BETWEEN-SESSION RELIABILITY OF DRY-LAND AND IN-WATER TESTS TO MEASURE INTER-LIMB ASYMMETRIES IN SWIMMERS

Débora A. Knihs[1], Chris Bishop[2], Haiko B. Zimmermann[1], Juliano Dal Pupo[1]

1. Biomechanics Laboratory, Centre of Sports, Federal University of Santa Catarina, Florianopolis, Brazil.
2. Faculty of Science and Technology, London Sports Institute, Middlesex University, London, United Kingdom.

Corresponding Author: Débora A. Knihs

Federal University of Santa Catarina, Sports Center, Deputado Antônio Edu Vieira, Pantanal, 88040-900 / Florianópolis – SC, Brazil. Phone: +55 041 47 99622 5202 deboraknihs@gmail.com

ORCiD's

Débora A. Knihs – 0000-0002-9217-7713

Chirs Bishop – 0000-0002-1505-1287

Haiko B. Zimmermann – 0000-0003-3703-5808

Juliano Dal Pupo – 0000-0003-4084-9474

ABSTRACT

The aims of the present study were to: i) analyse the between-session reliability of dry-land and in-water tests, and ii) investigate the prevalence of meaningful asymmetries in swimming athletes. Twenty-eight swimmers (21 males, 7 females) performed anthropometric, shoulder range of motion (ROM), countermovement jump, shoulder isokinetic torque, and 15-s tethered swimming tests two times, one week apart. Inter-limb asymmetries were calculated for each variable. Raw data reliability was determined using the intraclass coefficient correlation (ICC) and the typical error of measurement (TEM), and effect size (ES) was used to determine systematic bias between test sessions. At an individual level, inter-limb asymmetries were compared to the coefficient of variation (CV) to determine whether they were real. The between-session reliability was good to excellent (0.75 to 1.00) for most of the raw data, except for ROM. Between-session ES was predominately “trivial” or “small” for raw data and asymmetries, reinforcing that the values did not change significantly between the sessions. In addition, real asymmetries were seen in some tested metrics, depending on the test. In conclusion, the tested variables presented good levels of between-session reliability and were able to detect real and consistent asymmetries.

Key words: Swimming; side-to-side differences; performance; biomechanics.

Word count: 5979

INTRODUCTION

Inter-limb asymmetries can be defined as the difference between the body sides in terms of function, performance or morphology (Bishop et al., 2018; Maloney, 2018). In athletes of acyclic sports (e.g., racket sports), where one limb is frequently used more than the other, the presence of side-to-side anatomical/functional differences, is somewhat expected (Maloney, 2018). On the other hand, in cyclic sports like swimming one may expect a similar contribution from both limbs (Carvalho et al., 2019; dos Santos et al., 2013). This equivalent "work" of the limbs in swimming allows body alignment to be maintained (Sanders et al., 2015), minimizing drag (Sanders et al., 2011), and decreasing intra-cyclic velocity variation (Barbosa, 2010). In turn, it is thought that this could contribute to the absence of significant asymmetries and perhaps to the optimization of swimming performance (dos Santos et al., 2013; Morouço et al., 2015), although some studies have failed to corroborate this (Santos et al., 2020; Knihs et al., 2023).

While some studies have reported no meaningful asymmetries in swimmers upper and lower limbs (Carvalho et al., 2019; Morais et al., 2021; Psycharakis et al., 2021; Secchi et al., 2011), others have reported the presence of notable inter-limb differences in swimming athletes for physical characteristics such as upper limb muscle power (Potts et al., 2002), upper limb range of motion (Pereira et al., 2019), and even in tethered swimming tests (Barbosa & Andries Júnior, 2011; dos Santos et al., 2013; dos Santos et al., 2014; Morouço et al., 2015). Furthermore, it is hypothesised that the presence of asymmetries in swimmers can be a result of the often one-sided breathing action, training practice, injury history, chosen technique, and/or limb dominance or laterality (Maloney, 2018; Sanders et al., 2011; Seifert et al., 2005).

It is important to note that different methods have been used to analyse asymmetries in swimming. Both dry-land and in-water tests have been utilised (Carvalho et al., 2019; dos Santos et al., 2017), which provide an understanding of inter-limb differences in both physical capacity and the sport itself, respectively. Additionally, a recent scoping review analysed 60 studies about asymmetries in swimmers and noticed that between-limb side differences were determined through a variety of methods such as percentage calculations and statistical comparisons (Knihs et al., 2023). Naturally, when a variety of testing methods are utilised, a range of results are provided across the literature, making study comparisons somewhat challenging, and precluding a definitive conclusion from being reached about the relevance of asymmetry in swimming. Since statistical methods are influenced by factors such as sample size and metric variability and percentage methods should not use unique cut-off value to state a meaningful asymmetry (Bishop et al., 2021; Bishop et al., 2016; Knihs et al., 2023), another method should be used to determine the prevalence of meaningful asymmetries. Further to this, a plethora of research has outlined the requirement to determine whether an asymmetry is "real" by comparing it against the measurement error of the test (i.e., coefficient of variation [CV]) (Bishop et al., 2021; Exell et al., 2012; Phukan et al., 2021). That is, for an asymmetry to be considered "real" it has been suggested that the inter-limb percentage difference value (e.g., 12% asymmetry) must be higher than the intra-limb variability (e.g., 5% CV) (Bishop et al., 2021). However, to the authors' knowledge, this approach has not been utilised in swimming, to determine whether asymmetries are meaningful (Knihs et al., 2023).

Physical abilities such as strength, power, stroke propulsion, speed and range of motion are mentioned as important factors for swimming performance (Pyne & Sharp, 2014; Smith et al., 2002). Naturally then, investigating inter-limb asymmetries in these test measures is also relevant. Asymmetries have repeatedly been shown to be task-specific (Bishop et al., 2018). Thus, a test battery involving in-water and dry-land tests, that can provide the performance status of the athlete for the aforementioned physical capacities, and subsequent inter-limb differences, could be helpful in understanding the athlete's profile, as a whole. The first step to accurately determine asymmetries is to analyse the reliability of the raw data that will be used to calculate them, since it may affect the asymmetry results. Specifically, stronger reliability in the raw data may help to reduce the associated "noise" in the subsequent asymmetry calculation (Bishop et al., 2019). That is, since asymmetry is composed of two raw metrics, greater variability in the raw data may become magnified further, when a relative percentage difference is calculated, as shown by Bishop et al., (2021b), when comparing peak force and rate of force development asymmetries, during the isometric squat test. To the author's knowledge, only the between-session reliability of the tethered swimming test variables has been previously investigated in swimmers (Amaro et al., 2014; Nagle et al., 2021). With this in mind, investigating the between-session reliability of an appropriate physical testing battery in swimmers is warranted, with the purpose of identifying the prevalence of "real" asymmetries in this sport. In addition, it also seems relevant to investigate whether the reliability of in-water and dry-land tests are similar, since one is swimming-specific and the other tests are a general measure of physical capacity.

Therefore, the aims of the present study were to: i) analyse the between-session reliability of dry-land and in-water tests which can be used to measure inter-limb asymmetries in swimmers, and ii) investigate the prevalence of "real" asymmetries in swimming athletes. The hypotheses were that: i) all tests would present at least a good reliability (e.g., ICC ≥ 0.75) with some differences evident between metrics, and ii) that most athletes would present asymmetries higher than the variability in at least one metric, in each test.

MATERIALS AND METHODS

Experimental Approach to the Problem

This study was conducted to assess between session (test–retest) reliability of asymmetry variables in dry-land (anthropometric, range of motion, countermovement jump and isokinetic torque) and in-water (tethered swimming) tests, with assessments performed in the same manner, one week apart. Both limbs (right and left) were tested in all evaluations for the subsequent calculation of inter-limb asymmetries.

Participants

The sample was composed of 28 swimming athletes, 21 males (age: 20.7 years ± 6.0, body mass: 74.4 ± 11.6 kg, height: 180.9 ± 7.6 cm, body fat: 11.1 ± 3.9 %) and seven females (age: 16.0 ± 1.3 years, body mass: 61.3 ± 9.2 kg, height: 167.8 ± 8.2 cm, body fat: 19.3 ± 1.7 %). The number of participants was previously calculated in GPower software to obtain a statistical power of 80%, with an alpha (α) of 0.05, and effect size of 0.5 (n = 27). The athletes had a training history of 8.2 ± 4.8 years and no injury history in the three months before testing. Swimmers were training 5.8 ± 0.5 days a week, for 103.6 ± 17.5 minutes per session, completing a mean distance of 4166 ± 1272 m per session. The competitive level of the athletes varied between regional (n = 6) and national (n = 22) levels. Most athletes considered the right side as their preferred hand (71.4%) and foot (75%) use, based on the answers of the Edinburgh Handedness Inventory (Espírito-Santo et al., 2017) and the Waterloo Footness Questionnaire – Revised (Camargos et al., 2017), applied on the native language of the participants. This study was approved by the Federal University of Santa Catarina ethics committee (CAAE: 65671322.7.0000.0121). After being informed about the risks and benefits of the research, the athletes and their parents (when < 18 years old) signed a written informed consent to participate in this study.

