	International Journal of Performance Analysis in Sport (submitted)	A3

4.1. STUDY 1

BENEFITS AND LIMITATIONS OF ISOKINETIC FORCE ASSESSMENTS IN SWIMMER'S SHOULDERS: A SYSTEMATIC REVIEW

Accepted for publication in **Journal of Bodywork and Movement Therapies,** 2023.

Abstract

Objective: To indicate the benefits and limitations of the isokinetic test results for the performance of the main shoulder joint movements in swimmers, considering the different competitive levels, swimming techniques, race distances, and sex.
Methods: Search on the PubMed, CENTRAL, Medline, LILACS, and SCOPUS databases for the oldest records up to October 2022. Risk of bias, methodological quality, and level of evidence were evaluated based on the NHLBI checklist.
Results: 29 articles met the criteria and were included in this study. The quality analysis classified three as "good" and 26 as "regular", with a KAPPA index of 0.87. The main benefits found involved assessments of the clinical condition of the shoulder joint complex, relationships with performance, and reliability studies. The limitations found point to the participant's positioning in the instrument, use of angular velocity above 180°/s, and sample size.
Conclusion: The use of the isokinetic dynamometer allows verifying the levels of strength, endurance, balance, and asymmetries among swimmers of different techniques, distances, competitive levels, and sex. Thus, it helps in the analysis and monitoring of the clinical conditions of swimmers' shoulder joints, contributing to the decision-making process of physiotherapists and coaches.

Keywords: muscle strength dynamometer, injuries, performance, swimming.

INTRODUCTION

Athletes who practice sports characterized by elevation movements of the upper limbs above head level, like in competitive swimming, usually perform shoulder movements with high speed and extreme motion range, making them more prone to injury (Feijen *et al.*, 2020a). As a result, muscular imbalances appear in swimmers' shoulder joint not only over several years of sport practicing but also after a single season (Batalha *et al.*, 2015b) with injuries occurring at an estimated 23 to 38% (Chase *et al.*, 2013; Walker *et al.*, 2012).

Musculoskeletal conditions in the shoulder joint are a common and costly source of pain and functional disability in swimmers, resulting in potential injury to this joint (Bak; Magnusson, 1997; Beach; Whitney; Dickoff-Hoffman, 1992; Swanik *et al.*, 2002). In this context, investigating the isokinetic forces between the shoulder musculatures plays an important role in joint stability analyses (Cools *et al.*, 2002; Drigny *et al.*, 2020) and injury prevention (Vargas *et al.*, 2021). Among these analyses, the isokinetic dynamometer is commonly used (Batalha et al., 2018; Batalha et al., 2020), showing moderate to high reliability, with intraclass correlation values of 0.69 to 0.92 (Meeteren; Roebroeck; Stam, 2002) and 0.77 to 0.86 (Frisiello *et al.*, 1994) in test and retest measurements for isokinetic strength assessments of the shoulder joint. Furthermore, cross-sectional (Bae; Yu; Lee, 2016; Lawsirirat; Chaisumrej, 2017) and longitudinal (Batalha *et al.*, 2020; Drigny *et al.*, 2020; Swanik *et al.*, 2002) cohort studies have performed isokinetic assessments in swimmers and found important data and information for clinical and fitness training decision-making (Batalha et al., 2015a; Batalha et al., 2018; Swanik et al., 2002).

Accurate results on shoulder functionality depend on the understanding of the behavior of shoulder muscle forces applied through different swimming techniques (Carvalho *et al.*, 2019; Sanders *et al.*, 2015; West; Sole; Sullivan, 2005), different distances (Lawsirirat; Chaisumrej, 2017; Tourny-Chollet; Seifert; Chollet, 2009), and different levels (Liaghat *et al.*, 2018; West; Sole; Sullivan, 2005; Wiażewicz; Eider, 2016). These analyses can help coaches, physical therapists, and physical trainers in training adaptations, including out-of-water exercises to maintain balance and muscle strength (Batalha *et al.*, 2015b, 2020; Swanik *et al.*, 2002). Studies in this direction indicate that the external rotators and abductors muscles of the shoulder are especially less strengthened during swimming than their antagonists (Batalha *et al.*, 2015b).

Therefore, it is essential to analyze the variables assessed through the isokinetic dynamometer in swimmers for obtaining data that can help identify the clinical conditions of the swimmer's shoulder (Batalha *et al.*, 2012). In addition, it can assist with bilateral force symmetry index data that are directly related to unnecessary rotations of the swimmer's body, causing body misalignment and increased drag, as well as affecting muscular endurance and propulsion (Sanders, 2013).

Therefore, the main objective of this systematic review is to highlight the benefits and limitations of isokinetic test results for the performance of the main shoulder joint movements of swimmers, considering the different competitive levels, swimming techniques, distances, and sex. Our results will provide important information on the benefits and limitations reported in studies with swimmers in isokinetic assessments of shoulder strength; in addition to helping researchers, coaches, athletes, and physical therapists monitor and make decisions based on analysis through the isokinetic dynamometer directed at injury risks and the swimmers' performance.

METHODS

This study followed the preferred reporting items for systematic reviews and meta-analyses PRISMA (Shamseer *et al.*, 2015). The protocol was pre-registered with the International Prospective Registry of Systematic Reviews (PROSPERO; protocol CRD42021261246).

Research strategy

The searches started in September 2021 on the PubMed, PMC, Medline, Lilacs, and SCOPUS databases using a combination of descriptors and keywords ("isokinetic" AND "swimming" AND "shoulder") for all databases. Additional studies were found based on the article references and added to the database upon meeting the inclusion criteria. The additional studies were searched in April 2022 by including studies from the oldest one until October 2022.

Inclusion and exclusion criteria

Similarly to previous studies (Estrázulas *et al.*, 2020), the articles included herein should meet the following inclusion criteria: a peer-reviewed publication, full text, English language, and participation of swimmers in shoulder isokinetic assessments. Articles that met at least one of the following criteria were excluded: (1) duplicate, (2) incomplete text, (3) not peer-reviewed, (4) not in the English language, (5) non-swimmers assessed, (6) shoulders not assessed, (7) non-isokinetic assessment, or (8) review study. Conference abstracts, dissertations, theses, and studies that included secondary analyses were not considered.

Study selection

Two independent investigators reviewed all articles. The search process (illustrated in Fig. 1) was based on the evaluation hierarchy of studies by journal title (removing duplicates), abstract, full article review upon including or excluding the paper according to the inclusion and exclusion criteria. The researchers were not blinded to authors' names and affiliations or journal names. In case of disagreement between the two investigators, a third reviewer was consulted to reach a consensus. The two investigators read the full text of the selected articles independently to identify the benefits and limitations of the studies involving isokinetic strength analysis in swimmers.

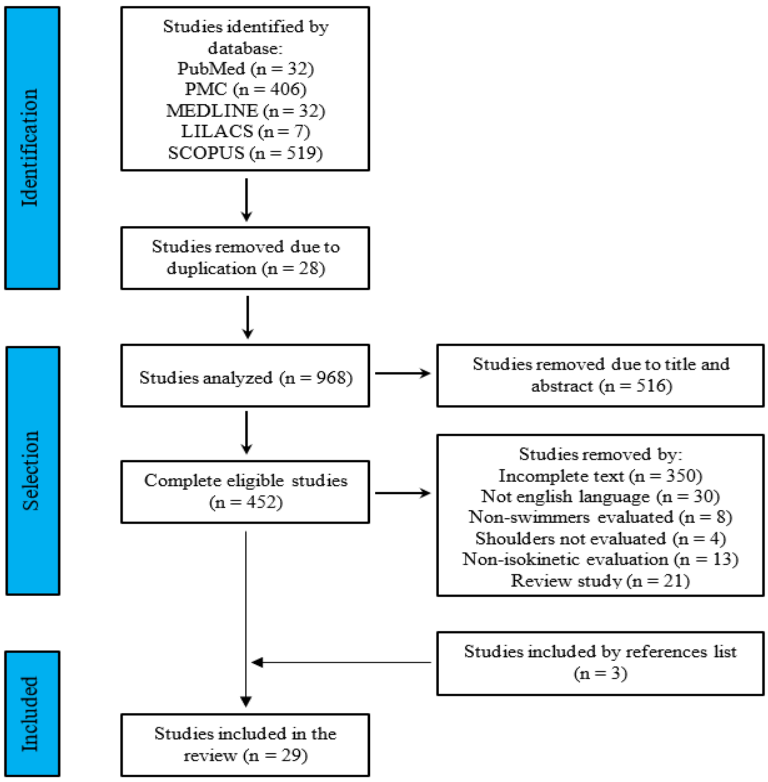

Figure 1. Search flowchart and selection process for the articles for review

Data extraction and quality assessment

The two researchers extracted the following data independently: authors's names, year of publication, number of participants, sex, age, joint movements, participant's positioning on the isokinetic dynamometer, angle of movement, angular velocity, types of contraction, swimming technique, level of swimmers, stimuli during the test, interval, and familiarization with the equipment (Table 2 and 3).

Two researchers assessed the quality of the articles independently based on the National Institutes of Health/National Heart, Lung, and Blood Institute (NHLBI) tool. Occasional differences were resolved by consensus by a third reviewer. The analysis of observational cohort, cross-sectional, and controlled intervention studies involved the evaluation of the following 14 (Table 4 and 5). The before and after (pre-post) studies without a control group were analyzed considering the following 12 questions (Table 6).

The studies were rated according the score attributed as follows: A poor, between 00.00 – 0.30, fair, 0.31 – 0.70, and good, 0.71 – 1.00 (Bagias *et al.*, 2021). The KAPPA coefficient was applied to estimate the degree of agreement between the researchers regarding the quality of the studies. This coefficient which is commonly used to assess agreement between the assessments of two raters on a nominal scale (De Raadt *et al.*, 2019). Cohen (1960)suggested that the Kappa coefficient result should be interpreted as follows: values ≤ 0, no agreement and 0.01 - 0.20, slight agreement, 0.21 - 0.40, fair, 0.41- 0.60, moderate, 0.61 - 0.80, substantial, and 0.81 - 1.00, almost perfect agreement. The analyses were performed on the SPSS Statistic v. 22.0.

RESULTS

Data synthesis

The search strategy identified 32 studies on the PubMed, 406 on the PMC, 32 on the Medline, 7 on the Lilacs, and 519 on the SCOPUS, numbering 996 articles. Out of these, 28 were excluded due to duplication and other 516 due to title and abstract. After screening, 452 studies were read in full, and out of which 426 were excluded based on the eligibility criteria. Finally, three studies included by references list and 29 studies were considered relevant and met all the criteria established for the analysis.

Data extraction and quality assessment

The participants in the studies included herein encompassed the elite (n = 7), national (n = 11), regional (n = 1), competitive (n = 8), practicing (n = 2) levels. These individuals were compared to non-athlete (n = 2) and sedentary (n = 2) groups, numbering 947 participants from all studies. The age of the participants ranged from 12 to 60 years. A total of eight studies included only male athletes, only two studies included only female athletes, and 18 studies included both male and female athletes. Only one study did not inform the sex of the participants. The outcomes of studies involving swimmers and isokinetic analyses are related to the clinical condition of the shoulder joint complex (n = 20), relationships with performance (n = 7), and the reliability of analyses with swimmers on an isokinetic dynamometer (n = 2). Tables 2 and 3 detail this information for each study.

Table 2. Overview of the sample characteristics including swimmers' sex, age, level, and swimming technique of each selected study

Authors	Sample	Sex	Age (in years)	Athlete Level	Swimming Technique
(Bae et al. 2016)	28	NR	G1: 16.8 ± 0.8 / G2: 17.4 ± 0.8	G1: Elite (n = 14); G2: National (n = 14)	FC
(Bak and Magnusson 1997)	15	9M / 6F	G1: 16-19; G2: 15-25	Competitive	NR
(Batalha et al. 2012)	120	M	G1: 14.55 ± 0,5 / G2: 14.62 ± 0.49	G1: NR (n = 60) / G2: Practitioners (n = 60)	NR
(Batalha et al. 2013)	36	M	G1:14.45 ± 0.50/ G2:14.69 ± 0.48	G1: NR (n = 20) / G2: Sedentary (n = 16)	NR
(Batalha et al. 2014)	40	M	G1: 14.65 ± 0.49 / G2: 14.45 ± 0.51	National	NR
(Batalha et al. 2015a)	49	M	G1: 14.48 ± 0.50 / G2: 14.64 ± 0.49	G1: NR (n = 27) / G2: Non-Practitioners (n = 22)	NR
(Batalha et al. 2015b)	56	M	G1: 14.65 ± 0.49 / G2: 14.45 ± 0.51 / G3: 14.69 ± 0.48	G1+G2: National (n = 40) / G3: Sedentary (n = 16)	FC
(Batalha et al. 2018)	25	M	G1: 13.28 ± 0.96 / G2: 13.52 ± 0.92	NR	NR
(Batalha et al. 2020)	23	14M / 9F	16.43 ± 1.38	National	NR
(Beach et al. 1992)	32	8M / 24F	19.0 ± 2.0	Competitive	NR
(Carvalho et al. 2019)	12	7M / 5F	M: 20.9 ± 3.4; F: 19 ± 2.2	Elite	FC / BS
(Collado-Mateo et al. 2018)	35	24M / 11F	15.17 ± 1.38	National	FC
(Drigny et al. 2020)	18	10M / 8F	16.1 ± 2.3 16.3 ± 1.7	Elite	FC
(Gaudet et al. 2018)	24	11M / 13F	22.8 ± 4.3	Competitive /Recreational	NR

(King et al. 2022)	37	F	G1: 24.7 ± 2.4 / G2: 22.2 ± 5.6 / G3: 20.4 ± 2,5	Elite	NR
(Lawsirirat and Chaisumrej 2017)	36	18M / 18F	>15	National	FC
(Liaghat et al. 2018)	38	16M / 22F	14.8 ± 1.3; 14.7 ± 1.1	G1: National / G2: Control	FC
(McMaster et al. 1992)	47	24M / 23F	G1: 22 / G2: 20 / G3: 23 / G4: 18.3	20 Control / 27 Elite	NR
(Rupp et al. 1995)	44	20M / 24F	G1: 17.7 / G2: 17.7	G1: Competitive / G2: Control	NR
(Sanders et al. 2015)	1	F	NR	Elite	BR
(Secchi et al. 2015)	80	M / F	GI: 21.8 ± 3.8 / G2: 20.3 ± 4.5 / RG: 24.5 ± 4.5 CG: 25.8 ± 3.5	G1 + G2: NR (n = 45) / CG: Sedentary (n = 21) / RG: Recreational (n = 14)	FC / BS / BR / BF
(Sonza and Andrade 2012)	10	M	16.3 ± 1.2	Competitive	NR
(Swanik et al. 2002)	26	13M / 13F	NR	National	NR
(Tan et al. 2021)	10	7M / 3F	21.3 ± 4.0; 21.8 ± 3.2	Elite/National	NR
(Tourny-Chollet et al. 2009)	13	M	18.6 ± 2.5	National	FC
(Vargas et al. 2011)	22	16M / 6F	21.0 ± 5.0 M 22.5 ± 2.5 F	Regional	NR
(West et al. 2005)	13	6M / 7F	G1: 25-58; CG: 25-60	Practitioners	FC / BS / BF
(Wiazewicz and Eider 2016)	18	M	NR	National	FC
(Wiazewicz and Eider 2021)	39	27M / 12F	16.58 ± 1.93 M / 17.8 2.51 F	Elite	NR

G: Group; CG: Control Group; RG: Recreational Group; FC: Front Crawl; BS: Backstroke; BR: Breastoke; BF: Butterfly; M: Male; F: Female; NR: Not Reported.

Table 3. Joint movements, position on the isokinetic dynamometer, familiarization with movement, repetitions, angular velocities, type of contraction, rest interval, and variables analyzed in each of the selected studies.

Authors	Joint Movements	Position	Familiarization (Attempt)	Protocol 1	Protocol 2	Rest Interval	Variables
(Bae et al. 2016)	IR / ER	NR	1	NR rep. 60º/s. Conc. / Conc.	NA	120 s	PT
(Bak and Magnusson 1997)	IR / ER	Seated	1	NR rep. 30°/s Conc. / Ecc.	NR rep. 30°/s Conc. / Ecc.	30 s	PT Conc. / PT Ecc. / CBR / FBR / ROM
(Batalha et al. 2012)	IR / ER	Seated	2	3 rep. 60º/s. Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	CBR / PT / FI
(Batalha et al. 2013)	IR / ER	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT / CBR / FI
(Batalha et al. 2014)	IR / ER	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT / CBR
(Batalha et al. 2015a)	IR / ER	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT / CBR
(Batalha et al. 2015b)	IR / ER	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT/ CBR
(Batalha et al. 2018)	IR / ER	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	60 s	PT / CBR / FI
(Batalha et al. 2020)	IR / ER	Seated	3	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT / CBR
(Beach et al. 1992)	IR / ER / FL / EX	Supine	1	3 rep. 60°/s Conc. / Conc.	50 rep. 240°/s Conc. / Conc.	60 s	PT/ CBR / RR
(Carvalho et al. 2019)	FL / EX	Supine	1	5 rep. 90º/s Conc. / Conc.	10 rep. 300º/s Conc. / Conc.	90 s	PT / APT / AP / SI
(Collado-Mateo et al. 2018)	IR / ER	Seated	1	3 rep. 60º/s. Conc. / Conc.	-	120 s	PT / W / CBR
(Drigny et al. 2020)	IR / ER	Seated	3	5 rep. 60º/s Conc. / Conc.	4 rep. 60º/s Ecc. / Ecc.	NR	PT Conc. / PT Ecc. / CBR / FBR

(Gaudet et al. 2018)	IR / ER	Seated	NR	50 rep. 240°/s Conc. / Conc.	-	NR	PT
(King et al. 2022)	IR / ER	Prone	NR	2x 3 rep. 120°/s Conc. / Conc.	2x 3 rep. 120°/s Conc. / Conc.	60 s	PT
(Lawsirirat and Chaisumrej 2017)	FL / EX	NR	1	3 rep. 60º/s Conc. / Conc.	3 rep. 90°/s Conc. / Conc.	60 s	APT
(Liaghat et al. 2018)	MR / LR	Prone	5	5 rep. 60º/s Conc. / Conc.	10 rep. 180º/s Conc. / Conc.	60 s	PT / MW
(McMaster et al. 1992)	IR / ER / AD / AB	Kneeling	2	3 rep. 30°/s Conc. / Conc.	3 rep. 180°/s Conc. / Conc.	10 s	PT / CBR
(Rupp et al. 1995)	IR / ER	Supine	1	10 rep. 60°/s Conc. / Conc.	10 reps. 180º/s Conc. / Conc.	60 s	PT / TW / CBR / RW
(Sanders et al. 2015)	FL / EX / IR / ER	Seated	1	12 rep. 60º/s Conc. / Conc.	12 rep. 180º/s Conc. / Conc.	90 s	PT / APT / CBR
(Secchi et al. 2015)	AB / AD / ER / IR	NR	3	5 rep. 60º/s Conc. / Conc.	20 rep. 300º/s Conc. / Conc.	30 s	PT BW / TW / CBR
(Sonza and Andrade 2012)	IR / ER / FL / EX / AD / AB	Supine	1	3 rep. 120°/s Conc. / Ecc.	-	NR	PT
(Swanik et al. 2002)	IR / ER	Seated	5	10 rep. 180°/s Conc. / Conc.	10 rep. 300º/s Conc. / Conc.	90 s	PT
(Tan et al. 2021)	IR / ER	NR	1	3 rep. 90°/s Conc. / Conc.	3 rep. 180°/s Conc. / Conc.	120 s	PT / APT / AP
(Tourny-Chollet et al. 2009)	MR / LR	Seated	NR	NR rep. 90°/s Conc. / Conc.	10 rep. 120°/s Conc. / Conc.	900 s	APT / SI
(Vargas et al. 2021)	IR / ER	Seated	3	5 rep. 60°/s Conc. / Conc. 5 rep. 240°/s Conc. / Conc.	5 rep. 240°/s Ecc. / Ecc.	60 s	PT Conc. / PT Ecc. / CBR / FBR
(West et al. 2005)	IR / ER	Seated	1	3 rep. 90°/s Conc. / Ecc.	3 rep. 90°/s Conc. / Ecc.	180 s	PT Conc. / PT Ecc. / COV/ CBR / FBR

(Wiazewicz and Eider 2016)	FL / EX	NR	NR	3 rep. 60°/s Conc. / Conc.	20 rep. 180°/s Conc. / Conc.	120 s	PT / MRW / COV / TW / AP / CBR
(Wiazewicz and Eider 2021)	FL / EX	Seated	2	3 rep. 60º/s Conc. / Conc.	20 rep. 180º/s Conc. / Conc.	120 s	PT / PT BW / PT TIME / PT ANGLE / MRW / COV / WBW / TW / WF / COV /AP / AT / DT / ROM APT / CBR

IR: internal rotator; ER: external rotator; FL: flexion; EX: extension; AD: adduction; AB: abduction; MR: medial rotation; LR: lateral rotation; REP: repetitions; CONC: concentric; ECC: eccentric; PT: peak torque; FI: fatigue index; CBR: conventional balance ratio; FBR: functional balance ratio; ROM: range of movement; RR: resistance ratio; APT: average peak torque: AP: average power; SI: symmetry index; MW: maximum work; TW: total work; RW: ratio work; PT BW: peak torque per body weight; COV: coefficient of variation; MRW: maximal repetition work; W: work; WBW: work per body weight; WF: work fatigue; PT TIME: time to peak torque; PT ANGLE: angle of peak torque; AT: acceleration time; DT: deceleration time; NR: not reported

The quality analysis of the observational cohort and cross-sectional studies indicated that out of the 24 included articles, only three were rated as "good" and 21 as "fair”, with a mean score of 0.54 ± 0.10 points. In addition, 21 studies did not meet questions 12, 13, and 14. The quality analysis of the controlled intervention studies was applied to evaluate four studies, all rated as "fair", with a mean score of 0.39 ± 0.08. Only one study was characterized as pre- and post-intervention, being rated "fair". The agreement between the reviewers according to the KAPPA coefficient was 0.87, indicating good agreement.

Table 4: Risk of bias assessment using NHLBI for observational cohort and cross-sectional. Criteria: (1) research question; (2 and 3) study population; (4) groups recruited from the same population and uniform electability criteria; (5) justification of sample size; (6) exposure assessed before the outcome measurement; (7) sufficient time frame to observe an effect; (8) different exposure levels of interest; (9) exposure and assessment measures; (10) assessment of repeated exposure; (11) outcome measures; (12) blinding of outcome assessors; (13) follow-up rate, and (14) confounding variables in statistical analyses.

	Criteria															
Observational cohort and cross-sectional studies	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Score**	**Quality**
(Bae et al. 2016)	Y	Y	CD	Y	Y	Y	Y	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Bak and Magnusson 1997)	Y	Y	CD	Y	N	N	Y	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Batalha et al. 2012)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Batalha et al. 2013)	Y	Y	CD	Y	N	Y	Y	NA	Y	Y	Y	NA	NR	N	0.73	Good
(Batalha et al. 2015a)	Y	Y	CD	Y	N	Y	Y	NA	Y	Y	Y	NA	NR	N	0.73	Good
(Beach et al. 1992)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Carvalho et al. 2019)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Collado-Mateo et al. 2018)	Y	Y	CD	Y	N	Y	Y	NA	Y	Y	Y	NA	NR	N	0.67	Fair

(Drigny et al. 2018)	Y	Y	Y	Y	N	Y	Y	NA	Y	Y	Y	NA	N	N	0.75	Good
(Gaudet et al. 2018)	Y	Y	CD	N	N	N	N	NA	Y	N	Y	NA	NA	NA	0.40	Fair
(King et al. 2022)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Lawsirirat and Chaisumrej 2017)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Liaghat et al. 2018)	Y	Y	CD	Y	Y	N	N	NA	Y	N	Y	Y	NA	NA	0.64	Fair
(McMaster et al. 1992)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Rupp et al. 1995)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Sanders et al. 2015)	Y	Y	NA	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Secchi et al. 2015)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Sonza and Andrade 2015)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Tan et al. 2021)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	N	0.45	Fair
(Tourny-Chollet et al. 2009)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Vargas et al. 2021)	Y	Y	Y	Y	N	N	N	NA	Y	N	Y	NA	Y	NA	0.64	Fair
(West et al. 2005)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	NA	0.50	Fair
(Wiazewicz and Eider 2016)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	N	0.45	Fair
(Wiazewicz and Eider 2021)	Y	Y	CD	Y	N	N	N	NA	Y	N	Y	NA	NA	Y	0.54	Fair

Y: yes; N: no; CD: cannot determine; NA: not applicable; NR: not reported.

Table 5: Risk of bias assessment using NHLBI for controlled intervention. Criteria (1) described as randomized; (2 and 3) treatment allocation – two interrelated pieces; (4 and 5) blinding; (6) group similarity at baseline; (7 and 8) dropout; (9) adherence; (10) avoid other interventions; (11) assessment of outcome measures; (12) sample power calculation; (13) pre-specified outcomes, and (14) analysis on intention to treat.

	Criteria															
Controlled intervention studies	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Score**	**Quality**
(Batalha et al. 2014)	N	N	NR	NR	NR	Y	Y	Y	Y	CD	Y	N	Y	Y	0.50	Fair
(Batalha et al. 2015b)	N	N	NR	NR	NR	Y	NR	NR	Y	CD	Y	N	Y	Y	0.35	Fair
(Batalha et al. 2018)	N	N	NR	NR	NR	Y	NR	NR	Y	CD	Y	N	Y	Y	0.35	Fair
(Swanik et al. 2002)	N	N	NR	NR	NR	Y	NR	NR	Y	CD	Y	N	Y	Y	0.35	Fair

Y: yes; N: no; CD: cannot determine; NA: not applicable; NR: not reported.

Table 6: Risk of bias assessment using NHLBI for before-after studies without control group. Criteria (1) study question; (2) eligibility criteria and study population; (3) study participants representating the populations of interest; (4) all eligible participants enrolled; (5) sample size; (6) clearly described intervention; (7) clearly described, valid, and reliable outcome measures; (8) blinding of outcome assessors; (9) follow-up rate; (10) statistical analysis; (11) multiple outcome measures, and (12) group-level interventions and individual-level outcome efforts.

	Criteria													
Before-after (Pre-Post) Studies without control group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Score**	**Qualty**
(Batalha et al. 2020)	Y	Y	Y	Y	N	Y	Y	N	NR	Y	N	NA	0.63	Fair

Y: yes; N: no; CD: cannot determine; NA: not applicable; NR: not reported.

Benefits and limitations

The main benefits found in studies with swimmers were assessments of the clinical status of the shoulder joint complex at 65.51 % (n = 19), relationships with a performance at 27.59 % (n = 8), and reliability studies at 6.90 % (n = 2). Considering the study population, the assessments included practitioners of different swimming techniques 10.34 % (n = 3), different distances 6.90 % (n = 2), and both males and females 58.62 % (n = 17), in addition to distinguished competitive levels 17.24 % (n = 5). Two studies (6.89 %) did not meet the specifications to be included in the mentioned items, since one involved a case study (Sanders *et al.*, 2015) and the other (Sonza; Andrade, 2012) did not characterize the sample in terms of competitive level, swimming techniques, or gender. In addition, the positioning of the swimmers on the isokinetic dynamometer in dorsal and ventral decubitus 6.89 % (n = 2) and 13.79 % (n = 4), respectively, were considered benefits as they resembled more the positions in swimming. The limitations found point to the positioning of the participant on the isokinetic dynamometer in the sitting and kneeling positions 55.17 % (n = 16) and 3.45 % (n = 1), respectively, and the non-recording of the positioning in the equipment 20.69 % (n = 6). In addition, the use of angular velocity above 180°/s 17.24 % (n = 5) and the justification of sample size calculation 96.55 % (n = 28) were also considered limitations. Table 7 present this information in detail.

Table 7. Benefits and limitations found in studies with swimmers subjected to isokinetic shoulder assessments. Benefits: clinical assessment (CA); performance relationship (PR); different swimming techniques (DST); different competitive levels (DCL); assessment in both sexes (ABS); prone positioning (PP); supine positioning (SP), and limitations: positioning not reported (PNR); positioning seated (PS); positioning kneeling (PK); speed above 180°/s (SP); sample size (SS).

Authors	Benefits								Limitations				
	CA	PR	DST	DSD	DCL	ABS	PP	SP	PNR	PS	PK	SP	SS
(Bae et al. 2016)		●			●				●				●
(Bak and Magnussun 1997)	●					●				●			●
(Batalha et al. 2012)	●									●			●
(Batalha et al. 2013)	●									●			●
(Batalha et al. 2014)	●									●			●

(Batalha et al. 2015a)	•									•			•
(Batalha et al. 2015b)	•									•			•
(Batalha et al. 2018)	•									•			•
(Batalha et al. 2020)	•					•				•			•
(Beach et al. 1992)	•				•	•	•					•	•
(Carvalho et al. 2019)	*	*	•			•		•					•
(Collado-Mateo et al. 2018)	*	*				•				•			•
(Drigny et al. 2020)	•					•				•			•
(Gaudet et al. 2018)	•					•				•		•	•
(Lawsirirat and Chaisumrej 2017)		•		•		•			•				•
(Liaghat et al. 2018)	•					•	•						
(King et al. 2022)		•			•		•						•
(McMaster et al. 1992)	•					•					•		•
(Rupp et al. 1995)	•					•	•						•
(Sanders et al. 2015)		•							•				•
(Secchi et al. 2015)	•	•	•		•	•			•			•	•
(Sonza and Andrade 2012)	*	*						•					•
(Swanik et al. 2002)	•					•				•		•	•
(Tan et al. 2021)		•			•	•			•				•

(Tourny-Chollet et al. 2009)		●		●			●		●
(Vargas et al. 2021)	●				●		●	●	●
(West et al. 2005)	●		●		●		●		●
(Wiazewicz and Eider 2016)	●					●			●
(Wiazewicz and Eider 2021)		●			●		●		●

Note: * Reliability studies

DISCUSSION

This systematic review aimed to indicate the benefits and limitations of the results among isokinetic assessments for the performance of the main shoulder joint movements of swimmers (Johnson; Gauvin; Fredericson, 2003), considering the different competitive levels, swimming techniques, distances, and sex. The main objective of the studies selected for this systematic review was to assess the clinical condition of the swimmer's shoulder (King *et al.*, 2022; McMaster; Long; Caiozzo, 1992; Rupp; Berninger; Hopf, 1995) . It had been found that a single competitive season is capable to imply muscular imbalances in the swimmer's shoulder joint. In addition, eight of the studies (27.59 %) included aimed to associate isokinetic variables with swimming performance since it is known that upper limb muscle strength, as well as its symmetrical application between stroke cycles, is a determining factor for higher velocity and lower active drag of the swimmer (Garrido *et al.*, 2010; Sanders, 2013; Toussaint; Beek, 1992).