Procedures

Participants were tested in four sessions, two in the first week (test) and two in the second (retest). On the first day, the swimmers started by answering a questionnaire addressing issues related to swimming practice, injury history, and hand and foot preference, and performed the dry-land tests. On the second day, the in-water tests were performed. The testing days were performed with at least 24 hours of intervals between them. In the second week, the procedures of the first and second days were repeated, aiming to assess the inter-session reliability of the measurements. The testing protocols are described below.

Anthropometric measurements: Anthropometric measurements were performed according to the protocol proposed by the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al., 2011), by an ISAK qualified evaluator. Body mass, height and wingspan were measured using a scale, a stadiometer and a measuring tape fixed to the wall, respectively. The lengths of the upper limb, arm, forearm, hand, lower limb, thigh, and leg; arm, forearm, mid-thigh, and calf perimeters; and the diameters of the elbow, wrist, knee and ankle, were measured on both sides of the body. The instruments used to measure lengths, perimeters and diameters were a segmometer, a flexible metallic measuring tape and a small calliper (CESCORF, Porto Alegre, Brazil), respectively. Two measurements of each variable were taken.

Shoulder range of motion (ROM): The ROM of the participants' shoulders was assessed using a mobile application (RateFast Goniometer – Alchemy Logic Systems). The active ROM of flexion, extension, abduction, external rotation, and internal rotation of the shoulder was evaluated in a standing (flexion and abduction) or lying position (extension, internal/external rotation). On the arm segment (considered in shoulder flexion, extension, and abduction movements), the anatomical references used to position the device with the application were the acromion and the lateral epicondyle of the humerus. The mobile was positioned in the middle of these references, perpendicular to the segment, in the lateral or posterior face of the arm, depending on the movement. On the forearm segment (considered in external/internal rotation movements) the anatomical references used to position the mobile were the radial head and the ulnar head. The device with the application was positioned perpendicularly to the segment, in the middle of these references, in the medial face (based on anatomical position) of the forearm. After the positioning of the smartphone on the segment, the participant was requested to perform the mentioned movements. The ROM was evaluated following the interpretation of the Goniometry Manual standardisation (Marques, 2003), and adapting it to the use of the smartphone with the application. Figure 1 illustrates the measurements. Any movement that resulted in body compensation was repeated to avoid super-estimated measures. A previous familiarisation with the movements was performed by the athletes, composed of two attempts of each movement on each body side. Then, two official measurements of each movement were taken.

Figure 1 about here

Countermovement jump (CMJ): The CMJ test was chosen to provide a measurement of the lower limb's capacity to produce force ballistically (Bosco, 2007). It is a widely used test (Claudino et al., 2017; Dal Pupo, et al., 2012; Phukan et al., 2021) with a movement pattern easy to execute by the athletes. A warm-up of five minutes on an ergometric bicycle at 75W was performed before testing. Then the participants were familiarised with the CMJ, performing two sets of 10 hopping jumps, three to five submaximal CMJs, and at least one CMJ near to the maximum effort. An evaluator judged if the jump pattern was of a sufficient quality by checking that: i) hands remained on the waist during the jump, ii) the trunk remained relatively erect during the flight phase of the jump, iii) the lower limbs remained extended during the flight phase of the jump, and iv) performing the transition between the eccentric and concentric phases in a continuous way. For testing, the participants were positioned over two AMTI force platforms (OR6-7-OP-2000, USA - 2000 Hz), spaced 10 cm apart, with a lower limb on each platform. From this position, the jump was performed bilaterally as follows: in an orthostatic position, with hands on the waist and feet shoulder-width apart, the athlete performed a maximum jump preceded by an eccentric preparatory movement in a self-selected depth to avoid unnecessary alterations to natural jump coordination patterns. Each swimmer performed three CMJs, with an interval of 1 minute between attempts.

Shoulder isokinetic torque: The isokinetic torque test is considered the gold standard to measure torque (i.e. strength), the isokinetic torque test allows the measurement of strength in movements involving specific muscular groups relevant for swimmers (Carvalho et al., 2019), such as shoulder internal and external rotators, and shoulder extensors. In addition, shoulder strength measured during an isokinetic test has previously shown moderate to large relationships with swimming performance (defined by FINA points) (r = 0.39-0.72) (Wiażewicz & Eider, 2021). In the present study, the isokinetic torque evaluation was performed on an isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, NY, USA – 100 Hz), calibrated according to the manufacturer's instructions. For internal/external rotation data collection, participants were seated, stabilised with straps to avoid compensatory movements, with the shoulder abducted at 70º in the plane of the scapula (approximately 30º ahead of the frontal plane), and the elbow flexed at 90º. The ROM considered were from 0° to 70°, with 0° being considered the beginning of internal rotation and 70° being the end of internal rotation/beginning of external rotation (Detanico et al., 2015). To evaluate the shoulder extensors, the athletes were lying in ventral decubitus on a stretcher, with the shoulder joint aligned to the axis of the equipment. The upper limb was positioned forward, in approximately 140° of shoulder flexion (considering the anatomic position 0°), and the participant performed the extension movement with the forearm supinated. The range of motion considered was from 140° to 20°, that is 120° of movement amplitude, simulating the propulsive phase of the front crawl stroke (Maglischo, 2010) and respecting the instrument limitations. Initially, there was a standardised warm-up, performed prior to testing each of the evaluated movements, on each of the body sides, to lubricate the joints and familiarise the athletes. The evaluation protocol consisted of performing four maximum concentric contractions, for the shoulder internal and external rotators, and four maximum concentric contractions for the shoulder extensors. The angular speed was $180^{\circ}\cdot s^{-1}$ (Perrin et al, 1987; Sanders et al., 2015), and the interval between the different conditions was approximately 5 min. The test order between the body sides was randomised, but the muscle group order was always the same (internal/external rotators first, extensors then), for logistical testing purposes.

Propulsive force at swimming: The tethered swimming test was chosen for being an accessible, low cost and specific test, that enables a direct measurement of the propulsive forces of each arm during swimming, and their subsequent asymmetries (dos Santos, et al., 2013; Santos et al., 2021). In addition, although some discrepancies between tethered swimming and free swimming are expected (e.g., differences in hand trajectory and disregard of water resistance), the test has been reported to be correlated to the front-crawl performance (Morouço et al., 2011) and used in previous studies (dos Santos et al., 2013; Morouço et al., 2015; Carvalho et al., 2019). The swimmers performed the in-water test in a 25-m heated pool. First, the athletes performed a standard warm-up used prior to competitions, which consisted in general of 300m front crawl swimming, 300m of corrective swimming exercises, 200m of kick exercises, and 200m of velocity progressive exercise. The warm-up varied slightly between the athletes with different specialities (50m x 800m, for example). Then, the swimmers were tied around the waist to an inextensible rigid cable (3 m), which was connected to a load cell (AEPH do Brasil, SP, Brazil – 200 kg) securely tied to the starting block at the edge of the pool. The load cell was connected to a Miotool signal acquisition system (Miotec Equipamentos Biomédicos Ltda., Porto Alegre, Brazil – 2000 Hz), which provided the propulsive force curve generated during swimming, for each of the upper limbs, through the Miotec software. Additionally, a manual synchroniser was triggered in every right-side stroke to create a pulse in the right side curve for posterior identification and analysis. Before testing, the athletes were familiarised with the equipment, swimming tethered until they felt familiar enough to perform their maximum performance. Then, after an interval, each participant performed three maximum attempts of 15 s of front crawl tethered swimming, with intervals of 5 min between attempts (which was the test itself). The use of lower limbs was not controlled, as well as breathing action.

Data Analysis

The ground reaction force (GRF) curves of each leg obtained during the vertical jump test were extracted from the NEXUS software and analysed through a mathematical routine in the MATLAB software. The curves were filtered using a low-pass, 4th order Butterworth filter with a cut-off frequency of 10 Hz (Suchomel et al., 2015). After, it was determined the beginning of the jump, considered the moment in which the GRF decreased (5%) in relation to baseline values (subject standing still) and the end of jump considered the last instant before the individual starts the fly phase. The following variables were calculated : a) Peak and Mean GRF: it was considered the maximum and the mean value of the GRF curve during the propulsive phase; b) rate of force development (RFD): the mean slope of the force-time curve in the time interval from the moment that GRF presents values greater than the body mass (positive acceleration) until the end of the propulsive phase; c) vertical net impulse: it was calculated the area of GRF from the moment when it presents values greater than the body mass until the end of the propulsive phase. Net vertical impulse was calculated by removing the vertical impulse exerted through acceleration due to gravity and then divided by the subjects' body mass to determine relative net vertical impulse; d) power output: it was obtained multiplying the GRF by velocity (obtained by integration of GRF) during propulsive phase of the jump. The peak and mean values of power curve were analysed; e), jump height was calculated by integration of velocity, obtaining the displacement of center of mass curve (Dal Pupo et al., 2012). A mean of the three curves was used for subsequent statistical analysis.