Benefits

Clinical assessments

Injuries to shoulder joint muscles in competitive swimming primarily result from repetitive strain (Feijen *et al.*, 2020b). Studies using the isokinetic dynamometer in swimmers have helped clarify the effects of training on the shoulder joint at different training periods (Batalha et al., 2015a; Batalha et al., 2013) , indicating to a disproportionate increase in strength between shoulder musculatures (Batalha et al., 2015a; Batalha et al., 2013). Such a disproportion is directed towards the musculature acting in the stroke phases, where the internal rotation, extension, and adduction are strengthened compared with their antagonists (Batalha *et al.*, 2013; Johnson; Gauvin; Fredericson, 2003) .

In this context, several studies recognize the importance of prescribing strength training out of the water to maintain shoulder muscle balance and endurance in swimmers (Batalha *et al.*, 2020; Swanik *et al.*, 2002; Tan *et al.*, 2021) acting as a preventive factor since its absence would decrease muscle strength and balance (Batalha *et al.*, 2014). The conventional ratio values between the internal and external rotators of the shoulder should range from 66-75% (Ellenbecker; Davies, 2000), and lower results are considered serious imbalances and can imply shoulder pain and injury (Batalha *et al.*, 2015a), compromising the swimmer's athletic life of.

Relationships with performance

The main variable analyzed aiming to establish a relationship with performance is the peak torque of shoulder joint movements (Bae; Yu; Lee, 2016; Batalha *et al.*, 2015a; Lawsirirat; Chaisumrej, 2017; Sanders *et al.*, 2015; Secchi; Brech; Greve, 2015; Tan *et al.*, 2021; Tourny-Chollet; Seifert; Chollet, 2009; Wiazewicz; Eider, 2021). The respective results can be entered into equations to define symmetry index (Tourny-Chollet; Seifert; Chollet, 2009), average peak torque (Sanders *et al.*, 2015; Tan *et al.*, 2021; Tourny-Chollet; Seifert; Chollet, 2009), in addition to agonist-antagonist ratios that are more related to the clinical condition (Sanders *et al.*, 2015; Secchi; Brech; Greve, 2015). The peak torque is a variable that is directly related to the ability to generate muscle force (Batalha *et al.*, 2012) and is determinant in sports such as competitive swimming (Garrido *et al.*, 2010) since the force generated by cyclic upper limb movements is the main source of propulsion for swimming (Wiazewicz; Eider, 2021), necessary for the swimmer to overcome drag forces (Baldassarre *et al.*, 2017).

A single study analyzed the relationships of isokinetic variables obtained from the joint movements of shoulder flexion and extension with the average speed in male and female swimmers(Wiazewicz; Eider, 2021). The results were significant only for men in the isokinetic variable left shoulder acceleration time (r_2 = -0.64; p < 0.01) in the flexion movement (Wiazewicz; Eider, 2021). However, previous studies have shown that maximal upper limb strength was moderately to highly related (r = 0.67) to swimming speed over short distances (Keiner *et al.*, 2021). Specific tests, for example, tethered swimming, were more related to swimming speed and are considered performance predictors (Castro *et al.*, 2010; Morouço *et al.*, 2011). However, Carvalho *et al*. (2019) showed that the symmetry index of upper limb forces made in tethered swimming and the isokinetic dynamometer have moderate to high relationships (*r* = -0.62 to 0.96, $p < 0.05$). Furthermore, it is known that efforts are needed during swimming to develop and maintain symmetrical forces on both sides of the body, thus having better efficiency during swimming by decreasing drag (Sanders *et al.*, 2015).

In another study (Tan *et al.*, 2021), positive relationships were found between the isokinetic variables obtained from the internal and external rotation (peak torque, average peak torque, and average power) with the tethered swimming test. The highest correlation was found in elite swimmers for the variable of average peak torque at 180°/s ($r = 0.95$, $p = 0.003$), and still managed to identify that elite swimmers are more efficient in transferring the force applied on land to the impulse in the water. Furthermore, found significant differences in peak torque of internal and external rotator values between international and national level swimmers (Bae; Yu; Lee, 2016). The international-level swimmers achieved higher peak torque values, indicating that the isokinetic strength of the shoulder muscles was related to performance.

Reliability

The isokinetic dynamometer is considered the gold standard for assessing muscle strength, providing reliable values under highly controlled circumstances (Aquino et al. 2007). Studies on the validity and reliability of tests have been developed based on this instrument in swimmers aiming to investigate the degree of association among propulsive forces in tethered swimming and isokinetic peak torque (Carvalho *et al.*, 2019), analysis of peak torque curves (Sonza; Andrade, 2012), and analysis of the reliability of concentric rotation force (Collado-Mateo *et al.*, 2018). Carvalho *et al*. (2019) obtained similar symmetry index values regardless of conditions, land, and water. It is important to investigate the symmetry index in swimmers to guide compensatory training since it is aimed at avoiding shoulder joint instability (Tourny-Chollet; Seifert; Chollet, 2009), responding to excessive asymmetry (Seifert; Chollet; Bardy, 2004), and providing relevant information for planning strength, flexibility, and technique intervention to improve performance (Sanders; Thow; Fairweather, 2011).

According to the authors (Sonza; Andrade, 2012), the torque curve of an isokinetic assessment allows determining the point of muscle weakness in the range of motion. Also, it identifies the structural integrity of joints and supports structures, providing the evaluator with indications of muscle performance, in addition to detecting strength deficits in swimmers' shoulder joint.

Collado-Mateo *et al*. (2018) found excellent reliability values for the peak torque, total work, and external/internal rotator ratio variables, thus proving an efficient measurement method. Previous studies identified deficits and even changes in strength performance in swimmers' shoulder joint muscles (Bae; Yu; Lee, 2016; Batalha et al., 2015a; Batalha et al., 2014).

Different swimming techniques

The simultaneous (breaststroke and butterfly) and alternate (freestyle and backstroke) techniques are factors that can influence strength by acting differently on the propulsive musculature of the shoulder. They require different types of preparation and training, both to improve performance and prevent and treat injuries (Secchi; Brech; Greve, 2015). In this sense, isokinetic assessments in practitioners of different swimming techniques allow identifying asymmetries and characterizing strength imbalances between shoulder musculatures (Carvalho *et al.*, 2019; Sanders *et al.*, 2015; West; Sole; Sullivan, 2005). Among the main determinants of performance, strength asymmetries between upper limbs, lower limbs, and right and left sides can affect endurance and propulsion due to strength imbalances by causing body rotations, leading to body misalignment and increased drag (Sanders, 2013).

Only one study compared isokinetic strength variables between swimmers of simultaneous and alternate swimming techniques in the shoulder muscles in the joint movements of internal and external rotator, peak torque body weight, total work, agonist-antagonist ratios, adductors, and abductors. However, no significant differences were found, thus indicating that isokinetic force production at the shoulder joint involving swimmers of different techniques showed similar results (Secchi; Brech; Greve, 2015).

Swimmers of different distances

Swimmers of different competitive distances need to adapt to different strategies, techniques, and physiological demands (Lawsirirat; Chaisumrej, 2017). Therefore, isokinetic assessments performed in short and middle-distance swimmers for the front crawl technique allowed comparing peak torque values and identifing the force symmetry in different lateral breathing profiles and arm coordination (Lawsirirat; Chaisumrej, 2017; Tourny-Chollet; Seifert; Chollet, 2009). Seeking the best competitive performance, swimmers need to be as symmetrical as possible when moving in the water (Carvalho *et al.*, 2019). Thereby, applying similar force on both sides of the shoulder can influence swimming performance by reducing drag, improving body alignment, and decreasing intracycle velocity variations (Sanders; Thow; Fairweather, 2011).

Furthermore, studies often show that the internal rotator and adductors are strengthened more than their antagonist, especially for the front crawl swimming technique (Collado-Mateo *et al.*, 2018), causing muscle imbalances due to the actions performed above the head, in addition to a potential adaptation of the soft tissues of the shoulder joint. Consequently, these adaptations may contribute to shoulder disorders (Tourny-Chollet; Seifert; Chollet, 2009).

Different levels

Assessment using an isokinetic dynamometer is important for young swimmers as they represent a group with a high prevalence of shoulder hypermobility (Liaghat *et al.*, 2018). In addition, at this particular age (Batalha *et al.*, 2015b), competitive swimmers have considerably higher training volume, which may cause significant muscle imbalances during a given season, for example (Batalha *et al.*, 2013). Coaches can use isokinetic assessments to determine muscle imbalances and monitor training-induced changes by assessing peak torque, agonist-antagonist ratios, and symmetry index variables throughout a competitive swimming season (Batalha *et al.*, 2013; Carvalho *et al.*, 2019).

Studies involving young swimmers showed that internal rotator strength values were proportionally stronger relative to external rotator, suggesting that aquatic training may cause agonist-antagonist ratios imbalances throughout the season (Batalha *et al.*, 2013). In this case, a compensatory training program is recommended since it produces beneficial effects on the shoulder joint muscles, increasing the strength values of the external rotator and reducing the differences between the internal and external rotators.

However, master swimmers are also susceptible to muscle imbalances (West; Sole; Sullivan, 2005; Wiażewicz; Eider, 2016). The results were compared with studies that assessed young athletes (Batalha *et al.*, 2012), with the internal rotator and adductors stronger than their antagonist, pointing out to the importance of including them in these analyses and compensatory strength training programs as well.

Limitations

The main limitation reported in the studies is concerning the participant positioning on the isokinetic dynamometer, with most assessments performed with the participant seated (Collado-Mateo *et al.*, 2018; Drigny *et al.*, 2020; Gaudet; Tremblay; Dal Maso, 2018). This position is not specific for swimming, and the prone position may be more suitable for swimmers (Batalha *et al.*, 2014). Analyses often need to be associated with other measurement instruments for better approaching the sport modality (Carvalho *et al.*, 2019; Gaudet; Tremblay; Dal Maso, 2018; Liaghat *et al.*, 2018). It is worth highlighting that the isokinetic dynamometer is difficult to access in the sports and scientific community due to its high cost.

Another limitation attributed to the use of the isokinetic dynamometer concerns the angular velocity used. Our findings revealed the use of the angular velocities of 240°/s (Beach; Whitney; Dickoff-Hoffman, 1992; Gaudet; Tremblay; Dal Maso, 2018)and 300°/s (Carvalho *et al.*, 2019; Swanik *et al.*, 2002). According to Mayer *et al.* (2001), it is not recommended to use speeds above 180°/s in isokinetic analyses of the shoulders, as they cause excessive torques peak. In addition, the data may interfere with the analyses and not approach the reality of the speed movement during swimming.

In addition, among the articles included in this review, only one study statistically justified the sample size (Liaghat *et al.*, 2018). According to Patino and Ferreira (2016), the sample should represent the target population with an adequate number of participants and should be sufficient to detect truly significant differences.

Study limitations and recommendations for further research

Since the aim was to indicate the benefits and limitations of isokinetic tests results for the performance of the main shoulder joint movements of swimmers, this systematic review has limitations regarding the protocols used in the articles that assessed swimmers on the isokinetic dynamometer. In addition, a larger number of studies could have been found if the eligibility criteria included languages other than English.

We suggest that further research investigate comparisons of isokinetic variables between groups of different distances, techniques, aquatic modalities, competitive levels, and sexes. Also, further research should involve swimmers based on a prospective cohort design and a large sample size to provide further evidence on the subject and relevant results for coaches, swimmers, physiotherapists, and personal trainers.

CONCLUSION

This systematic review highlights important benefits and limitations found in isokinetic shoulder assessments in swimmers. The use of the isokinetic dynamometer allows for verifying the levels of strength, endurance, balance, and asymmetries among swimmers of different techniques, distances, competitive levels, and sexes. Thus, it helps analyze and monitor the clinical conditions of swimmers' shoulder joints, thus contributing to the decision-making process of physiotherapists and coaches. However, most studies focus on the clinical condition of the shoulder, and little is reported on the relationship between isokinetic variables and swimming performance. Still, the equipment has limitations regarding the position adopted since the sitting position, reported in most studies, is not specific to the sport modality. Moreover, the use of velocities above 180°/s in the joint analysis is not recommended since it may cause overshot peak torque and the data may be misinterpreted. Finally, among the studies included in this review, only one justified the sample size, which is essential for the sample to be representative of the study population.

4.2. STUDY 2

MAGNITUDE AND DIRECTION OF SHOULDER TORQUE ASYMMETRIES BETWEEN DIFFERENT ANGULAR VELOCITIES IN COMPETITIVE SWIMMERS

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Abstract

Asymmetries in swimming manifest as disparities in strength between a swimmer's body sides, potentially affecting their swimming efficiency and technique. Therefore, this study aimed to compare the magnitude and determine the consistency of isokinetic peak torque asymmetries between the angular velocities of 60 and 180°/s in the shoulder joint movements of internal and external rotation, flexion, and extension. Twenty-one competitive swimmers, front crawl technique specialists, who performed three and 20 concentric repetitions at angular velocities 60 and 180°/s, respectively, using the isokinetic dynamometer. Peak torque variables of shoulder internal and external rotations, flexion, and extension were accessed to determine the symmetry index. The results showed greater magnitude of asymmetries in internal rotation ($p = 0.007$; ES: -1.38 to -0.13) and flexion ($p = 0.008$; ES: -1.30 to -0.06) performed at 60°/s. The agreement levels of the direction of asymmetries between angular velocities were fair to substantial (Kappa: 0.40 to 0.69). Bilateral asymmetries imbalances and deficits in strength can hamper performance by reducing the capacity to produce propulsive force and range of motion or affecting resistive drag decrease. Therefore, identifying and understanding asymmetries is crucial for training planning, both for improving performance and reducing the risk of injury.

Keywords: isokinetic, agreement, symmetry, swimming, individual monitoring.

INTRODUCTION

Swimming is a cyclical modality, and its performance can be determined by executing a specific distance in the shortest possible time within the established rules (Lubkowska; Wiażewicz; Eider, 2017). The front crawl is the technique with the lowest energy cost compared to other swimming techniques when maintaining the same speed (Barbosa *et al.*, 2010). In addition, approximately 90% of propulsive actions are carried out by the upper limbs, with shoulder joint movements of internal rotation, adduction, and extension to overcome hydrodynamic resistance (Gonjo *et al.*, 2021; Silveira *et al.*, 2019; YANAI; HAY; MILLER, 2000), making it clear that muscle strength is critical to successful swimming performance (Formosa; Mason; Burkett, 2011; Lubkowska; Wiażewicz; Eider, 2017). Consequently, the repetitive nature of movements in the shoulder joint during swimming makes this region susceptible to pain and potential injury (Feijen *et al.*, 2020b). Studies in this area (Krüger; Dressler; Botha, 2012; Sein *et al.*, 2010; Tate *et al.*, 2012) have reported a significant correlation between the duration (number of hours) and weekly volume (distance in kilometers) of training with such an increase and the risk of shoulder pain.

Although swimming is considered a symmetrical sport, prior studies have not guaranteed the symmetry of forces between the sides of the body (Alberty *et al.*, 2009; Tourny-Chollet; Seifert; Chollet, 2009). High-performance swimmers need to apply propulsive forces between the sides of the body to minimize resistive drag during swimming (Carvalho *et al.*, 2019). Physical asymmetries may result in greater effort by one side of the body compared to the other, reducing the swimmer's ability to produce propulsive forces (Sanders; Thow; Fairweather, 2011). Front crawl swimming technique involves alternating bilateral coordination (Nikodelis; Kollias; Hatzitaki, 2005) and studies have indicated that asymmetries exist in kinetics (Dos Santos *et al.*, 2013; Morouço *et al.*, 2015), arm coordination (Alberty *et al.*, 2009; Seifert; Chollet; Allard, 2005), shoulder and hip rotations (Psycharakis; Sanders, 2008). The main causes may be related to lateral dominance, injury occurrence, fatigue development, and swimming technique (Sanders; Thow; Fairweather, 2011). In addition, the respiratory movement during the front crawl swimming technique might be associated with asymmetries since such a movement causes a greater angle of body rotation (Seifert *et al.*, 2008).

Asymmetry refers to the difference in performance or function between limbs and has been a popular line of research in recent years (Bishop et al., 2018; Bishop et al., 2020). Research has reported asymmetries in isokinetic parameters of the shoulder musculature in athletes from individual and team sports, such as cricket (Oliver; Lala; Gillion, 2020), tennis (Brito *et al.*, 2022), volleyball (Hadzic *et al.*, 2014), and swimming (Batalha *et al.*, 2018).

However, upper limb isokinetic torque asymmetries are not a consensus in the literature (Carvalho *et al.*, 2019; Sanders *et al.*, 2015; Tourny-Chollet; Seifert; Chollet, 2009). Only more recently has the analysis of the direction of asymmetries been encouraged, allowing to analyze which limb is favored by the asymmetry (Bishop *et al.*, 2017, 2018a). The direction of asymmetries can vary across different tasks or between assessments conducted on different days, thus justifying the relevance of exploring the consistency of the favored limb over time to monitor the progression of asymmetries (Bishop *et al.*, 2018a, 2018b). Thus, both the magnitude and direction of asymmetries should be considered to better understand such a phenomenon.

Investigating the magnitude and direction of asymmetries can provide coaches and swimmers with information on the interaction between right and left arm movements, hence determining training strategies focusing on a more balanced force pattern on both sides of the body in front crawl swimming technique. This study aims to (i) compare the magnitude of isokinetic peak torque (PT) asymmetries between the angular velocities of 60 and 180°/s in the shoulder joint movements of internal (IR) and external rotations (ER), flexion (FL), and extension (EX), and (ii) determine the consistency of the direction of inter-limb asymmetries in the shoulder joint movements of IR, ER, FL, and EX at angular velocities of 60 and 180°/s. Our hypothesis is that both the magnitude and direction of asymmetries are specific for each shoulder angular velocity and joint movement.

MATERIALS AND METHODS

Participants

Twenty-one competitive swimmers specialized in the front crawl technique of different race distances were selected, four females (29 ± 17 years old; 56.5 ± 2.3 kg body mass; 163.1 ± 4 cm height; 165.2 ± 4.6 cm of arm span; 6 ± 1 days of weekly frequency; and 27875 ± 10363 m of weekly training volume) and 17 males (27 ± 10 years of age; 72.8 ± 13.7 kg of body mass; 173.8 ± 6.3 cm of height; 177.5 ± 4.5 cm of arm span; 6 ± 1 days of weekly frequency; and 22765 ± 7996 m of weekly training volume). As in the Wiażewicz and Eider (2021) study, the calculation of World Aquatics Points was based on each athlete’s specialty according to the 2021 world records in the 50 m pool. All the swimmers had a background of training for competitions for at least 3 years. Inclusion criteria were: (i) not having any clinical history of upper-limb disorders; (ii) competing at the national level; (iii) having a minimum of 8 hours of training per week, and (iv) being at least 15 years old. The subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to take part in the study. Additionally, participants under the age of 18 had their consent signed by their parental or guardian. This study was approved by the Ethics Committee for Research with Human Beings of the Federal University of Amazonas (Ethics number: 79527917.5.0000.5020) and the Declaration of Helsinki.

Procedures

Swimmers were tested along three consecutive steps, performed on the same day, in sequence, with a total test duration of approximately 45 minutes. There was no randomization between steps. Initially, training characteristics (main competitive event, respiratory side, and best result in the season) were recorded (Table 8). Still, the questionnaire by Van Strien (39) was applied to determine the lateral preference of the upper limbs, in which lateral dominance was defined as preferred and non-preferred upper limbs. In the second moment, the body mass, height, and arm span of each participant were measured.

Table 8. Characteristics of the study participants

Participants	Sex	Age (years)	Main competitive event	World Aquatics Points	Preferred side	Preferred breathing side
1	F	16	50 m FC	518	R	L
2	M	19	100 m FC	478	R	R
3	M	25	50 m FC	591	R	R/L
4	M	34	50 m FC	502	R	R/L
5	M	32	50 m FC	520	R	R
6	M	15	100 m FC	376	L	R
7	M	15	100 m FC	522	L	R/L
8	M	22	400 m FC	606	R	L
9	M	16	400 m FC	628	R	L
10	M	18	400 m FC	579	R	R
11	M	40	400 m FC	795	R	L
12	M	27	1500 m FC	287	R	R
13	F	35	1500 m FC	182	L	R
14	F	15	400 m FC	526	R	R/L
15	M	24	10 km	*	R	R
16	M	28	5 km	*	R	R
17	M	47	5 km	*	L	R/L
18	F	51	10 km	*	R	R/L

19	M	20	10 km	*	R	R
20	M	43	10 km	*	R	R
21	M	42	5 km	*	R	R/L
Mean ± SD	-	28 ± 10	-	-	-	
[95% CI]		[22.56 – 33.06]				

M: male; F: female; R: right upper limb; L: left upper limb; SD: standard deviation; CI: confidence intervals; FC: front-crawl.
*Open water events do not have World Aquatics Points.

Isokinetic evaluation

The analysis protocols proposed by Batalha *et al*. (2020) for IR and ER and Wiażewicz and Eider (2021) for FL and EX were used to evaluate the isokinetic PT of the shoulder muscles. Isokinetic variables were collected during concentric actions for agonist and antagonist muscles, with movements performed on an isokinetic dynamometer (BIODEX SYSTEM 4; Biodex Corp., Shirley, NY, USA). Each participant was secured by Velcron® straps around the trunk and pelvis to stabilize the body and eliminate compensatory movements.

For the shoulder rotator assessment, the upper limb was flexed to 90°, the shoulder abducted to 90° and the acromion, in the sagittal plane, was aligned to the rotation axis of the dynamometer. The non-assessed upper limb was free in a neutral position or holding the handle under the dynamometer seat. For the assessment of shoulder FL and EX, participants were positioned supine on the equipment, with supination of the forearm resembling the positioning of the hand during the front crawl swimming movement; in addition, as in the rotator protocol, the non-assessed upper limb at the time was free in a neutral position or holding the handle under the seat.

For both joint movements, the isokinetic dynamometer was set to "isokinetic" mode at constant angular velocities of 60 and 180°/s. All participants were instructed on the test procedure and asked to exert maximal effort within their tolerance level. Two previous repetitions at each speed and joint movement were performed to familiarize the participants with the test procedure. Soon after familiarization, the swimmers performed three maximal repetitions at 60°/s and 20 repetitions at 180°/s with a two-minute interval between velocities and five minutes interval between shoulders, as proposed in previous studies (Batalha *et al.*, 2018; Wiazewicz; Eider, 2021). A ten-minute resting interval was given between joint movements. The participant was given verbal stimulation to perform maximal effort, as in prior studies (Batalha *et al.*, 2018, 2020; Wiazewicz; Eider, 2021).

Data analysis and variables

Peak torque (PT) values were extracted from BIODEX and analyzed using Microsoft Excel 365. The average of the three repetitions performed in the joint movements was calculated to determine the PT at 60°/s. The average of the first three PTs reached during the twenty repetitions was calculated to determine the PT at 180°/s. The values of asymmetries between the preferred and non-preferred upper limbs were determined by Equation (1), proposed by Bishop *et al*. (2018a):

$$Asymmetries\ (\%) = 100/(max\_value) * (min\_value) * -1 + 100 \quad (1)$$

However, this equation only provides positive values; therefore, to analyze the direction of asymmetries, a negative sign was added when the asymmetry showed a tendency to the non-preferred upper limb. Although there is no consensus in the literature, a prior study (Bishop *et al.*, 2018a) suggested that 10% in asymmetry values can be considered a potential threshold at which decreases in performance and increases in injury risk occur.

Statistical Analysis

Data normality was verified by the Shapiro-Wilk test. Thereafter, descriptive statistics were calculated using mean, standard deviation, and confidence interval values. The magnitudes of the asymmetries between the velocities of 60 and 180°/s were compared using the t-test for dependent samples with a significance level of 5%. The effect size (ES) was calculated using Cohen's d equation (Lakens, 2013), whose values were classified according to (Hopkins *et al.*, 2009) where < 0.20 = trivial; 0.20 to 0.60 = small; 0.61 to 1.20 = moderate; 1.21 to 2.0 = large; 2.01 to 4.0 = very large. Inter-rater reliability was checked using the intraclass correlation coefficient (ICC) based on absolute agreement. ICC classifications were interpreted as follows: > 0.90 = excellent; 0.75 to 0.90 = good; 0.50 to 0.75 = moderate; and < 0.50 = poor (Koo; Li, 2016). The Kappa coefficient was used to assess the level of agreement of the direction of asymmetries between velocities (60°/s vs. 180°/s), whose values were interpreted as follows: 0.01 to 0.20 = slight, 0.21 to 0.40 = fair, 0.41 to 0.60 = moderate, 0.61 to 0.80 = substantial and 0.81 to 0.99 = almost perfect (Vieira; Garrett, 2005). All analyses were performed using SPSS Statistics Base 22.0 statistical software (SPSS, IBM Corporation, New York).

RESULTS

Table 9 presents the mean and standard deviation of the PT in the IR, ER, FL, and EX movements at velocities 60 and 180°/s in the P and NP upper limbs, ICC, and classification. All ICC results for the evaluated joint movements, at both velocities and upper limbs, were classified as excellent (range 0.96 to 0.99).

Table 9. Mean ± standard deviation (SD) absolute peak torque values (PT), intraclass correlation coefficient (ICC), 95% confidence intervals (95% CI), coefficient of variation (CV) in the preferred (P) and non-preferred (NP) upper limbs for shoulder internal (IR) and external rotators (ER), flexors (FL), and extensors (EX) muscles in both velocities in the group of swimmers.

Movement	PT (N m)	Mean ± SD [95% CI]	ICC [95% CI]	CV [95% CI]
IR	60°/s P	44.80 ± 12.77 [38.98 to 50.61]	0.97 [0.94 to 0.99]	5.39 [2.96 to 7.82]
	60°/s NP	44.09 ± 13.07 [38.14 to 50.03]	0.98 [0.96 to 0.99]	5.96 [3.73 to 8.19]
	180°/s P	46.54 ± 14.34 [40.01 to 53.07]	0.99 [0.99 to 0.99]	1.78 [1.27 to 2.30]
	180°/s NP	46.11 ± 16.42 [38.64 to 53.59]	0.99 [0.99 to 0.99]	1.82 [1.16 to 2.48]
ER	60°/s P	30.92 ± 8.14 [27.21 to 34.62]	0.96 [0.93 to 0.99]	5.54 [2.39 to 8.68]
	60°/s NP	30.09 ± 8.52 [26.21 to 33.97]	0.99 [0.97 to 0.99]	4.78 [3.22 to 6.35]
	180°/s P	28.96 ± 7.16 [25.70 to 32.22]	0.99 [0.99 to 0.99]	1.61 [1.08 to 2.13]
	180°/s NP	29.19 ± 9.33 [24.94 to 33.43]	0.99 [0.99 to 0.99]	2.15 [1.52 to 2.77]
FL	60°/s P	64.78 ± 17.66 [56.74 to 72.81]	0.98 [0.96 to 0.99]	6.23 [4.54 to 7.93]
	60°/s NP	60.75 ± 14.38 [54.21 to 67.30]	0.98 [0.95 to 0.99]	5.48 [3.58 to 7.39]
	180°/s P	71.83 ± 17.57 [63.83 to 79.82]	0.99 [0.99 to 0.99]	1.61 [0.80 to 2.42]
	180°/s NP	70.31 ± 15.88 [63.08 to 77.54]	0.99 [0.99 to 0.99]	2.22 [1.69 to 2.75]
EX	60°/s P	76.49 ± 23.49 [65.80 to 87.18]	0.99 [0.98 to 0.99]	6.23 [3.85 to 8.60]
	60°/s NP	75.87 ± 23.61 [65.18 to 86.61]	0.99 [0.98 to 0.99]	4.20 [2.92 to 5.49]
	180°/s P	71.27 ± 19.70 [62.30 to 80.24]	0.99 [0.99 to 0.99]	1.42 [1.00 to 1.85]
	180°/s NP	70.79 ± 20.65 [61.38 to 80.19]	0.99 [0.99 to 0.99]	1.71 [1.11 to 2.31]

Table 10 shows the mean values for IR, ER, FL, and EX joint motion, as well as the comparison of the magnitude of asymmetries and between the velocities of 60 and 180°/s. The magnitude of asymmetries occurred in the ranges of 4.08% (ER 180°/s) and 16.86% (IR 60°/s), with small to moderate effect sizes.

Table 10. Mean ± standard deviation (SD) of asymmetry magnitude values, 95% confidence intervals (95% CI), *p*-value, and effect size (ES) in the shoulder joint movements of internal (IR) and external rotators (ER), flexors (FL), and extensors (EX) muscles for comparison of magnitude between angular velocities in the group of swimmers.

		Asymmetry (%) [95% CI]	***p***	**ES [95% CI]**
IR	60°/s	16.86 ± 9.89 [12.35 to 21.36]	0.007*	-0.75 [-1.38 to -0.13]
	180°/s	9.86 ± 8.63 [5.93 to 13.79]		
ER	60°/s	11.04 ± 7.45 [7.64 to 14.43]	0.284	-0.32 [-0.93 to 0.29]
	180°/s	8.67 ± 7.21 [5.39 to 11.95]		
FL	60°/s	12.06 ± 7.53 [8.63 to 15.48]	0.008*	-0.68 [-1.30 to -0.06]
	180°/s	7.35 ± 6.25 [4.50 to 10.19]		
EX	60°/s	6.60 ± 4.36 [4.62 to 8.59]	0.093	-0.57 [-1.18 to 0.05]
	180°/s	4.08 ± 4.55 [2.01 to 6.15]		

*Significance value ($p < 0.05$).