The torque curves were collected using the BIODEX software and then analysed in a specific mathematical routine in the MATLAB software. The curves were filtered using the same filter as GRF curves. The mean and peak torque, of each muscle group (shoulder internal rotators, external rotators, extensors), on each of the body sides, were analysed. The peak torque was considered the highest value on the curve, while the average torque was considered the average value on the curve. The mean of the best three curves in each situation was used for statistical analysis.

For the tethered swimming test, the data was analysed according to dos Santos et al. (2017), being treated and analysed by a mathematical routine implemented in the MATLAB software (Mathworks Inc., USA). First, the force curves were filtered with a 2nd order Butterworth low-pass filter, with a cutoff frequency of 15 Hz. Three curves on each side of the body were manually selected in each attempt. Each curve is equivalent to a stroke, defined from the moment the force rises abruptly until it reaches its lowest value. The following variables were calculated in each stroke: a) peak force: it was considered the highest value of the resulting force (considering the angle of the cable in relation to the water level/horizontal plane); b) the mean values of the force curve; c) Impulse: it was calculated by integrating the area of the force-time curve for each stroke; d) RFD: it was considered the slope of the curve, in the corresponding range from 20 to 80% of the peak force. A mean was calculated between the three selected strokes for each body side to represent the attempt mean. Then, the mean of the three attempts was considered for statistical analysis.

Asymmetries were calculated using a percentage difference equation: 100 / (maximum value) * (minimum value) * -1 + 100 (Bishop et al., 2020). Only for identification purposes, a negative sign was added to those whose left side was favoured, to show the direction of asymmetry without changing the magnitude. The asymmetries were calculated for each attempt in each test, and then a mean between the two or three attempts (depending on the test) was calculated to represent a mean value for each specified metric, for each athlete.

Statistical Analysis

Initially, descriptive statistics of the data were calculated (mean and standard deviation). The between-session reliability of measurements was verified for the raw variables by consistency (a two-way random intraclass correlation coefficient [ICC] with 95% confidence intervals [CI]) and agreement (typical error measurement [TEM] with 95% CI). The following classification for ICC was considered: < 0.50 poor; 0.50-0.75 moderate; 0.75-0.90 good; and > 0.90 excellent (Koo & Li, 2016). Additionally, effect size (ES) analysis was performed ([(Mean 1 – Mean 2) / SD pooled)] to determine whether any systematic bias was present between test sessions, with results classified as < 0.2 trivial; 0.2 - 0.6 small; 0.6 - 1.2 moderate; 1.2 - 2.0 large; 2.0 - 4 very large; and > 4.0 near perfect (Hopkins et al., 2009).

The coefficient of variation (CV) of the absolute variables was calculated through the equation: CV = (SD (attempts 1 and 2)/mean (attempts 1 and 2)) * 100, for each body side. Additionally, the CV value was used as a sensitivity measure in relation to asymmetry scores, in which inter-limb percentage differences greater than the CV were considered "real" (Bishop, 2021; Bishop et al., 2021; Exell et al., 2012). The higher CV value (from the right or left side) was used to compare with the asymmetry value and determine the "real" asymmetries. Finally, levels of agreement for the direction of asymmetry (between test sessions) were verified using the Kappa coefficient test. Values were interpreted as < 0 = poor, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81– 0.99 = almost perfect (Vieira & Garrett, 2005). JASP software and an available spreadsheet for analysis of reliability (Hopkins, 2015) were used to perform the necessary statistical tests.

RESULTS

The mean absolute raw values of the right and left sides for both sessions can be seen in Table 1. The between-session effect size showed that all variables had only trivial effects, except for hand length (left side) which presented a small effect. In general, this reinforces that the data measurement presented no systematic bias between sessions.

Table 1 about here

Table 2 shows the results of the between-session (test-retest) reliability tests, for right and left sides. The relative reliability (ICC) of all variables was classified as good or excellent, except for shoulder abduction ROM (both sides) and shoulder internal rotation ROM (right side) whose reliability was classified as moderate. Specifically, all the torque and anthropometric variables (both sides) presented excellent consistency between the test and retest sessions, as the force variables of the swimming test.

Table 2 about here

Table 3 presents the mean asymmetry values for each test session, as well as the effect size between the sessions and the consistency of the asymmetry direction between the sessions. The swimming test variables showed the highest asymmetry values (11.5 to 28.5 %), while the anthropometric measures presented the lowest ones (0.4 to 2.2 %). The between-session asymmetry effect size was classified as trivial or small for all variables, indicating that the values remained similar between the sessions. The higher effect size was for forearm length (ES = 0.59), showing a tendency to a smaller asymmetry in the retest session.

In Table 3 we also can see the level of agreement of swimming test variables asymmetry's direction between the sessions. Substantial to nearly perfect agreement was verified between the sessions, pointing out that the asymmetries favoured the same side on both days. On the other hand, the torque and ROM variables presented only slight to fair agreement with some variables presenting 'poor' levels of agreement, indicating that the asymmetries favoured distinct sides in each session. Countermovement jump and anthropometric variables presented mixed asymmetry direction classifications, showing that some asymmetries were consistent in terms of side, while others were not.

Table 3 about here

Lastly, the individual values of asymmetry and coefficient of variation for each variable are presented in Figures 2 to 5. Figure 2 (panels a-d) shows the individual asymmetries (grey bars) and CVs (black dots) for the swimming test variables. It was observed that most of the swimmers showed asymmetries greater than the CVs for peak force (*n* = 24; 85.7%), mean force (*n* = 21; 75.0%), RFD (*n* = 20; 71.4%), and impulse (*n* = 22; 78.5%), indicating the prevalence of real asymmetries.

Figure 2 about here

The individual asymmetries and CVs of torque variables are shown in Figure 3 (panels a-f). While for EXT peak torque, most athletes showed asymmetries higher than the CV (*n* = 18; 64.3%), for ER peak torque, that happened for only half of the participants (*n* = 14; 50.0%). In addition, most athletes present asymmetry values lower than the variable CV (i.e. not real asymmetries) in IR peak torque (*n* = 17; 60.7%), ER mean torque (*n* = 15; 53.6%), IR mean torque (*n* = 17; 60.7%), and EXT mean torque (*n* = 16; 57.1%).

Figure 3 about here

Individual asymmetries and CVs of countermovement jump variables are presented in Figure 4 (panels a-f). Asymmetries greater than CVs were observed for the majority of the participants, in peak power (*n* = 21; 75.0%), mean power (*n* = 20; 71.4%), peak GRF (*n* = 15; 53.6%), mean GRF (*n* = 17, 60.7%), and impulse (*n* = 21; 75.0%). However, for RFD the individual CVs were bigger than the asymmetries values in most of the participants (*n* = 17), meaning that 60.7% of the asymmetries can be unreal.

Figure 4 about here

For the ROM variables, the individual asymmetry and CVs values can be seen in Figure 5 (panels a-e). Asymmetry values for shoulder flexion and abduction were very low (0.3 to 7.1 %), and the variable's CV was similar to the asymmetry for most participants (0.4 to 6.5 %). For shoulder internal and external rotation, the individual asymmetry values were higher than the CV individual values for most athletes (ER *n* =

15; 53.6% - IR n = 16; 57.1%). On the other hand, for shoulder extension, the CV was higher than the asymmetry in most cases (n = 20; 71.4%), indicating unreal asymmetry values.

Figure 5 about here

Anthropometric asymmetries were very low, less than 2.5% on average. Thus, it was decided not to present figures with individual values, since this percentage would rarely have significance for the athletes.

DISCUSSION

This study aimed to verify the between session reliability of dry-land and in-water swimming-related testing variables, and the prevalence of meaningful asymmetries in swimming athletes. The primary findings were that: i) most of the tested variables presented high between-session reliability; ii) asymmetries did not change between the sessions, and meaningful asymmetries (i.e., superior than CV) were shown in some variables for most of the athletes; and iii) the direction of asymmetries was consistent for the in-water swimming test variables, but less consistent for the dry-land tested variables.