Table 11 shows the levels of agreement for the direction of asymmetries between velocities (60°/s vs. 180°/s), calculated through the Kappa coefficient. The results showed agreement levels from “fair” to “substantial” (range = 0.40 to 0.69). Only the ER shoulder showed substantial levels of agreement (k = 0.69).

Table 11. Kappa agreement level of asymmetry direction between different velocities in the joint movements of shoulder internal (IR) and external rotators (ER), flexors (FL), and extensors (EX) muscles in the group of swimmers.

	60°/s vs. 180°/s	***p***	**Classification**
IR	0.52	0.017	Moderate
ER	0.69	0.001	Substantial
FL	0.40	0.061	Fair
EX	0.44	0.031	Moderate

Figures 2, 3, 4, and 5, respectively, presents the individual values of magnitude and direction of asymmetries between velocities 60°/s vs. 180°/s in the IR, ER, FL, and EX joint movements.

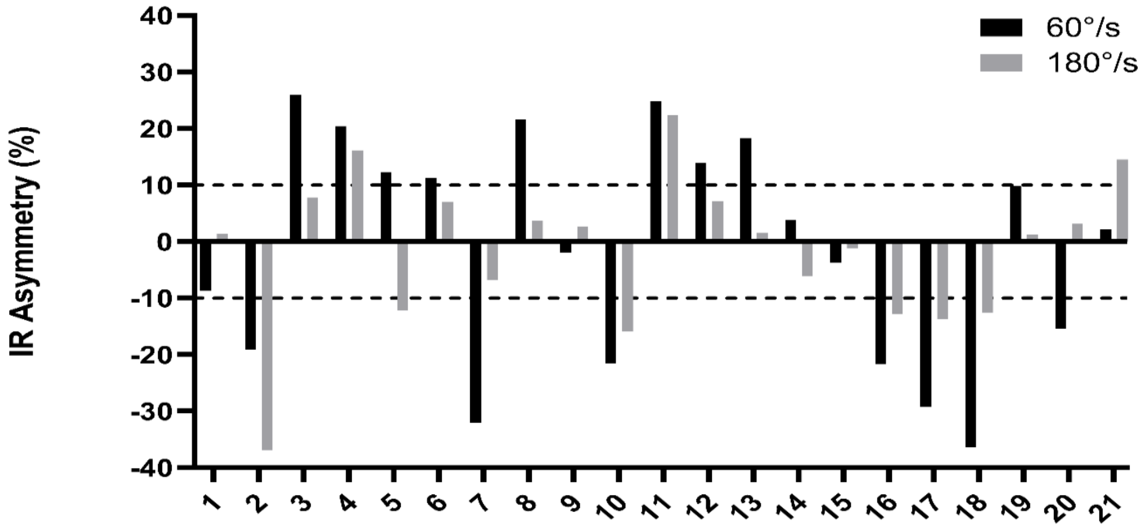

Figure 2. Individual asymmetry data for the internal rotator (IR). Values above 0 indicate the preferred upper limb, whereas values below 0 indicate the non-preferred upper limb.

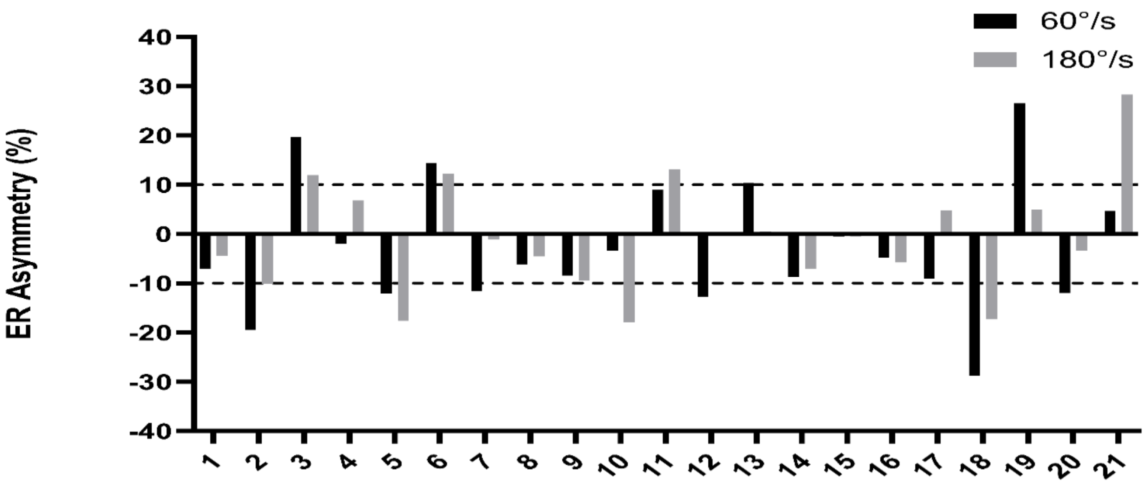

Figure 3. Individual asymmetry data for the external rotators (ER). Values above 0 indicate the preferred upper limb, whereas values below 0 indicate the non-preferred upper limb.

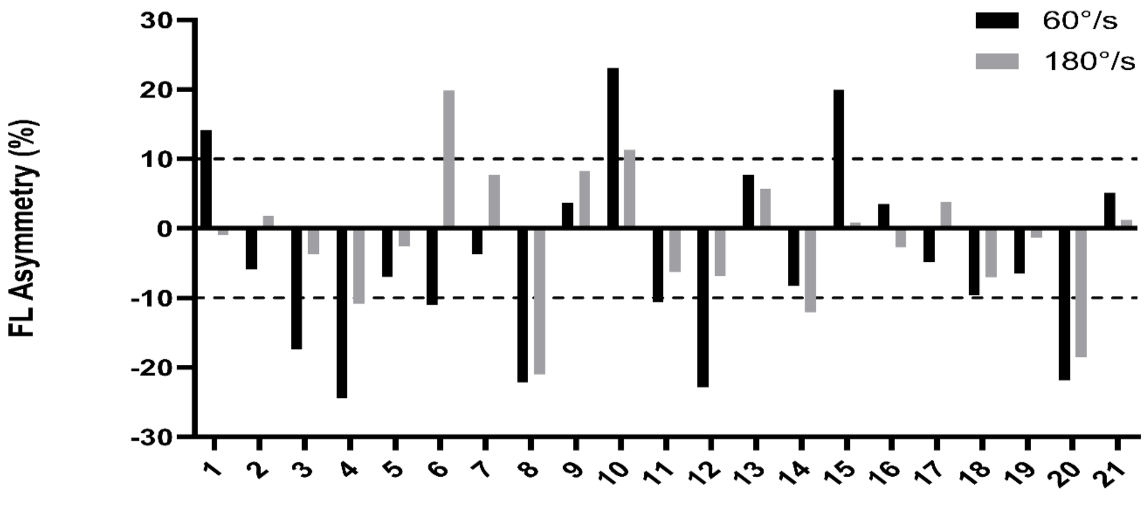

Figure 4. Individual asymmetry data for the flexors (FL). Values above 0 indicate the preferred upper limb, whereas values below 0 indicate the non-preferred upper limb.

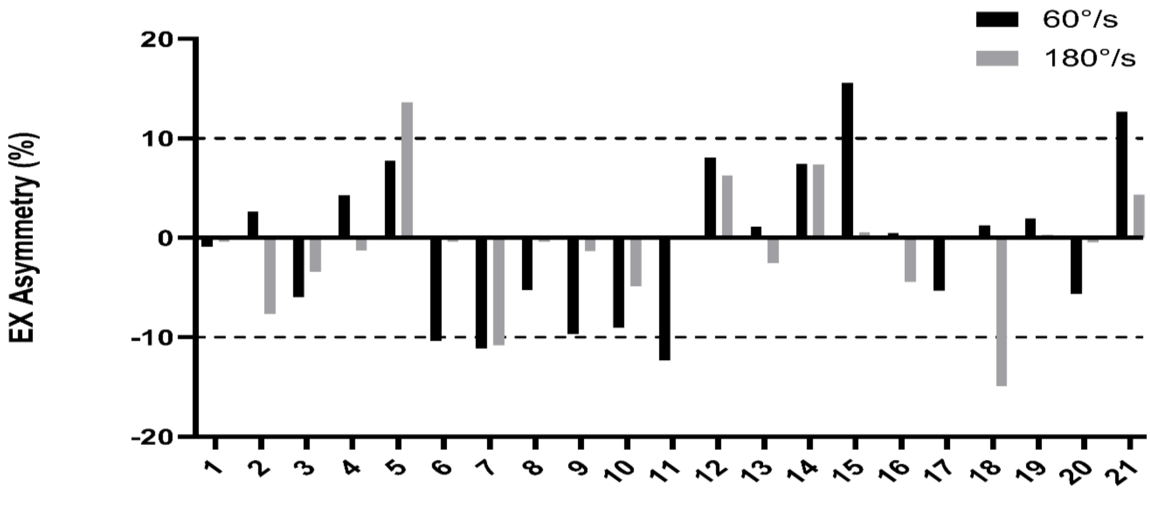

Figure 5. Individual asymmetry data for the extensors (EX). Values above 0 indicate the preferred upper limb, whereas values below 0 indicate upper limb non-preferred.

DISCUSSION AND IMPLICATION

This study aimed (i) to compare the magnitudes of isokinetic torque asymmetries between angular velocities of 60 and 180°/s in IR, ER, FL, and EX shoulder joint movements; (ii) to determine the consistency of the direction of inter-member asymmetries in the IR, ER, FL, and EX shoulder joint movements at angular velocities of 60 and 180°/s. The results for the magnitude of the asymmetries showed higher values in the IR and FL shoulder movements at 60°/s. For the direction of the asymmetries, the agreement levels between the angular velocities were moderate to substantial (except for FL) in competitive front crawl swimmers. Two variables showed differences in the magnitude of the asymmetries at different speeds (IR and FL torque). As for the direction of the asymmetries, one variable showed low agreement (FL), two showed moderate agreement (IR and EX), and only one variable (ER) showed substantial agreement between the angular velocities (60 vs 180°/s), partially confirming our hypothesis. As in prior studies, low agreement was found in different directions of asymmetry in different tests (Bishop *et al.*, 2018a, 2020), suggesting that different tests should be applied to analyze asymmetry.

Table 9 shows the average isokinetic torque asymmetry values in the shoulder joint at different speeds. In this sample of competitive front crawl swimmers, the mean isokinetic torque asymmetry values were higher at lower angular velocities (60°/s). Specifically, the difference in isokinetic torque asymmetry values was significant, showing a moderate effect size in IR (-1.38 to -0.13) and FL (-1.30 to -0.06). These results differ from a previous study (Carvalho *et al.*, 2019), where swimmers showed higher torque asymmetry values at higher angular velocities (90 vs. 300°/s), although the study did not aim at such an investigation. However, the values found by Carvalho *et al.* (2019) might have been affected using velocities above 180°/s for isokinetic assessment of the shoulders. The use of speeds of up to 180°/s is highly recommended, as torque overshoot can occur above this limit (Mayer *et al.*, 2001). In addition, high angular velocities in isokinetic shoulder assessments are similar to those of competitive swimming (Carvalho *et al.*, 2019).

Considering the direction of the asymmetries between the different angular velocities, our results showed moderate agreement. Prior studies have shown low agreement in the different directions of asymmetries in different tests and assessment days (Bishop *et al.*, 2018a, 2020) , indicating the need to use multiple tests to detect asymmetries. No study aimed to verify the direction agreement of asymmetries in swimmers in different contexts. The isokinetic dynamometer provides objective and reliable data on muscle strength (Tourny-Chollet; Seifert; Chollet, 2009). However, the isokinetic torque measured on a dynamometer may not reflect specific swimming movements accurately since the position of the swimmer and the speed of the stroke are individual. Despite this, previous studies evaluating swimmers on the isokinetic dynamometer have made important contributions to researchers, coaches, and athletes concerning the integrity of the shoulder joint (Batalha *et al.*, 2020; Carvalho *et al.*, 2019; Sanders *et al.*, 2015).

Individually (Figures 2-5), the results showed different directions of asymmetries in the shoulder joint movements of the IR 5/21 (23.81%), ER 2/21 (9.52%), FL 6/21 (28.57%) and extension 5/21 (23.81%). Despite being a common phenomenon, asymmetry can affect swimmers' performance negatively in different contexts (Bishop *et al.*, 2020; Carvalho *et al.*, 2019). Our participants were all healthy, with no history of shoulder pain or injury, so they should not present isokinetic torque asymmetries in the shoulder joint. It is suggested that, for healthy young athletes, the direction of asymmetries is as important as the magnitude (Bishop *et al.*, 2020). It is worth noting that in the front crawl swimming technique, applying asymmetric force between the upper limbs can increase the intracycle velocity variation, in addition to causing functional imbalances and increased energy expenditure (Carvalho *et al.*, 2019; Gonjo *et al.*, 2020; Sanders, 2013). The individual assessment of isokinetic torque asymmetries in the shoulder joint of swimmers is a fundamental tool to better understand the biomechanical characteristics of each swimmer, optimizing technical performance and reducing the risk of injury.

Analyzing the direction and magnitude of asymmetries can help understand which limb performed better, as an absolute value of asymmetry would not be able to identify it (Bishop *et al.*, 2018a). Swimmers can develop bilateral force asymmetries due to several factors (e.g., injuries, technique used, preferred breathing side), having their ability to produce propulsive forces reduced (Sanders; Thow; Fairweather, 2011; Tourny-Chollet; Seifert; Chollet, 2009). However, international-level swimmers showed low asymmetries, thus reducing drag at certain speeds, which can be attributed to high training load and constant technical adjustments (Barbosa *et al.*, 2010; Sanders; Thow; Fairweather, 2011). In the performance of front crawl swimming technique, the non-dominant upper limb is usually used for control and support of the movement, while the dominant limb is more used for propulsion (Morouço *et al.*, 2015; Seifert; Chollet; Allard, 2005).

Elite swimmers swim approximately four hours per day with an average training volume of 60000 to 80000 m per week, performing 1.5 million swimming cycles for each limb per year (Heinlein; Cosgarea, 2010). These repetitive, high-intensity movements can cause muscle imbalances and trigger bilateral strength asymmetries (Batalha *et al.*, 2020; Sanders, 2013). In isokinetic evaluations, competitive adolescent swimmers achieved higher PT values in the ER and IR movements, at 60 and 180°/s, compared to sedentary swimmers (Batalha *et al.*, 2020). In another study (Olivier; Quintin; Rogez, 2008), front crawl swimmers presented a lower balance ratio between ER/IR in the dominant shoulder compared to sedentary swimmers. During a competitive season, swimming practice favors the unequal strengthening of the IR compared to the ER, causing muscle imbalances in the joints, pain, and shoulder injuries (Batalha *et al.*, 2020). Having a limb affected by pain and injury might be a cause of bilateral asymmetries in swimmers, who tend to compensate for the application of propulsive force with the other limb (Sanders; Thow; Fairweather, 2011).

Seifert, Chollet, and Allard (2005) evaluated swimmers with different levels of experience and observed that breathing affected the coordination of the upper limbs and the propulsive discontinuity of the swim. In front crawl swimmers, asymmetries were related to lateral preference and dominance (unilateral breathing) and shoulder rotations even without breathing (Psycharakis; Sanders, 2008; Seifert; Chollet; Allard, 2005). This suggests a link among asymmetries, breathing technique, and body rotation during swimming. In addition, Tourny-Chollet, Seifert, and Chollet (2009) noted that the arm opposite the breathing had longer execution times for certain phases despite a faster underwater movement. This arm also generated less propulsion. In our study, we found no associations between the side of breathing and the direction of asymmetries in the IR, ER, FL, and EX movements. However, it is known that the impact of asymmetry on performance and efficiency lies in its influence on the timing of the swimming technique phases and the generation of propulsive force.

Morouço et al. (2015) suggested that for short swimming distances, maximal speed depends more on the impulse generated in the pull and push phases than on the swimmers' technical skills. Therefore, understanding and correcting upper limb muscular and technical asymmetries in swimmers is essential to optimize performance. Such results should be applied in individualized training, aiming to improve technique, reduce drag, improve propulsive efficiency, correct muscle strength imbalances, and minimize the risk of injury.

Although these observations provide new perspectives on assessing asymmetries in swimmers, this study has some limitations that should be considered. Bishop et al. (2018b) pointed out that the unilateral test could be a more suitable method for detecting lateral asymmetries, as there is no involvement of the other limb. However, in swimming there are two competitive swimming techniques with simultaneous actions (breaststroke and butterfly) and two swimming techniques with alternating actions (front crawl and backstroke) between the right and left limbs. The assessment of bilateral form, when carried out in competitive swimmers using simultaneous techniques, could add useful information to this study; however, the isokinetic dynamometer does not allow this type of analysis. Furthermore, the use of electromyography for isokinetic analysis could complement this study by detecting the continuous coordination between the muscle actions involved in the IR, ER, FL, and EX movements. That said, further studies should identify the direction agreement of asymmetries in specific swimming tests, such as the timing of stroke phases at different swimming speeds and peak isokinetic torque of the shoulder joint in stroke tests.

Understanding and addressing asymmetries is vital for enhancing performance and averting injuries in swimmers. Pronounced imbalances in force generation between limbs can lead to inefficient movements and increased risk of injury. Individualized assessment is key due to the unique movement patterns and muscle variations of each swimmer. This helps coaches to identify the muscle groups that require attention accurately to improve performance and prevent injury. Group assessments are limited as they do not consider individual features, which might lead them to miss muscle imbalances and strength asymmetries. In addition, they may disregard root causes. Although the isokinetic dynamometer is not easily accessible, asymmetries should be identified individually since coaches and health professionals can design strength training programs and technical adjustments in and out of the water to correct strength imbalances and asymmetries, hence boosting swimmers' performance.

CONCLUSION

In conclusion, the magnitude of isokinetic torque asymmetries in the present study was more pronounced at lower angular velocities (60°/s), with significance in shoulder internal rotation and flexion movements. Furthermore, there were differences in the direction of asymmetries between angular velocities, emphasizing the need to consider both magnitude and direction for a better understanding. Muscle force asymmetries can impact propulsion efficiency and movement coordination during swimming. These findings are crucial for coaches and physiotherapist when planning individualized training strategies for swimmers. Understanding muscle asymmetries enables the development of targeted training programs to correct strength imbalances and optimize swimming techniques. This not only enhances performance but also reduces the risk of injuries.

4.3. STUDY 3

COMPLEX RELATIONSHIPS BETWEEN SHOULDER JOINT ISOKINETIC PARAMETERS AND PERFORMANCE IN SWIMMERS: A NETWORK ANALYSIS

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Abstract

Network analysis allows identifying relationships and influences between variables within the same structure helping identify determinants of swimming performance. This study aimed to (i) investigate the complex and simultaneous relationships between the World Aquatics points (performance) and the isokinetic test parameters through network analysis, and (ii) compare the isokinetic parameters between the preferred and non-preferred sides of the shoulders of competitive swimmers. Twenty-three male competitive swimmers participated in this study, whose performance was determined by World Aquatics points. The external and internal rotators, flexors, and extensors were assessed using an isokinetic dynamometer. Twenty repetitions were performed at 180°/s for each joint movement, with a five-minute interval between sides and ten minutes between joint movements. The networks formed used the World Aquatic points, peak torque, and total work. The network analysis identified that the non-preferred limb presented complex relationships between the study variables. The comparison showed a greater rotation ($p = 0.028$; $ES = -0.24$) for the total work of external rotation for the preferred side. Force application by the non-preferred side due to the swimmer's difficulties seems to represent a window to increase performance.

Keywords: biomechanics, performance evaluation, complex networks, swimming.

INTRODUCTION

Swimming performance is usually assessed based on the final time to cover a given distance, under specific rules, average swimming speed, and the World Aquatics points (formerly FINA points) obtained in the race (Wiazewicz; Eider, 2021). However, there are several variables (e.g., biomechanical, coordinative, and energetic) that simultaneously interfere with or determine performance (Correia; Feitosa; Castro, 2023). In at least three of the four competitive swimming techniques, around 90% of the propulsive actions are performed by the upper limbs, with shoulder joint movements involving internal rotation (IR), extension (EX), and adduction to generate propulsion (Silveira *et al.*, 2019; Toussaint *et al.*, 2000; Wiazewicz; Eider, 2021).

Evaluating the performance determinants is fundamental in a training program for competitive swimming by favouring to monitor adaptations to training, predict performance, and provide feedback to guide future training programs (Nagle Zera *et al.*, 2021). In this regard, several investigations have focused on learning the factors that contribute to swimming performance, such as the isokinetic parameters of shoulder flexion (FL) and EX movements (Wiazewicz; Eider, 2021); the relationship among leg stroke, swimming speed, and front crawl stroke efficiency (Silveira *et al.*, 2017); and isokinetic parameters of shoulder EX and countermovement jumps (Carvalho *et al.*, 2023). Notably, bivariate analysis studies have identified that upper limb muscle strength is one of the main factors contributing to swimmers' performance as it correlates strongly with swimming speed (Carvalho *et al.*, 2023; Cuenca-Fernández *et al.*, 2020; Morouço *et al.*, 2015).

Performing laboratory assessments of muscle strength must resemble swimming conditions as much as possible, considering factors such as the position of the upper limbs and angular velocities. In this context, researchers have investigated the relationships between the isokinetic parameters of the shoulder muscles and the stroke test and found very strong relationships between force production on land and in the water (Carvalho *et al.*, 2019). To date, few studies have used bivariate analysis to investigate relationships between the isokinetic parameters of swimmers' shoulder muscles and swimming performance (Carvalho *et al.*, 2023; Tan *et al.*, 2021; Wiazewicz; Eider, 2021). For example, Wiazewicz and Eider (2021) reported that the isokinetic parameters of the right and left upper limbs – such as peak torque of flexion (PT FL), total work of flexion (TW FL), peak torque of extension (PT EX), and total work of extension (TW EX) – showed moderate relationships with performance, as determined by FINA points. However, the authors also found that none of these variables were statistically significant in the relationships.

Bivariate analysis cannot, by definition, analyse multiple variables simultaneously, and regression analyses are limited data distribution and no multicollinearity in the studied variables, often excluding variables from the analysis. In turn, network analysis is a relatively new approach to understanding phenomena in the sports and health sciences, allowing identifying relationships and influences between variables through the network structure (Hevey, 2018). To date, none of the few studies using the network analysis method to investigate swimming performance (Fiori *et al.*, 2022; Pereira-Ferrero *et al.*, 2019) addressed the relationships among isokinetic parameters of swimmers' shoulder joints, and swimming performance.

The analysis of the networks formed from interactions between shoulder isokinetic parameters and performance allows personalizing training to meet the individual needs of each athlete. In addition, comparing the isokinetic parameters of the preferred and non-preferred side reveals muscle imbalances linked to increased active drag (loss of performance) and musculoskeletal injuries (Batalha *et al.*, 2012; Sanders; Thow; Fairweather, 2011). Therefore, this study aimed to: (i) investigate the complex and simultaneous relationships between the World Aquatics points (performance) and the isokinetic test parameters through network analysis, and (ii) compare the isokinetic parameters between the preferred and non-preferred sides of the shoulders of competitive swimmers. Our hypotheses are that (i) the network analysis would show strong relationships between the isokinetic variables and the World Aquatics points for both the preferred and non-preferred upper limp sides and (ii) the isokinetic parameters would not differ between the sides of the shoulders in the group of competitive swimmers.

MATERIALS AND METHODS

Participants

Twenty-three competitive male swimmers (age: 22 ± 7.6 years; body mass: 67.9 ± 7.9 kg; body height: 1.73 ± 5.9 m; upper arm span: 1.78 ± 4.8 m; World Aquatics points: 519 ± 122) participated in this study. As in Wiażewicz and Eider (2021), World Aquatics points were calculated based on each athlete's specialty according to the 2021 world records in a 50-m pool. All swimmers had a history of training for competitions of at least three years. The following inclusion criteria were considered: (i) no clinical history of upper limb disorders; (ii) competing at the national level; (iii) performing a minimum of 8 hours of training per week; and (iv) minimum age of 15 years old. All participants were informed about the benefits and risks of the research before signing an informed consent document approved by the institution to participate in the study. In addition, parents or guardians signed the consent for participants under the age of 18. This study was approved by the local Institutional Ethics Committee (ethics number: 79527917.5.0000.5020) and by the Declaration of Helsinki.

Procedures

Before data collection, the swimmers were instructed not to perform any physical activity 24 hours before the tests (Vasques *et al.*, 2023). The swimmers were tested over three consecutive steps, performed on the same day, in sequence, with a total duration of approximately 45 minutes. There was no randomization between stages. Initially, training characteristics were recorded (main competitive event, breathing side, and best result of the season). Van Strien's questionnaire (2003) was used to determine the lateral preference of the upper limbs, defining lateral dominance as preferred and non-preferred upper limbs. Table 12 provides the swimmers' individual characteristics. In the second stage, the anthropometric variables of body mass, height, and upper arm span were measured for each participant (Alves *et al.*, 2022).

Table 12. Characteristics of the study participants

Swimmer	Main Competitive Event	Best Record of the Long Curse (min:s)	World Aquatics points	Preferred Side	Breathing side preferred
1	1500 FC	21min41s	300	R	R
2	200 FC	2min16s20	420	R	R
3	50 FC	25s00	585	R	R
4	50 FC	27s11	459	R	R
5	50 BS	34s00	351	R	R
6	50 BF	27s00	561	R	R
7	200 BS	2min09s01	653	L	L
8	400 FC	4min17s00	628	R	L
9	100 FC	59s98	478	R	R
10	100 FC	55s90	591	R	R
11	50 BR	30s98	588	R	R
12	400 FC	3min57s	795	R	R
13	50 BS	28s99	567	R	R
14	1500 FC	20min00s44	382	R	R
15	50 FC	24s91	591	R	R

16	200 FC	2min01s	599	R	R
17	1500 FC	21min41s	300	R	R
18	50 FC	26s	520	R	R
19	100 FC	1min05s00	376	L	L
20	100 FC	58s27	522	L	L
21	50 FC	26s30	502	R	L
22	50 BF	27s29	543	R	R
23	100 BF	57s94	623	R	L
MD ± SD [95% CI]			519 ± 122 [466 to 572]		

R: right; L: left; MD: mean; SD: standard deviation; CI: confidence intervals; FC: front-crawl; BS: backstroke; BR: breaststroke; BF: butterfly.

Subsequently, the protocols proposed by Batalha et al. (2018) and Wiazewicz and Eider (2021) were used to assess the isokinetic torque of the shoulder's IR and external rotators (EX), flexors (FL), and EX. The tests were carried out on an isokinetic dynamometer (Biodex System 4, Biodex Corp., Shirley, NY, USA) in concentric actions for the agonist and antagonist muscles. The isokinetic dynamometer was set to "isokinetic" mode with a constant speed of 180°/s. To ensure body stability and eliminate compensatory movements, each participant was secured to the equipment's armchair with straps around the trunk and pelvis.

Figure 6 shows the participants' positions, with panels A and B indicating the assessment of the IR and ER, respectively. The participants were seated, with the upper limb assessed flexed at 90°, the shoulder abducted at 90°, the acromion aligned with the axis of rotation of the dynamometer in the sagittal plane, and the range of motion 90° (Batalha *et al.*, 2018). Panels C and D show the assessment of the shoulder FL and EX, respectively. The participants were in the supine position, with a supinated forearm (like the hand position during swimming) and the range of movement was 180° (Carvalho *et al.*, 2019). The upper limb not assessed at the time was free in a neutral position or holding the handle under the seat in both joint movements. Initially, the IR and ER were assessed, followed by the FL and EX, and all assessments began with the right upper limb. Two prior repetitions at each speed and joint movement were performed to familiarize the participants with the test procedure, after which twenty repetitions were performed at 180°/s for each joint movement with an interval of five minutes between sides and ten minutes between joint movements, as in previous studies (Batalha *et al.*, 2018; Wiazewicz; Eider, 2021).

Figure 6. Positioning of swimmers on the isokinetic dynamometer. A: start position of external rotation and end position of internal rotation; B: start position of internal rotation and end position of external rotation; C: start position of flexors and end position of extensors; D: start position of extensors and end position of flexors.

Data analysis

The highest score based on the table of the 2021 World Aquatics Championships points in the 50m race was obtained from the best individual mark achieved in the official competition. The following isokinetic variables were used herein: peak torque for internal (PT IR) and external rotation (PT ER), PT FL, and PT EX, total work for internal (TW IR), and external rotation (TW ER), TW FL, TW EX of the shoulders. The individual results were obtained from the forms provided by the isokinetic dynamometer.

Statistical analysis

The Shapiro-Wilk test verified data normality and descriptive statistics were calculated based on mean values, standard deviation, and mean confidence interval (95%). The PT and TW values between the preferred and non-preferred upper limbs were compared using the t-test for dependent samples with a significance level of 5%. The effect size (ES) was calculated using Glass's Delta (Lakens, 2013), and the values found were classified according to Sawilowsky (2009): d < 0.1 = very small; 0.2 to 0.4 = small; 0.5 to 0.7 = medium; 0.8 to 1.1 = large; 1.2 to 1.9 = very large; and 2.0 = huge.

The Machine Learning Network Analysis technique was used (Epskamp *et al.*, 2012) to investigate the multiple simultaneous relationships between World Aquatics points and the isokinetic test parameters PT and TW. This technique considers that the analysis parameters form a complex system. Thus, centrality measures are generated to understand the role of each variable in the system. To better understand the centrality of each variable, the values are transformed into z-scores. Herein, we used the following three measures (Epskamp *et al.*, 2012): (i) expected influence – estimated from the magnitude of the negative and positive edges connecting one node to the others; (ii) closeness centrality – determined from the inverse of the distances from one node to all the others, and (iii) strength centrality – sum of all the weights of the paths connecting one node to the others.