The between-session reliability data for the swimming, isokinetic torque, countermovement jump and anthropometric tests, were classified as “good” or “excellent”. The lowest ICC values were presented in the shoulder abduction (both body sides) and external rotation ROM test, whose classification was “moderate”. Furthermore, effect size data for all testing variables was “trivial” (≤ 0.20), with only hand length (for the left side) presenting a “small” effect (ES = 0.21), indicating no meaningful changes were evident between test sessions. These results show that the chosen variables can be trusted for testing, enabling the calculation of asymmetries to also be undertaken, since good reliability was seen for both sides of the body. However, some caution must be paid when testing shoulder ROM. With ICC values being moderate, more familiarisation may be required to enhance the reliability of this test. Although using different protocols, previous studies are in agreement with the present results, also showing good to excellent between-session reliability for tethered swimming protocols (Amaro et al., 2014), shoulder isokinetic torque (Meeteren et al., 2002), CMJ (Souza et al., 2020), shoulder ROM (Kim & Kim, 2016), and anthropometric (Siastras et al., 2010) tests. It is worth mentioning that except for the tethered swimming test the other studies mentioned above were not conducted in swimmers.

In accordance with the raw data, the asymmetries did not change between the test sessions (Table 3). The effect sizes between the sessions were classified as "trivial" or "small". The only metric that approached meaningful difference was the forearm length asymmetry (ES = 0.59 – moderate effect). However, with forearm length being a steady anthropometric measure, it seems likely that such variability was down to intra-rater error. Few studies have shown the changes in asymmetry scores between different sessions. Bishop et al. (2019) analysed the between-session asymmetry effect sizes in the isometric squat and jump tests, and also found no meaningful between-session changes, except for impulse in the isometric squat test. However, when the authors analysed the direction of asymmetry, levels of agreement ranged from "fair" to "substantial" between test sessions, depending on the test.

If we take a deeper analysis of our asymmetry data, despite no meaningful between-session variation in the magnitude of asymmetry, the within-group variability was large (i.e., the SD was often almost as large as the mean asymmetry value, for several variables). This high SD frequently precludes finding "significant differences" in group mean analysis (Bishop et al., 2022), which highlights the need for an alternative approach, where individual analysis is key (Bishop et al., 2021). Previous research has suggested a focus on both the magnitude and consistency in directionality (or limb dominance) in helping to differentiate the "signal from the noise" (Bishop et al., 2019, 2021). Specifically, for an asymmetry to be considered "real" it has been suggested that the inter-limb percentage difference value must be higher than the intra-limb variability (i.e., CV) (Bishop et al., 2019; Exell et al., 2012). It can be seen through the individual analysis results that the athletes evaluated presented meaningful asymmetries in some of the tested variables (Figures 1-4). Specifically, in the swimming and jump tests, most of the tested athletes presented asymmetries > the CV in almost all variables. In contrast, the group showed no real inter-limb differences for most variables in the isokinetic torque test. In addition, in the ROM test, three of the five tested movements presented CV higher or similar to the asymmetry values, suggesting that the inter-limb percentage difference value might be indicative of natural variability for the metric. Thus, these results indicate the prevalence of some real asymmetries in the evaluated swimmers, but depending on the metric.

When focusing on the direction of asymmetry, Kappa Coefficients showed substantial or near perfect levels of agreement for the swimming test variables. In contrast, greater fluctuation was evident in land-based assessment methods. In the CMJ test, half of the variables (peak power, maximal GRF, and net impulse) also showed good consistency in the direction of the asymmetry. However, in the isokinetic torque, ROM and anthropometric tests, most of the metrics presented only "poor" to "fair" levels of agreement. The explanation for the high consistency in the direction of asymmetry for the swimming test, might be because swimming is a daily activity for these athletes, enabling a more consistent stroke pattern, and thus, reduced variability in the asymmetry's direction. It may also point out to a preferred asymmetric technique adopted by the athlete that is performed consistently, that is, the athlete chooses to use one limb more than the other during swimming and repeats this pattern constantly during training. For some of the land-based protocols (e.g., CMJ and isokinetic assessments), these are performed on a less routine basis, which may contribute to greater fluctuations in performance. These results show that for most tests (except the swimming test) the limb presenting the higher values has a tendency to "swap sides" for many participants, and if focus is only given to the magnitude of the asymmetry, a misinterpretation of the results can be easily made; since asymmetry is a ratio metric and fluctuations in the limb presenting higher values will have a subsequent effect on how asymmetry is presented (Bishop et al., 2020, 2021). In a practical example, let's consider that participants number three and 12, in all swimming variables, presented high values of meaningful asymmetries (> CV) and consistency in the direction of asymmetry between sessions. On the other hand, swimmer number two showed direction-consistent asymmetries, but with all values < than the CV in almost all jump variables. For swimmer number four, they showed "real" asymmetries in the internal rotators peak and mean isokinetic torque, but no consistency in the favoured limb between test sessions. While in the last two cases, it is hard to know if an intervention would be needed (because of the variability of the asymmetry), in the first case, a decision can likely be made towards an intervention that strengthens the weaker limb. From this athlete-specific data, we can deduce that the magnitude and direction of asymmetries should be considered in the monitoring process to guide decision-making. In addition, an important aspect is that practitioners should investigate whether any existing inter-limb differences are influencing swimming performance or not, before a decision is made to pursue a specific, targeted training intervention.

While having strong points such as a significant sample size and an extensive test battery in a test-retest design, the present study is not without limitations. Firstly, the sample was not composed of professional swimmers, and some swimmers were youth athletes (ages 13-17). Although most of the athletes competed at a national level in their categories, the aforementioned factors must be considered when interpreting and extrapolating the results. Secondly, a kinematic analysis (e.g., filming the test), especially during the swimming test, could have been useful. For example, understanding whether propulsive force asymmetries are associated with the stroke movement would provide greater insights into the relevance of side-to-side differences. In addition, video analysis could have been useful in analysing the athlete's coordination during swimming, which is also considered a performance factor. Thirdly, the one-week interval between test sessions might have allowed some changes in the athlete's technique to develop, possibly interfering with the reliability of our results (although most of the metrics presented excellent reliability). Thus, future studies should consider a shorter interval between test sessions, such as 48-72 hours. In addition, males and females composed the sample and the data was analysed as a group. However, splitting the sample by gender was not an option due to the number of female swimmers; a point that future studies should be cognisant of. An important aspect to consider is that the present study did not aim to investigate whether the asymmetries have an influence on swimming performance. Thus, future research should also focus on answering this aspect, which may be crucial for the sport.

In summary, the evaluated variables from the dry-land and in-water swimming tests presented high between-session reliability, and inter-limb asymmetries showed no between-session changes. In an individual analysis, most athletes presented meaningful asymmetries in the swimming and jump tests, but not in the isokinetic and ROM tests. Additionally, the asymmetry's direction was more consistent for the in-water swimming test variables but less consistent for the dry-land tested variables.

PRACTICAL APPLICATIONS

- The present evidence suggests that the tested variables are good choices for coaches and researchers aiming to measure asymmetries in swimmers, since they present good levels of between-session reliability.

- Asymmetries are shown to be "real" in most athletes evaluated, so it is necessary to understand and monitor the possible implications on performance and/or injuries.
- The magnitude and direction of asymmetry in swimmers vary between individuals. These results highlight the need for individual and periodic asymmetry analysis in this population, together with robust methods that establish "signal to noise" within the context of limb differences. Once achieved, this may help practitioners determine whether targeted interventions are necessary.

ACKNOWLEDGMENTS

The authors would like to thank the swimmers for their participation. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

DECLARATION OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

REFERENCES

Amaro, N., Marinho, D. A., Batalha, N., Marques, M. C., & Morouço, P. (2014). Reliability of tethered swimming evaluation in age group swimmers. *Journal of Human Kinetics*, 41, 155–162. https://doi.org/10.2478/hukin-2014-0043

Barbosa, A. C., Andries Júnior, O. (2011). Effects of different hand paddle sizes on bilateral propulsive force difference in front crawl swimming. *Serbian Journal of Sports Science*, 5(3), 91-97.