Therefore, to avoid eliminating variables, the following two networks were built and analysed for isokinetic variables: one for the preferred upper limb and one for the non-preferred upper limb. Concerning centrality measures, the further away from zero, the greater the relevance of the variable within the system. The analysis was performed based on a cut-off point of 0.900 to indicate the relevance of each parameter in the networks identified. Our study uses the "pairwise Markov" random field model to improve the accuracy of the partial correlation network. The estimation algorithm used assumes the highest-order iteration of the true graph. The algorithm includes an L1 penalty (regularized neighbourhood regression). Regularization is achieved by an absolute selection and contraction operator that controls the dispersion of the model (Friedman; Hastie; Tibshirani, 2008).

The use of the Extended Bayesian Information Criterion (EBIC) is based on its more conservative nature for selecting the Lambda from the regularization parameter. EBIC uses a hyperparameter (y) that determines how well it selects sparse models (Chen; Chen, 2008; Foygel; Drton, 2010). The y value is generally 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. This study uses a y-value of 0.25, which is a potentially useful value for exploratory networks (Foygel; Drton, 2010). The fitting function returns the estimated parameters for a weighted and unweighted adjacency matrix. All analyses were performed, and networks were built on the JASP program version 0.17.2.0 (JASP Team, 2023).

RESULTS

Table 13 shows the results of comparisons between the preferred and non-preferred upper limbs for the isokinetic variables PT and TW IR, PT and TW ER, PT and TW FL, and PT and TW EX. "Very small" and "small" effect sizes were observed. The variable TW ER was greater ($p < 0.05$) for the preferred upper limb.

Table 13. Mean peak torque and total work values, mean difference, confidence interval, *p*-value, and effect size for shoulder internal and external rotators, flexors, and extensors muscles in between upper limb preferred and non-preferred in the group of swimmers.

Variables	Mean ± SD [95% CI]	Mean Difference ± SD [95% CI]	*p*-value	Effect Size [95% CI]
PT ER P (N m.)	31.72 ± 6.02 [29.12 to 34.33]	0.96 ± 3.12 [-0.39 to 2.31]	0.156	-0.16 [-0.74 to 0.44]
PT ER NP (N m.)	30.77 ± 6.20 [28.08 to 33.45]			
TW ER P (J)	668.31 ± 148.47 [604.11 to 732.51]	35.54 ± 72.70 [4.11 to 66.98]	0.028	-0.24 [-0.82 to 0.36]
TW ER NP (J)	632.77 ± 160.85 [563.21 to 702.32]			
PT IR P (N m.)	51.13 ± 12.18 [45.86 to 56.40]	1.20 ± 7.93 [-2.22 to 4.63]	0.474	-0.10 [-0.68 to 0.50]
PT IR NP (N m.)	49.93 ± 12.14 [44.68 to 55.18]			
TW IR P (J)	1029.38 ± 279.36 [908.58 to 1150.19]	20.72 ± 177.35 [-55.98 to 97.41]	0.581	-0.07 [-0.65 to 0.52]
TW IR NP (J)	1008.67 ± 297.68 [879.94 to 1137.39]			
PT FL P (N m.)	77.81 ± 16.95 [70.48 to 85.14]	0.40 ± 8.40 [-3.24 to 4.03]	0.823	-0.02 [-0.60 to 0.57]
PT FL NP (N m.)	77.41 ± 14.36 [71.20 to 83.62]			
TW FL P (J)	2212.24 ± 595.18 [1954.87 to 2469.62]	43.75 ± 187.44 [-37.30 to 124.81]	0.275	-0.07 [-0.65 to 0.52]
TW FL NP (J)	2168.49 ± 624.24 [1898.55 to 2438.43]			
PT EX P (N m.)	74.83 ± 16.96 [67.49 to 82.16]	0.21 ± 6.93 [-2.79 to 3.20]	0.886	-0.01 [-0.59 to 0.58]
PT EX NP (N m.)	74.62 ± 18.13 [66.78 to 82.46]			
TW EX P (J)	2507.82 ± 740.23 [2187.72 to 2827.92]	12.46 ± 233.27 [-88.41 to 113.34]	0.900	-0.02 [-0.59 to 0.57]
TW EX NP (J)	2495.36 ± 766.93 [2163.71 to 2827.00]			

PT: peak torque; TW: total work; ER: external rotation; IR: internal rotation; FL: flexors; EX: extensors; P: preferred side; NP: non-preferred side.

Table 14 shows the centrality measures for the preferred and non-preferred sides concerning the variables of World Aquatics points and isokinetic parameters.

Table 14. Centrality measurement values between World Aquatics points, peak torque, and total work of the internal and external rotation, flexors, and extensors of the shoulder joint for the preferred (P) and non-preferred (NP) upper limb of the swimmers' group.

Variables	Closeness		Strength		Expected influence	
	P	NP	P	NP	P	NP
Word Aquatics points (1)	0.477	**0.917**	0.145	0.772	0.145	0.229
PT ER (2)	**0.973**	**1.000**	0.798	0.757	0.798	0.634
TW ER (3)	**1.000**	0.844	0.795	0.800	0.795	0.795
PT IR (4)	0.788	0.848	0.825	0.798	0.825	0.792
TW IR (5)	0.804	**0.925**	0.855	**1.000**	0.855	**1.000**
PT FL (6)	0.783	0.860	0.585	**0.936**	0.585	0.713
TW FL (7)	0.884	0.844	0.840	0.848	0.840	**0.921**
PT EX (8)	0.807	0.789	**1.000**	0.761	**1.000**	**0.925**
TW EX (9)	0.773	0.781	0.798	0.889	0.798	0.610

PT: peak torque; TW: total work; ER: external rotation; IR: internal rotation; FL: flexors; EX: extensors

Figures 7 and 8 show the network graphs for the preferred and non-preferred sides, respectively, indicating World Aquatics points, PT and TW IR, PT and TW ER, PT and TW FL, and PT and TW EX. The graphs show different models between the relationships of the variables, where the World Aquatics points variable on the non-preferred side is closer to the assessed isokinetic variables.

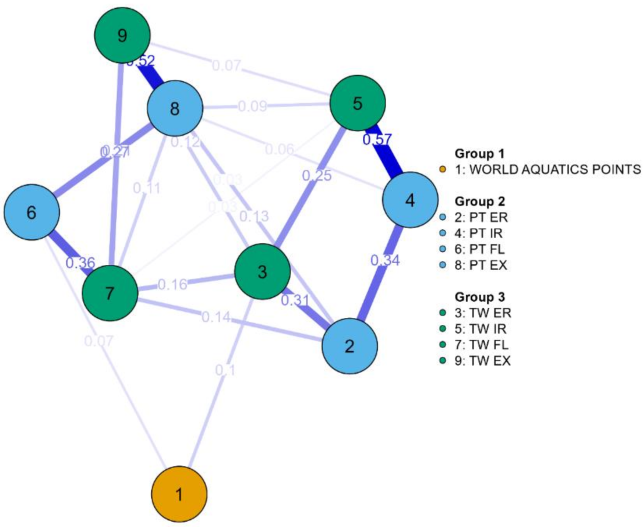

Figure 7. Network plot between World Aquatics points and preferred side isokinetic variables. Blue lines indicate positive and red negative relationships. The thickness represents the magnitude of the associations.

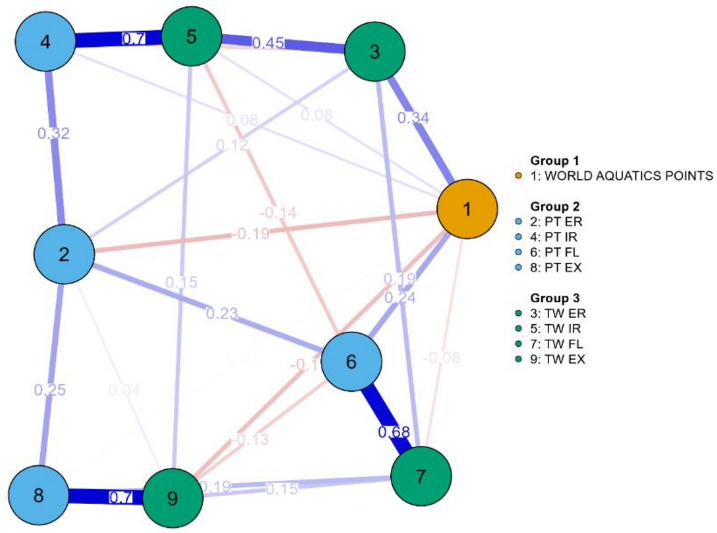

Figure 8. Network plot between World Aquatics points and non-preferred side isokinetic variables. Blue lines indicate positive and red negative relationships. The thickness represents the magnitude of the associations.

DISCUSSION

This study aimed to: (i) investigate the complex and simultaneous relationships between the World Aquatics points (performance) and the isokinetic test parameters through a network analysis, and (ii) compare the isokinetic parameters between the preferred and non-preferred sides of the shoulders of competitive swimmers. Our main finding is that the networks formed for the non-preferred side showed a more complex distribution among the studied variables, potentially influencing swimming performance, unlike the network formed for the preferred limb, which indicates stability and greater difficulty in influencing the isokinetic parameters in the World Aquatics points. Furthermore, differences were found in the isokinetic parameter TW ER between preferred and non-preferred sides, with a small effect size. Thereby, our hypothesis was partially confirmed for network analysis and the comparison between the upper preferred and non-preferred sides.

Among the isokinetic variables obtained by the preferred and non-preferred upper limb, only the TW ER showed some difference, with the preferred side presenting higher values (Table 13). The ER movement of the shoulder joint during swimming aims to control and stabilize the joint during the propulsive phases of the stroke cycles (Deschodt; Arsac; Rouard, 1999). The propulsive actions are mainly performed by the internal rotators, extensors, and adductors of the shoulder (Batalha *et al.*, 2018). In isokinetic tests, work is assessed based on the area under the torque versus angular displacement (time) curve, and TW is the sum of the work performed over all repetitions of the test (Sapega; Kelley, 1994). TW analysis can provide additional information about the swimmer's muscular capacity, and its values are commonly inserted into equations to identify the muscle fatigue index, which is related to the incidence of pain and injury in swimmers' shoulders (Batalha *et al.*, 2018).

In the centrality measures, the PT (0.973) and TW ER (1.000) variables had the highest closeness values, for network 1, and PT ER (1.000) and TW IR (0.925), for network 2. According to Hevey (2018), these results indicate that these variables are closer to all the others within their network and maybe a more efficient intermediary in influencing the other variables, i.e., those that can be affected by the intervention more quickly.

In the centrality measure of strength, the PT EX (1.000) variable had the highest values, for network 1, and TW IR (1.000) and PT FL (0.936), for network 2. This centrality measure indicates that these variables have stronger links with others within their network since it derives from the sum of all the paths linking one node to the others, with the centrality index as the most important (Newman, 2010). In the measure centrality of expected influence, the PT EX (1.000) variable had the highest values, for network 1, and TW IR (1.000), TW FL (0.921), and PT EX (0.925), for network 2. The variables with the highest expected influence have the greatest potential to influence the others in the network, as well as indicating which variables are most susceptible to intervention (Hevey, 2018).

In this group of swimmers, the graphical analysis of the networks and the values of the centrality measures allowed identifying the multiple relationships between the isokinetic variables for the preferred and non-preferred upper limbs, based on the performance variable World Aquatics points. Network 1 (preferred side) shows a more homogeneous pattern, in which the variables PT and TW are closer to each other in the same joint movement, while further away from the World Aquatics points. Such an arrangement might suggest greater stability and resistance to changes between isokinetic parameters and performance variables. In turn, network 2 (non-preferred side) shows a more complex interaction between the variables, indicating that multiple factors might be needed to improve swimmers' performance.

The results suggest that PT EX is an important variable in both networks in terms of strength centrality and expected influence, while the other variables vary between the two networks. In addition, high expected influence values for TW IR and TW FL on the non-preferred side suggest that these joint movements might play a more important role in influencing other movements in the network, thus representing important training targets.

Wiazewicz and Eider (2021), reported that among the 68 isokinetic variables analysed, only the variable acceleration time of the left shoulder during the shoulder FL movement had significant relationships with competitive swimming performance. Carvalho *et al*. (2019) described greater isokinetic torques in the shoulder EX and FL movements in elite swimmers compared with non-elite swimmers. Similarly, Carvalho *et al*. (2023) have also found that, regardless of swimming technique, the upper limb strength and power tests using an isokinetic dynamometer can determine different performance groups. According to multivariate analysis, the network formed for the non-preferred side in our group of nationally competitive swimmers appeared to be more susceptible to change.

The swimmer's force application during a swimming cycle in water accelerates masses of water that respond accordingly, but not linearly, to the force itself and how it is applied (Toussaint *et al.*, 2000). Therefore, force application by the preferred side seems to be "accommodated" and not to generate greater demands for the swimmer, being practically excluded from possible modifications to increase performance. In contrast, force application by the non-preferred side due to the swimmer's individual difficulties seems to represent a window to increase performance.

In this context, Guignard *et al*. (2017) suggested studying and understanding the swimmer's movements and interactions by focusing on the water properties rather than manipulating the movements. Modifying the swimmer's environment can lead to the reorganization of degrees of freedom and impact performance. Thus, of the network analysis between the isokinetic variables of the swimmers' main shoulder muscle actions indicated that there appear to be more windows for modification and performance enhancement on the non-preferred side.

Despite having been increasingly used in sports and health sciences, network analysis has some limitations, such as the need for theoretically excessive decisions and the difficulty of estimating networks with many parameters in synthetic samples (Lord *et al.*, 2020). Statistical regularization techniques, such as LASSO, have been used to deal with these limitations by producing sparse networks (Friedman; Hastie; Tibshirani, 2008). However, the tuning parameter (λ) must be selected carefully (Foygel; Drton, 2010) and further studies should consider these restrictions. In addition, isokinetic parameters may not capture all the specific swimming characteristics since the swimmer is usually assessed seated and fixed to the bench. However, several studies have made important contributions to the clinical conditions of swimmers' shoulders (Batalha et al., 2018; Batalha et al., 2013; Batalha et al., 2012). Finally, in studies that include other isokinetic variables (e.g., acceleration time and peak torque per body weight), the use of different angular velocities (e.g., 60, 90, and 120°/s) and other joint movements (e.g., adduction and abduction) may explain the relationships with the World Aquatics points better and contribute to future research.

CONCLUSION

This study contributes to the understanding of the complex relationships between World Aquatics points and isokinetic parameters in swimmers, as well as identifying differences between the preferred and non-preferred sides of the shoulders. We found that the non-preferred limb of the swimmers showed complex relationships between the study variables and a specific gap in attention for athletes and coaches that could help competitive performance through appropriate intervention. Further research using network analysis in the context of swimming could explore aspects, such as the relationship with other determinants of performance, in addition to longitudinal studies, injury prevention, and integration with monitoring technologies. Such research would deepen our understanding of the complex interactions between the physical and technical aspects of swimming performance, providing tangible benefits for athletes and coaches in optimizing training, improving performance, and preventing injuries.

5. FINAL CONSIDERATIONS

This thesis was made up of three studies, all three of which focused on aspects related to the assessment of swimmers' shoulders using the isokinetic dynamometer. The first study (systematic review) investigated the benefits and limitations of isokinetic assessments on the shoulders of swimmers of different age groups, genders, competitive levels and different swimming techniques. The second study sought to investigate the magnitude and concordance of the direction of torque asymmetries in competitive swimmers, assessing the internal and external rotators, flexors and extensors of the shoulders at 60 and 180°/s. The third study sought to analyze the complex and simultaneous relationships between a performance variable (World Aquatics points) and isokinetic parameters (peak torque and total work) of the internal and external rotation, flexion and extension movements at 180°/s.