Barbosa, T. M., Bragada, J. A., Reis, V. M., Marinho, D. A., Carvalho, C., & Silva, A. J. (2010). Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. *Journal of Science and Medicine in Sport*, 13(2), 262–269. https://doi.org/10.1016/j.jsams.2009.01.003

Bishop, C. (2021). Interlimb Asymmetries: Are Thresholds a Usable Concept? *Strength & Conditioning Journal*, 43(1), 32-36. https://doi.org/10.1519/SSC.0000000000000554

Bishop, C., Lake, J., Loturco, I., Papadopoulos, K., Turner, A., & Read, P. (2021). Interlimb Asymmetries: The Need for an Individual Approach to Data Analysis. *Journal of Strength and Conditioning Research*, 35(3), 695–701. https://doi.org/10.1519/JSC.0000000000002729

Bishop, C., Pereira, L. A., Reis, V. P., Read, P., Turner, A. N., & Loturco, I. (2020). Comparing the magnitude and direction of asymmetry during the squat, countermovement and drop jump tests in elite youth female soccer players. *Journal of Sports Sciences*, 38(11-12), 1296–1303. https://doi.org/10.1080/02640414.2019.1649525

Bishop, C., Read, P., Chavda, S., Jarvis, P., Brazier, J., Bromley, T., & Turner, A. (2022). Magnitude or Direction? Seasonal Variation of Interlimb Asymmetry in Elite Academy Soccer Players. *Journal of Strength and Conditioning Research*, 36(4), 1031–1037. https://doi.org/10.1519/JSC.0000000000003565

Bishop, C., Read, P., Chavda, S., Jarvis, P., & Turner, A. (2019). Using Unilateral Strength, Power and Reactive Strength Tests to Detect the Magnitude and Direction of Asymmetry: A Test-Retest Design. *Sports*, 7(3), 58. https://doi.org/10.3390/sports7030058

Bishop, C., Read, P., Chavda, S., & Turner, A. (2016). Asymmetries of the lower limb: The calculation conundrum in strength training and conditioning. *Strength & Conditioning Journal*, 38(6), 27-32. https://doi.org/10.1519/SSC.0000000000000264.

Bishop, C., Read, P., Lake, J., Loturco, I., Dawes, J., Madruga, M., Romero-Rodrigues, D., Chavda, S., & Turner, A. (2021b). Unilateral Isometric Squat: Test Reliability, Interlimb Asymmetries, and Relationships With Limb Dominance. *Journal of Strength and Conditioning Research*, 35, S144–S151. https://doi.org/10.1519/JSC.0000000000003079

Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *Journal of Sports Sciences*, 36(10), 1135–1144. https://doi.org/10.1080/02640414.2017.1361894

Bosco, C. A. (2007). *Força Muscular*. Phorte, São Paulo.

Camargos, M. B., Palmeira, A. D. S., & Fachin-Martins, E. (2017). Cross-cultural adaptation to Brazilian Portuguese of the Waterloo Footedness Questionnaire-Revised: WFQ-R-Brazil. *Arquivos de Neuro-psiquiatria*, 75(10), 727–735. https://doi.org/10.1590/0004-282X20170139

Carvalho, D. D., Soares, S., Zacca, R., Marinho, D. A., Silva, A. J., Pyne, D. B., Vilas-Boas, J. P., & Fernandes, R. J. (2019). In-Water and On-Land Swimmers' Symmetry and Force Production. *International Journal of Environmental Research and Public Health*, 16(24), 5018. https://doi.org/10.3390/ijerph16245018

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport*, 20(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Dal Pupo, J., Detanico, D., & Santos, S. G. (2012) Kinetic parameters as determinants of vertical jump performance. *Revista Brasileira de Cineantropometria e Desempenho Humano*, 14(1), 41-51, 2012. https://doi.org/10.5007/1980-0037.2012v14n1p41.

Detanico, D., Dal Pupo, J., Franchini, E., & Dos Santos, S. G. (2015). Effects of successive judo matches on fatigue and muscle damage markers. *Journal of Strength and Conditioning Research*, 29(4), 1010–1016. https://doi.org/10.1519/JSC.0000000000000746

dos Santos, K. B., Bento, P. C. B., Pereira, G., Payton, C., & Rodacki, A. L. F. (2017). Front Crawl Swimming Performance and Bi-Lateral Force Asymmetry during Land-Based and Tethered Swimming Tests. *Journal of Sports Science & Medicine*, 16(4), 574–580.

dos Santos, K. B., Pereira, G., Papoti, M., Bento, P. C., & Rodacki, A. (2013). Propulsive force asymmetry during tethered-swimming. *International Journal of Sports Medicine*, 34(7), 606–611. https://doi.org/10.1055/s-0032-1327575

Espírito-Santo, H., Pires, C. F., Garcia, I. Q., Daniel, F., Silva, A. G., & Fazio, R. L. (2017). Preliminary validation of the Portuguese Edinburgh Handedness Inventory in an adult sample. *Applied Neuropsychology: Adult*, 24(3), 275-287. https://doi.org/10.1080/23279095.2017.1290636

Exell, T. A., Irwin, G., Gittoes, M. J., & Kerwin, D. G. (2012). Implications of intra-limb variability on asymmetry analyses. *Journal of Sports Sciences*, 30(4), 403–409. https://doi.org/10.1080/02640414.2011.647047

Hopkins, W. G. (2015). Spreadsheets for analysis of validity and reliability. *Sportscience*, 19, 36-44.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, 41(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Knihs, D. A., Bishop, C., Zimmermann, H. B., & Dal Pupo, J. (2023). Interlimb Asymmetries in swimming and their impact on performance: evidence from a scoping review. *Strength & Conditioning Journal*, 45(6),642-662. https://doi.org/10.1519/SSC.0000000000000769.

Kim, S. G., & Kim, E. K. (2016). Test-retest reliability of an active range of motion test for the shoulder and hip joints by unskilled examiners using a manual goniometer. *Journal of Physical Therapy Science*, 28(3), 722–724. https://doi.org/10.1589/jpts.28.722

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability *Research. Journal of Chiropractic Medicine*, 15(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Maglischo, E. W. (2010). *Nadando o mais rápido possível* (3rd ed). Manole: Barueri, SP.

Maloney S. J. (2019). The Relationship Between Asymmetry and Athletic Performance: A Critical Review. *Journal of Strength and Conditioning Research*, 33(9), 2579–2593. https://doi.org/10.1519/JSC.0000000000002608

Marques, A. P. (2003). *Manual de goniometria* (2nd ed). Manole Barueri, SP.

Meeteren, J.v, Roebroeck, M. E., & Stam, H. J. (2002). Test-retest reliability in isokinetic muscle strength measurements of the shoulder. *Journal of Rehabilitation Medicine*, 34(2), 91–95. https://doi.org/10.1080/165019702753557890

Morais, J., Barbosa, T. M., Lopes, V. P., Marques, M. C., & Marinho, D. A. (2021). Propulsive Force of Upper Limbs and its Relationship to Swim Velocity in the Butterfly Stroke. *International Journal of Sports Medicine*, 42(12), 1105–1112. https://doi.org/10.1055/a-1386-4985

Morouço, P., Keskinen, K. L., Vilas-Boas, J. P., & Fernandes, R. J. (2011). Relationship between tethered forces and the four swimming techniques performance. *Journal of Applied Biomechanics*, 27(2), 161–169. https://doi.org/10.1123/jab.27.2.161

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

Nagle Zera, J., Nagle, E. F., Nagai, T., Lovalekar, M., Abt, J. P., & Lephart, S. M. (2021). Tethered Swimming Test: Reliability and the Association With Swimming Performance and Land-Based Anaerobic Performance. *Journal of Strength and Conditioning Research*, 35(1), 212–220. https://doi.org/10.1519/JSC.0000000000002501

Pereira, F. R., Gonçalves, G. G. P., Reis, D. R., Rohlfs, I. C., Mendonça, L. M., & Bittencourt, N. F. N. (2019). Comparison of glenohumeral joint rotation range of motion in young athletes. *Revista Brasileira de Medicina do Esporte*, 25(1), 53-57. https://doi.org/10.1590/1517-869220192501141465

Perrin, D. H., Robertson, R. J., & Ray, R. L. (1987). Bilateral lsokinetic Peak Torque, Torque Acceleration Energy, Power, and Work Relationships in Athletes and Nonathletes. *The Journal of Orthopaedic and Sports Physical Therapy*, 9(5), 184–189. https://doi.org/10.2519/jospt.1987.9.5.184

Phukan, M. I., Thapa, R. K., Kumar, G., Bishop, C., Chaabene, H., & Ramirez-Campillo, R. (2021). Inter-Limb Jump Asymmetries and Their Association with Sport-Specific Performance in Young Male and Female Swimmers. *International Journal of Environmental Research and Public Health*, 18(14), 7324. https://doi.org/10.3390/ijerph18147324

Potts, A. D., Charlton, J. E., & Smith, H. M. (2002). Bilateral arm power imbalance in swim bench exercise to exhaustion. *Journal of Sports Sciences*, 20(12), 975–979. https://doi.org/10.1080/026404102321011733

Psycharakis, S. G., Soultanakis, H., González Ravé, J. M., & Paradisis, G. P. (2021). Force production during maximal front crawl tethered swimming: exploring bilateral asymmetries and differences between breathing and non-breathing conditions. *Sports Biomechanics*, 3, 1–15. https://doi.org/10.1080/14763141.2021.1891277

Pyne, D. B., & Sharp, R. L. (2014). Physical and energy requirements of competitive swimming events. *International Journal of Sport Nutrition and Exercise Metabolism*, 24(4), 351–359. https://doi.org/10.1123/ijsnem.2014-0047

Sanders, R. H., Fairweather, M. M., Alcock, A., & McCabe, C. B. (2015). An approach to identifying the effect of technique asymmetries on body alignment in swimming exemplified by a case study of a breaststroke swimmer. *Journal of Sports Science & Medicine*, 14(2), 304–314.

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

Santos, K. B., Bento, P., Payton, C., & Rodacki, A. (2020). Symmetry in the front crawl stroke of different skill level of able-bodied and disabled swimmers. *PLoS One*, 15. https://doi.org/10.1371/journal.pone.0229918

Santos, C. C., Marinho, D. A., Neiva, H. P., & Costa, M. J. (2021). Propulsive forces in human competitive swimming: a systematic review on direct assessment methods. *Sports Biomechanics*, 9, 1–21. https://doi.org/10.1080/14763141.2021.1953574

Secchi, L. L., Muratt, M. D., Ciolac, E. G., & Greve, J. (2011). Knee muscles isokinetic evaluation in short distance elite swimmers: A comparison between symmetric and asymmetric swimming styles. *Isokinetics and Exercise Science*, 19, 261-264. https://doi.org/10.3233/IES-2011-0422.

Seifert, L., Chollet, D., & Allard, P. (2005). Arm coordination symmetry and breathing effect in front crawl. *Human Movement Science*, 24(2), 234–256. https://doi.org/10.1016/j.humov.2005.05.003

Siatras, T., Skaperda, M., & Mameletzi, D. (2010). Reliability of anthropometric measurements in young male and female artistic gymnasts. *Medical Problems of Performing Artists*, 25(4), 162–166.

Smith, D. J., Norris, S. R., & Hogg, J. M. (2002). Performance evaluation of swimmers: scientific tools. *Sports Medicine*, 32(9), 539–554. https://doi.org/10.2165/00007256-200232090-00001

Souza, A. A., Bottaro, M., Rocha, V. A., Lage, V., Tufano, J. J., & Vieira, A. (2020). Reliability and Test-Retest Agreement of Mechanical Variables Obtained During Countermovement Jump. *International journal of Exercise Science*, 13(4), 6–17.

Stewart, A., Marfell-Jones, M., Olds, T., & Ridder, H. (2011). *International standards for anthropometric assessment*. Lower Hutt, New Zealand: International Society for the Advancement of Kinanthropometry - ISAK.

Suchomel, T. J., Bailey, C. A., Sole, C. J., Grazer, J. L., & Beckham, G. K. (2015). Using Reactive Strength Index-Modified as an Explosive Performance Measurement Tool in Division I Athletes. *Journal of Strength and Conditioning Research*, 29(4), 899-904, 2015. https://doi.org/10.1519/JSC.0000000000000743.

Viera, A. J., & Garrett, J. M. (2005). Understanding interobserver agreement: the kappa statistic. *Family Medicine*, 37(5), 360–363.

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

Table 1. Descriptive raw data and effect size (ES) between sessions.

Variable	Test (mean ± SD)		Retest (mean ± SD)		ES (95%CI)	
	Right	Left	Right	Left	Right	Left
Swimming test						
Peak force (N)	206.5 ± 70.4	174.6 ± 46.4	197.9 ± 65.7	170.0 ± 53.2	0.13 (-0.40, 0.65)	0.09 (-0.43, 0.61)
Mean force (N)	131.9 ± 41.7	115.4 ± 29.6	129.0 ± 37.4	115.1 ± 32.3	0.07 (-0.45, 0.60)	0.01 (-0.51, 0.53)
RFD ($N.s^{-1}$)	754.1 ± 330.7	684.1 ± 306.4	754.0 ± 386.4	652.8 ± 158.7	0.00 (-0.52, 0.52)	0.10 (-0.43, 0.62)
Impulse (N.s)	37.7 ± 17.0	29.4 ± 11.6	35.3 ± 15.8	27.0 ± 12.0	0.15 (-0.38, 0.67)	0.20 (-0.32, 0.73)
Isokinetic shoulder torque (N.m)						
ER peak torque	44.4 ± 16.5	44.7 ± 13.5	45.6 ± 16.2	44.8 ± 14.4	-0.07 (-0.58, 0.47)	-0.01 (-0.53, 0.52)
IR peak torque	62.8 ± 20.1	63.1 ± 20.6	62.5 ± 20.3	64.3 ± 21.4	0.01 (-0.51, 0.54)	-0.06 (-0.58, 0.47)
EXT peak torque	74.1 ± 24.3	71.3 ± 22.6	74.9 ± 23.8	72.5 ± 23.2	-0.03 (-0.56, 0.49)	-0.05 (-0.58, 0.47)
ER mean torque	47.2 ± 14.3	49.1 ± 15.5	47.3 ± 14.4	49.9 ± 15.9	-0.01 (-0.53, 0.52)	-0.05 (-0.57, 0.47)
IR mean torque	39.5 ± 13.1	39.5 ± 10.9	40.0 ± 12.3	39.3 ± 11.3	-0.04 (-0.56, 0.49)	0.02 (-0.51, 0.54)
EXT mean torque	32.1 ± 11.6	33.2 ± 10.0	32.4 ± 12.0	33.3 ±10.6	-0.04 (-0.56, 0.49)	-0.16 (-0.68, 0.37)
Countermovement jump						
Jump height (cm)	31.1 ± 9.7		30.8 ± 10.4		0.02 (-0.50, 0.54)	
Peak power (W/kg)	17.6 ± 5.3	17.8 ± 5.1	17.8 ± 5.0	18.1 ± 5.4	-0.04 (-0.56, 0.49)	-0.06 (-0.58, 0.47)
Mean power (W/kg)	8.9 ± 2.6	9.0 ± 2.5	9.0 ± 2.5	9.1 ± 2.7	-0.04 (-0.56, 0.49)	-0.04 (-0.56, 0.49)
Peak GRF (N)	471.5 ± 107.6	469.3 ± 109.2	459.1 ± 103.6	462.9 ± 116.1	0.02 (-0.50, 0.54)	-0.03 (-0.56, 0.49)
Mean GRF (N)	322.4 ± 100.2	319.7 ± 99.7	308.3 ± 87.2	302.3 ± 96.3	0.03 (-0.50, 0.55)	0.07 (-0.46, 0.59)
Net impulse ($m \cdot s^{-1}$)	148.3 ± 35.0	151.9 ± 36.3	142.6 ± 32.6	145.4 ± 34.6	-0.10 (-0.62, 0.42)	-0.08 (-0.61, 0.44)
RFD ($N \cdot s^{-1}$)	2800.0 ± 993.9	2694.1 ± 950.4	2676.7 ± 930.8	2629.8 ± 950.8	0.11 (-0.42, 0.63)	0.05 (-0.47, 0.57)
Range of motion (°)						