In general, study 1 identified that the main benefit of isokinetic assessments to date is the analysis of the clinical condition of the swimmer's shoulder and its relationship with performance. Swimming creates musculoskeletal adaptations that can lead to an imbalance of strength between the shoulder muscles. The main joint movements used to generate propulsion are performed by the internal rotators, extensors and adductors of the shoulder. These muscles become stronger than their antagonists, creating muscle imbalances, which are often reported as sources of pain and inability to move. In addition, swimmers with muscle imbalances tend to have bilateral strength asymmetries, affecting the technical side of the stroke, causing the swimmer to have a greater hydrodynamic drag (loss of performance). The main limitation is in relation to the swimmer's position on the isokinetic dynamometer, which most of the studies analyzed evaluated in a seated position, which is not a specific swimming position.

In study 2, the magnitude values of the asymmetries were more prominent at low angular velocities (60°/s). As for the direction of asymmetries at different angular velocities (60 vs. 180°/s), agreement was moderate to substantial (except for FL) in competitive crawl swimmers. With the graphical analysis and the agreement values between the tests, it is clear that the investigation of asymmetries must be carried out individually and in different contexts. In addition, both the magnitude and direction of the asymmetries should be taken into account for a strategic intervention approach to correct the asymmetries.

In study 3, by investigating complex and simultaneous relationships using network analysis, we found that the relationships between World Aquatic points (performance) and shoulder isokinetic parameters (peak torque and total work) were more complex for the non-preferred upper limb than for the preferred side. The application of force by the non-preferred side due to the swimmer's individual difficulties seems to represent a specific window of attention for athletes and coaches who could, with appropriate intervention, help to increase performance.

The three studies, one theoretical (systematic review) and two experimental (studies 2 and 3), provide important information for researchers, coaches and athletes about isokinetic tests on swimmers' shoulders. The results found can help with decision-making in the choice of assessments and the individualization of the results found. This information is crucial for the quality and interpretation of the tests, as well as helping swimmers with the clinical condition of the shoulder and levels of inter-limb asymmetries. In studies using bivariate analysis, no relationships were found between isokinetic parameters and swimming performance, but with network analysis and its multiple relationships, we were able to verify that there is interaction between the variables, especially for the non-preferred upper limb.

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8. APPENDIX – A

Análise da variabilidade intracíclica e intertentativas do pico de força na pernada do nado peito

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Contextualização: A força requerida que cada nadador precisa aplicar na técnica de nado peito pelos membros inferiores é de primária importância, e a respectiva mensuração é essencial para a prescrição do treinamento. **Objetivo:** O objetivo do presente estudo foi analisar a variabilidade intracíclica e inter tentativas para os valores do pico de força gerado pelos membros inferiores durante um teste de 30 s máximo de nado amarrado na técnica de nado peito. **Material e Métodos:** Foi avaliado um atleta paraolímpico, classe SB8, campeão brasileiro, com estatura 1,76 m, peso 81,0 kg e como melhor marca nadando a 75,30 % da velocidade do recorde mundial na prova de 100 m nado de peito. O mesmo voluntariou-se a participar do estudo aprovado pelo comitê de ética local (CAAE: 79527917.5.0000.5020). Foram realizadas três repetições de 30 s máximos somente em condição de pernada de peito com 10 min de intervalo entre as tentativas. O nadador vestiu um cinto de cabo de aço de 5 m, suficientemente rígido, conectado a uma célula de carga (100 Hz; CEFISE Ltda, Nova Odessa, Brasil). O teste foi iniciado e finalizado com um sinal sonoro. A recolha dos dados iniciou após a realização do primeiro ciclo de pernada após os 10 s iniciais do teste para evitar efeitos inerciais da extensão do cabo. Os dados foram corrigidos em função do ângulo entre o cabo de aço e a superfície da água. Para análise dos dados, cada tentativa de 30 s foi separada em três momentos distintos: 00,01-10 s (M1), 10,01-20 s (M2) e 20,01-30 s (M3). **Resultados:** A média dos valores de pico de força intracíclica da primeira, segunda e terceira tentativas foram de 1205,96 ± 148,15 N, 1116,66 ± 183,54 N e 735,40 ± 134,20; 1354,07 ± 112,61 N, 1215,30 ± 129,19 N e 947,11 ± 173,99 N; 913,75 ± 134,72 N, 1228,83 ± 127,10 N e 951,90 ± 228,99 N. As médias inter-tentativas foram de M1 = 1157,93 N, M2 = 1186,93 N, M3 = 878,14 N e desvio padrão de ± 170,52. O coeficiente de variação intracíclica da primeira, segunda e terceira tentativa foram de: 0,12, 0,16 e 0,18; 0,08, 0,1 e 0,19; 0,14, 0,1 e 0,24. E o coeficiente de variação inter tentativas foram de M1 = 0,12, M2 = 0,12 e M3 = 0,16. Foi observado uma oscilação no coeficiente de variação ao longo das tentativas intracíclicas e inter tentativas o que mostra que há uma tendência de um declínio na produção de força durante os 30 s do teste e entre as tentativas, o que evidencia a fadiga principalmente no M3 de cada tentativa. **Conclusão:** Técnicos e treinadores necessitam elaborar estratégias para melhorar o ganho de força específica em nadadores com amputação dos membros superiores e tardar ainda mais o efeito da fadiga, fazendo com que o atleta melhore sua performance durante os treinos e nas competições.

Palavras-chave: Dinamometria. Natação. Paraolímpico. Desempenho.

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APPENDIX - B

COMPARISON OF ISOKINETIC FORCE OF THE INTERNAL AND EXTERNAL ROTATORS OF THE SHOULDERS BETWEEN SWIMMERS OF ALTERNATE ANDSIMULTANEOUS 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 andtwenty 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, peaktorque 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 thespecialization of the swimming technique, that is, alternate or simultaneous, swimmers canpresent imbalances in the internal and external rotators of the shoulders, which reveal theneed 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, sincethe 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 injuriesin swimmers, were evaluated mainly in concentric and eccentric contractions, where there arefunctional and conventional reasons between the strengths of the ER and IR to indicate probable injury risks due to muscle imbalance. However, the functional relationship, performedwith 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 thearms. 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 propulsionmuscles 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 eighthours 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 ofgroups, 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 shoulderat 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 ERand 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 levelwas 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). Calculationswere 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' rightand left shoulder rotators (ER/IR) for alternate and simultaneous swimming techniques, *p*-valueand effect size (ES).

		Variables				
Shouder Side	Swimming Techniques	PT/ER (60°/s)	PT/IR (60°/s)	PT/ER (180°/s)	PT/IR (180°/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 werealso 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 studyfor 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 at300º/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 specializedswimmers 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 limitof normality, which seems to be due to the higher qualitative PT of the right shoulder of the RImuscle 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.

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APPENDIX - C

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.

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APPENDIX - D

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). **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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APPENDIX – E

atletas que apresentaram descontrole com o peso (64,8%). Portanto, a partir das respostas positivas ao questionário foi possível observar o risco de desenvolvimento da síndrome da tríade da mulher atleta em mulheres lutadoras de BJJ. Desse modo, verifica-se a necessidade de realizar essa triagem, por meio da aplicação do questionário, com objetivo de auxiliar na prevenção e possibilidade do diagnóstico precoce da síndrome. Para aumentar as chances de reverter as consequências da tríade da mulher atleta e assim, auxiliar na tomada de decisão de treinadores e atletas frente a essa síndrome.

Palavras-chave: Tríade da Mulher Atleta; Brazilian Jiu-Jitsu feminino; Disfunções fisiológicas; ;

Apoio

Agradeço a Universidade Federal do Pará de Castanhal por está aberta quando precisei estudar e fazer minhas pesquisas a respeito do trabalho, agradeço ao Grupo de Treinamento Físico e Esportivo por me ajudar com as orientações necessárias para a contrução desse trabalho, agradeço a CNPq por incentivar esse trabalho e sua importância, assim como agradeço ao meu orientador Dr. Victor Sileveira Coswig por me proporcionar a oportunidade de dar andamento ao presente estudo.

ÍNDICE DE COORDENAÇÃO E CONCENTRAÇÃO DE LACTATO EM NADADOR COM PARALISIA CEREBRAL - UM ESTUDO DE CASO

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Resumo:
A coordenação motora e as respostas metabólicas são relevantes para prescrever e monitorar melhor o processo de treinamento da natação adaptada. No entanto, a literatura sobre paranatação reivindica uma análise e prescrição individualizada do treinamento para entender o impacto dos tipos de deficiência física dentro dos treinos e resultado da competição. Analisar a cinética das concentrações sanguíneas de lactato ([La-]) e o índice de comportamento de coordenação intermembros durante protocolo incremental intermitente de natação. Um para-nadador (46 anos de idade, 55,2 kg de peso corporal e 175 cm de altura) de nível nacional masculino (classe S6) especialista em provas de 400m livre, realizou protocolo incremental intermitente de crawl de 5x200 m até a exaustão, com incrementos de 0,05 m/s a cada tiro de 200m, com intervalos de 30 s de descanso entre os estímulos. Amostras de sangue capilar foram coletadas do lóbulo da orelha durante os intervalos, ao final do exercício, 3° e 5° min do período de recuperação (Lactate Pro, Japão). O perfil de lactato sanguíneo foi avaliado usando uma função personalizada do Matlab (The Mathworks Inc., EUA) modelando a curva [La-] vs. velocidade. O índice de coordenação entre membros (IdC) foi determinado medindo o tempo de atraso entre as fases propulsivas de cada braço, expresso como uma porcentagem da duração total do ciclo de braçada, propondo três modos de índice de coordenação: (i) captura (IdC<0%), (ii) oposição (IdC=0%) e (iii) superposição (IdC>0%). Os valores individuais para cada variável foram computados para todos os passos incrementais de 200 m. O paranadador atingiu seu limiar anaeróbio mais próximo da 4ª volta de 200 m (em 2,1 mmol.l-1) e o IdC permaneceu em modo de superposição (IdC>0%). O aumento da [La-] durante o protocolo incremental não parece influenciar o modo de coordenação do crawl. Ainda é necessário estudar o comportamento metabólico e de coordenação para a prescrição e acompanhamento do treinamento em paranadadores de diferentes classes.

Palavras-chave: Natação; Paratleta; Performance esportiva; Fisiologia;

Apoio

Este estudo foi financiado por bolsas da Fundação de Amparo à Pesquisa do Amazonas (FAPEAM), Programa de Infraestrutura para Jovens Pesquisadores - Programa Primeiro Projeto PPP n°/004/2017 (número 062.01554/2018).

APPENDIX – F

CORRELAÇÃO ENTRE VOLUME DE TREINO E DESEQUILÍBRIOS MUSCULARES EM NADADORES

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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 60°/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.
Palavras-chave: natação; força muscular; articulação do ombro; ;

Apoio

Este estudo foi financiado por bolsas: Fundação de Amparo à Pesquisa do Amazonas (FAPEAM), Programa de Infraestrutura para Jovens Pesquisadores - Primeiro Projeto Programa PPP nº/004/2017 sob Bolsa (número 062.01554/2018).

APPENDIX – G

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).

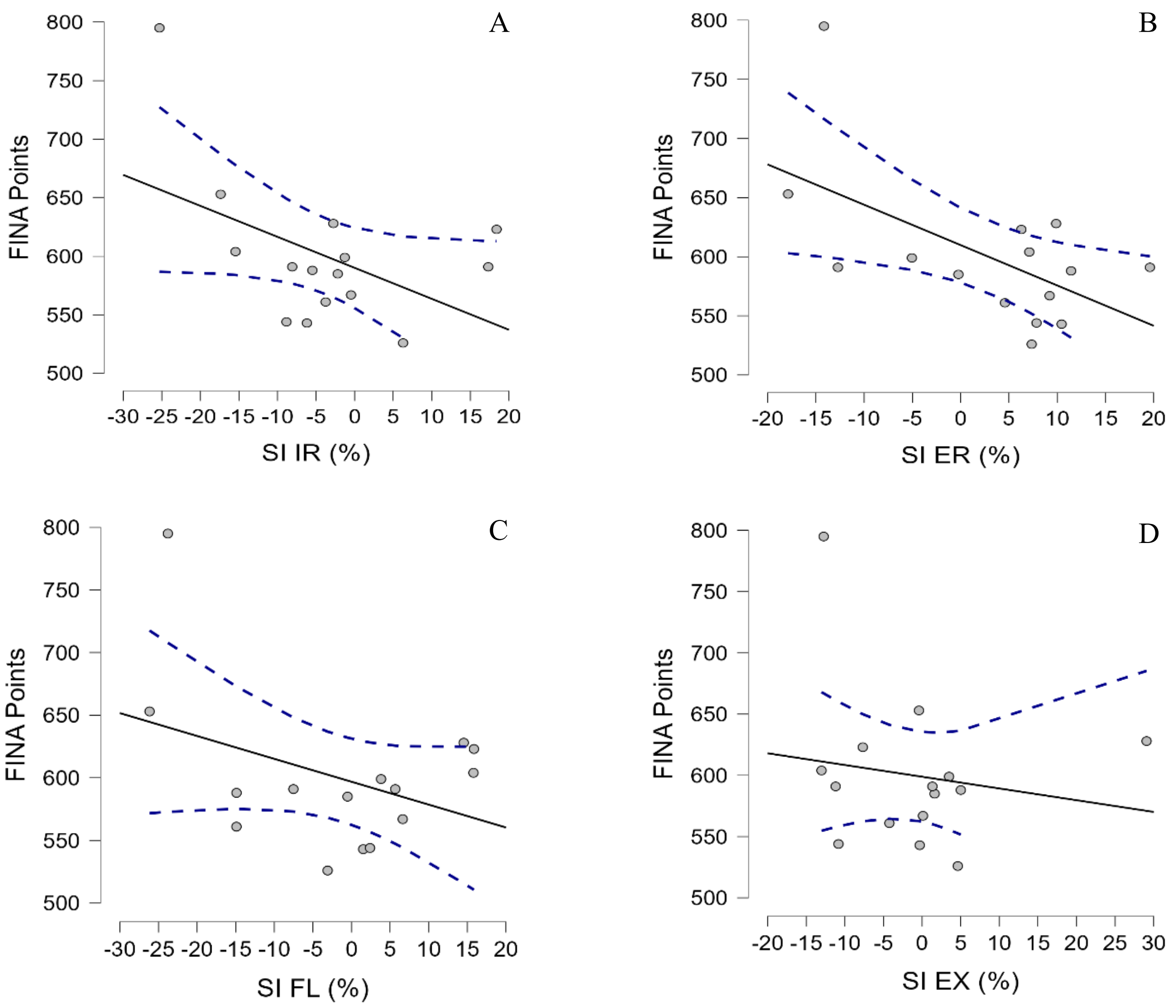

Figure 1: Correlation values between the FINA points and symmetry index (SI) variables of internal (IR) and external rotation (ER), flexion (FL), and extension (EX) of the shoulders at angular velocity 180°/s.

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.

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