Shoulder flexion	167.3 ± 10.6	167.2 ± 9.6	166.5 ± 10.5	167.0 ± 9.2	0.08 (-0.45, 0.60)	0.02 (-0.50, 0.54)
Shoulder extension	35.1 ± 11.9	35.9 ± 11.6	36.4 ± 14.0	35.5 ± 12.8	-0.10 (-0.62, 0.43)	0.03 (-0.49, 0.56)
Shoulder abduction	177.9 ± 6.8	176.8 ± 6.6	178.5 ± 6.6	176.9 ± 6.5	-0.09 (-0.61, 0.44)	-0.02 (-0.54, 0.51)
Shoulder IR	55.6 ± 11.9	58.7 ± 12.2	55.9 ± 11.3	57.2 ± 12.1	-0.03 (-0.55, 0.50)	0.12 (-0.40, 0.65)
Shoulder ER	83.8 ± 9.2	79.1 ± 9.2	83.2 ± 10.7	79.4 ± 9.3	0.06 (-0.46, 0.58)	-0.03 (-0.56, 0.49)
Anthropometric measures (cm)						
Upper limb length	80.3 ± 5.3	80.1 ± 5.4	80.3 ± 5.3	80.2 ± 5.3	0.00 (-0.52, 0.52)	-0.02 (-0.54, 0.51)
Arm length	35.4 ± 2.5	35.2 ± 2.5	35.4 ± 2.6	35.3 ± 2.4	0.00 (-0.52, 0.52)	-0.04 (-0.56, 0.48)
Forearm length	24.3 ± 1.6	24.6 ± 1.7	24.4 ± 1.6	24.5 ± 1.8	-0.06 (-0.59, 0.46)	0.06 (-0.47, 0.58)
Hand length	20.8 ± 1.5	20.3 ± 1.4	20.6 ± 1.5	20.3 ± 1.4	0.13 (-0.39, 0.66)	0.21 (-0.31, 0.74)
Lower limb length	84.5 ± 5.0	84.3 ± 5.1	84.5 ± 5.1	84.4 ± 5.2	0.00 (-0.52, 0.52)	-0.02 (-0.54, 0.50)
Thigh length	42.1 ± 2.5	42.0 ± 2.6	42.2 ± 2.6	41.9 ± 2.7	-0.04 (-0.56, 0.49)	0.04 (-0.49, 0.56)
Leg length	42.7 ± 2.8	42.5 ± 2.7	42.7 ± 2.8	42.8 ± 2.7	0.00 (-0.52, 0.52)	-0.10 (-0.60, 0.41)
Arm flexed girth	30.4 ± 3.1	30.2 ± 3.1	30.3 ± 3.1	30.3 ± 3.1	0.03 (-0.49, 0.56)	-0.03 (-0.56, 0.49)
Arm relaxed girth	32.2 ± 3.2	31.8 ± 3.3	32.2 ±3.2	31.9 ± 3.3	0.00 (-0.52, 0.52)	-0.03 (-0.55, 0.49)
Forearm girth	26.4 ± 2.2	26.1 ± 2.3	26.5 ± 2.2	26.2 ± 2.3	0.05 (-0.57, 0.48)	-0.04 (-0.57, 0.48)
Thigh girth	54.4 ± 4.5	54.3 ± 4.3	54.5 ± 4.4	54.4 ± 4.4	-0.02 (-0.55, 0.50)	-0.02 (-0.55, 0.50)
Calf girth	36.0 ± 2.9	35.9 ± 2.8	36.0 ± 2.9	35.9 ± 2.8	0.00 (-0.52, 0.52)	0.00 (-0.52, 0.52)
Wrist diameter	5.5 ± 0.5	5.5 ± 0.5	5.5 ± 0.5	5.5 ± 0.5	0.00 (-0.52, 0.52)	0.00 (-0.52, 0.52)
Elbow diameter	6.9 ± 0.6	7.0 ± 0.6	7.0 ± 0.6	7.0 ± 0.6	-0.17 (-0.69, 0.36)	0.00 (-0.52, 0.52)
Knee diameter	9.5 ± 0.6	9.5 ± 0.6	9.5 ± 0.6	9.5 ± 0.6	0.00 (-0.52, 0.52)	0.00 (-0.52, 0.52)
Ankle diameter	7.2 ± 0.6	7.3 ± 0.6	7.3 ± 0.6	7.3 ± 0.6	-0.17 (-0.69, 0.36)	0.00 (-0.52, 0.52)

SD: standard deviation, ES: effect size, RFD: rate of force development, ER: external rotation, IR: internal rotation, EXT: extension, GRF: ground force reaction.

Table 2. Between-session reliability data for all variables.

Variable	ICC		TEM (absolute) (95% CI)	
	Right	**Left**	**Right**	**Left**
Swimming test (N.m)				
Peak force (N)	0.95 (0.90, 0.98)	0.94 (0.88, 0.97)	15.30 (12.10, 20.84)	12.44 (9.84, 16.94)
Mean force (N)	0.95 (0.98, 0.89)	0.96 (0.91, 0.98)	9.24 (7.31, 12.58)	6.51 (5.15, 8.87)
RFD ($N.s^{-1}$)	0.81 (0.63, 0.91)	0.90 (0.79, 0.95)	160.96 (127.26, 219.10)	106.44 (84.16, 144.89)
Impulse (N.s)	0.88 (0.75, 0.94)	0.87 (0.74, 0.94)	5.99 (4.74, 8.16)	4.35 (3.43, 5.97)
50-m time trial (s)	0.98 (0.96, 0.99)		0.29 (0.23, 0.39)	
Isokinetic shoulder torque (N.m)				
ER peak torque	0.94 (0.97, 0.97)	0.92 (0.83, 0.96)	4.20 (3.33, 5.73)	4.20 (3.32, 5.72)
IR peak torque	0.95 (0.89, 0.98)	0.96 (0.91, 0.98)	4.78 (3.78, 6.51)	4.44 (3.51, 6.04)
EXT peak torque	0.98 (0.96, 0.99)	0.97 (0.94, 0.99)	3.39 (2.68, 4.62)	4.05 (3.20, 5.52)
ER mean torque	0.93 (0.86, 0.97)	0.91 (0.82, 0.96)	3.44 (2.72, 4.69)	3.42 (2.71, 4.66)
IR mean torque	0.93 (0.86, 0.97)	0.95 (0.90, 0.98)	3.84 (3.04, 5.23)	3.57 (2.83, 4.87)
EXT mean torque	0.93 (0.85, 0.97)	0.92 (0.83, 0.96)	3.31 (2.62, 4.51)	3.05 (2.42, 4.16)
Countermovement jump				
Jump height (cm)	0.95 (0.90, 0.98)		2.23 (1.77, 3.04)	
Peak power (W/kg)	0.94 (0.87, 0.97)	0.95 (0.90, 0.98)	1.36 (1.08, 1.86)	1.15 (0.92, 1.58)
Mean power (W/kg)	0.93 (0.86, 0.97)	0.95 (0.90, 0.98)	0.68 (0.54, 0.93)	0.57 (0.46, 0.79)
Peak GRF (N)	0.89 (0.78, 0.95)	0.90 (0.79, 0.95)	36.77 (29.07, 50.05)	36.60 (28.94, 49.82)
Mean GRF (N)	0.92 (0.83, 0.96)	0.92 (0.84, 0.96)	29.41 (23.25, 40.03)	26.80 (21.19, 36.49)
Net impulse ($m{\cdot}s^{-1}$)	0.95 (0.90, 0.98)	0.96 (0.91, 0.98)	7.91 (6.26, 10.78)	7.25 (5.73, 9.87)
RFD ($N{\cdot}s^{-1}$)	0.77 (0.56, 0.88)	0.76 (0.54, 0.88)	482.56 (381.53, 656.84)	477.63 (377.63, 650.13)

Range of motion (°)				
Shoulder flexion	0.78 (0.58, 0.89)	0.79 (0.60, 0.90)	5.08 (4.02, 6.91)	4.40 (3.48, 5.99)
Shoulder extension	0.83 (0.66, 0.92)	0.90 (0.79, 0.95)	5.53 (4.37, 7.53)	4.04 (3.20, 5.51)
Shoulder abduction	0.63 (0.34, 0.81)	0.65 (0.37, 0.82)	4.15 (3.29, 5.66)	3.94 (3.12, 5.37)
Shoulder IR	0.86 (0.72, 0.93)	0.78 (0.59, 0.89)	4.43 (4.59, 7.90)	5.80 (4.29, 7.39)
Shoulder ER	0.72 (0.47, 0.86)	0.79 (0.60, 0.90)	5.43 (4.29, 7.39)	4.33 (3.43, 5.90)
Anthropometric measures (cm)				
Upper limb length	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)	0.41 (0.33 – 0.56)	0.37 (0.29 – 0.51)
Arm length	0.99 (0.98, 1.00)	0.98 (0.97, 0.99)	0.24 (0.19, 0.33)	0.31 (0.25, 0.43)
Forearm length	0.95 (0.90, 0.98)	0.97 (0.93, 0.99)	0.36 (0.29, 0.49)	0.32 (0.25, 0.44)
Hand length	0.97 (0.94, 0.99)	0.98 (0.96, 0.99)	0.26 (0.21, 0.36)	0.20 (0.16, 0.28)
Lower limb length	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)	0.39 (0.31, 0.53)	0.42 (0.34, 0.58)
Thigh length	0.96 (0.92, 0.98)	0.95 (0.90, 0.98)	0.50 (0.40, 0.68)	0.59 (0.47, 0.81)
Leg length	0.98 (0.96, 0.99)	0.99 (0.98, 0.99)	0.39 (0.31, 0.54)	0.29 (0.24, 0.41)
Arm flexed girth	0.99 (0.99, 1.00)	1.00 (0.99, 1.00)	0.25 (0.20, 0.34)	0.22 (0.18, 0.30)
Arm relaxed girth	1.00 (0.99, 1.00)	0.99 (0.99, 1.00)	0.19 (0.16, 0.27)	0.24 (0.20, 0.34)
Forearm girth	0.99 (0.98, 0.99)	0.99 (0.99, 1.00)	0.24 (0.19, 0.33)	0.18 (0.14, 0.25)
Thigh girth	0.98 (0.96, 0.99)	0.98 (0.96, 0.99)	0.62 (0.49, 0.85)	0.60 (0.48, 0.83)
Calf girth	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)	0.29 (0.23, 0.40)	0.25 (0.20, 0.35)
Wrist diameter	0.97 (0.94, 0.99)	0.98 (0.97, 0.99)	0.08 (0.07, 0.11)	0.06 (0.05, 0.09)
Elbow diameter	0.98 (0.95, 0.99)	0.99 (0.97, 0.99)	0.09 (0.07, 0.13)	0.06 (0.05, 0.09)
Knee diameter	0.99 (0.98, 1.00)	0.99 (0.99, 1.00)	0.05 (0.04, 0.07)	0.04 (0.04, 0.07)
Ankle diameter	0.98 (0.96, 0.99)	0.98 (0.97, 0.99)	0.08 (0.07, 0.12)	0.08 (0.07, 0.12)

ICC: intraclass correlation coefficient, TEM: typical error of measurement, RFD: rate of force development, ER: external rotation, IR: internal rotation, EXT: extension, GRF: ground force reaction.

Table 3. Mean inter-limb asymmetry values (%), effect size, and levels of agreement of the asymmetry direction between sessions.

Variable	Test (%)	Retest (%)	ES (95%CI)	Kappa Coefficient	Kappa Classification
Swimming test					
Peak force (N)	15.2 ± 10.3	15.2 ± 10.8	0.00 (-0.52, 0.52)	0.86	Nearly perfect
Mean force (N)	12.7 ± 7.9	11.5 ± 9.1	0.14 (-0.39, 0.66)	0.88	Nearly perfect
RFD ($N.s^{-1}$)	28.5 ± 17.0	23.7 ± 17.4	0.28 (-0.25, 0.80)	0.63	Substantial
Impulse (N.s)	25.3 ± 15.0	26.5 ± 15.1	-0.08 (-0.60, 0.45)	0.75	Substantial
Isokinetic shoulder torque (N.m)					
ER peak torque	12.4 ± 9.5	11.1 ± 8.4	0.14 (-0.38, 0.67)	0.27	Fair
IR peak torque	7.7 ± 6.3	9.2 ± 7.6	-0.21 (-0.74, 0.31)	-0.09	Poor
EXT peak torque	10.3 ± 10.6	14.1 ± 10.3	-0.36 (-0.89, 0.17)	0.32	Fair
ER mean torque	7.8 ± 7.7	9.8 ± 8.0	-0.25 (-0.78, 0.27)	0.35	Fair
IR mean torque	7.6 ± 5.9	7.1 ± 6.1	0.08 (-0.44, 0.61)	0.08	Slight
EXT mean torque	11.5 ± 8.7	9.3 ± 7.9	0.26 (-0.26, 0.79)	-0.12	Poor
Countermovement jump					
Peak power (W/kg)	10.6 ± 8.5	10.2 ± 5.8	0.05 (-0.47, 0.58)	0.44	Moderate
Mean power (W/kg)	10.5 ± 8.4	10.2 ± 5.8	0.04 (-0.48, 0.56)	0.37	Fair
Maximal GRF (N)	8.8 ± 7.4	9.6 ± 8.1	-0.10 (-0.63, 0.42)	0.43	Moderate
Mean GRF (N)	10.5 ± 9.6	12.4 ± 11.9	-0.18 (-0.70, 0.35)	0.15	Slight
Net impulse ($m \cdot s^{-1}$)	11.8 ± 9.3	12.3 ± 10.9	-0.05 (-0.57, 0.48)	0.72	Substantial
RFD ($N \cdot s^{-1}$)	11.4 ± 8.0	11.6 ± 8.3	-0.02 (-0.55, 0.50)	0.28	Fair
Range of motion (°)					
Shoulder flexion	2.4 ± 2.2	2.4 ± 1.8	0.00 (-0.52, 0.52)	0.21	Fair
Shoulder extension	11.2 ± 9.7	11.3 ± 9.6	-0.01 (-0.53, 0.51)	0.28	Fair

Shoulder abduction	2.0 ± 1.5	1.9 ± 1.6	0.06 (-0.46, 0.59)	0.34	Fair
Shoulder IR	14.0 ± 9.0	11.7 ± 10.0	0.24 (-0.29, 0.76)	0.33	Fair
Shoulder ER	8.2 ± 5.9	8.4 ± 5.2	-0.04 (-0.56, 0.49)	0.30	Fair
Anthropometric measures (cm)					
Upper limb length	0.4 ± 0.3	0.4 ± 0.3	0.00 (-0.52, 0.52)	0.55	Moderate
Arm length	0.9 ± 0.7	1.0 ± 0.7	-0.14 (-0.67, 0.38)	0.17	Slight
Forearm length	1.9 ± 1.4	1.2 ± 0.9	0.59 (0.05, 1.12)	-0.08	Poor
Hand length	2.2 ± 1.7	1.7 ± 1.5	0.31 (-0.22, 0.83)	0.03	Slight
Lower limb length	0.4 ± 0.3	0.5 ± 0.3	-0.33 (-0.86, 0.20)	0.25	Fair
Thigh length	0.8 ± 0.7	1.1 ± 1.1	-0.33 (-0.85, 0.21)	-0.09	Poor
Leg length	0.9 ± 0.7	0.9 ± 0.6	0.00 (-0.52, 0.52)	0.43	Moderate
Arm flexed girth	1.2 ± 1.1	1.2 ± 1.1	0.00 (-0.52, 0.52)	0.64	Substantial
Arm relaxed girth	1.5 ± 1.2	1.6 ± 1.3	-0.08 (-0.60, 0.45)	0.60	Moderate
Forearm girth	1.8 ± 1.5	1.5 ± 1.4	0.21 (-0.32, 0.73)	0.36	Fair
Thigh girth	0.8 ± 0.7	0.7 ± 0.5	0.16 (-0.36, 0.69)	0.27	Fair
Calf girth	1.0 ± 0.9	1.4 ± 1.2	-0.38 (-0.90, 0.16)	0.42	Moderate
Wrist diameter	1.3 ± 1.1	1.3 ± 0.9	0.00 (-0.39, 0.39)	0.00	Poor
Elbow diameter	1.2 ± 1.0	1.0 ± 1.0	0.20 (-0.33, 0.72)	0.42	Moderate
Knee diameter	0.7 ± 0.5	0.5 ± 0.5	0.40 (-0.13, 0.92)	0.16	Slight
Ankle diameter	1.5 ± 1.9	1.2 ± 1.5	0.18 (-0.35, 0.70)	0.18	Slight

ES: effect size, RFD: rate of force development, ER: external rotation, IR: internal rotation, EXT: extension, GRF: ground force reaction.

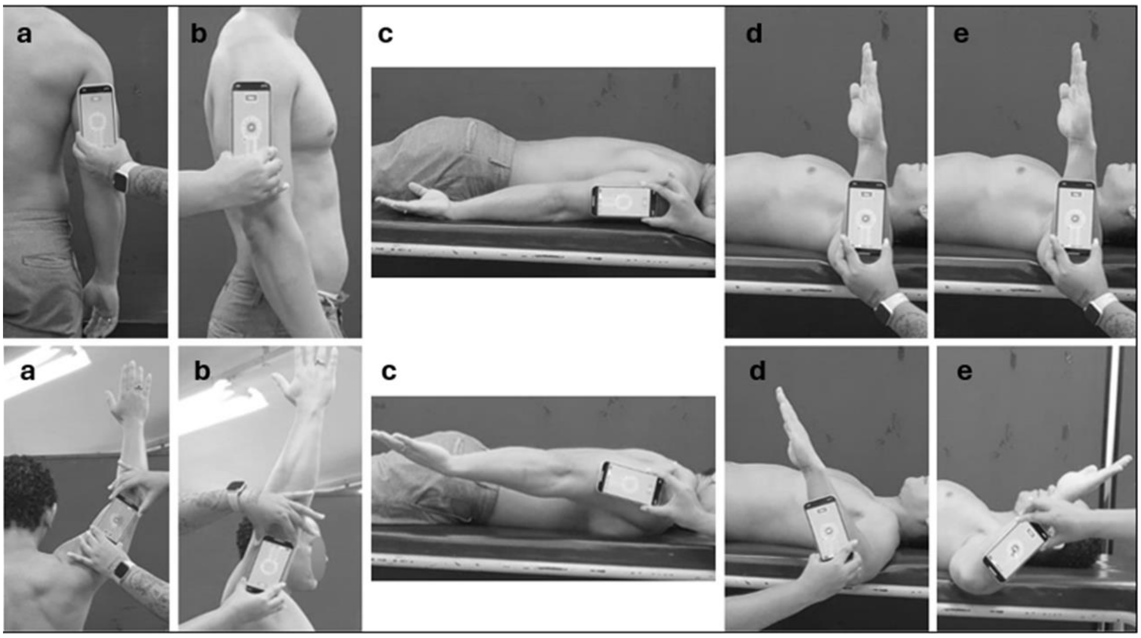

Figure 1. The final positions are examples since they will depend on each tested athlete.

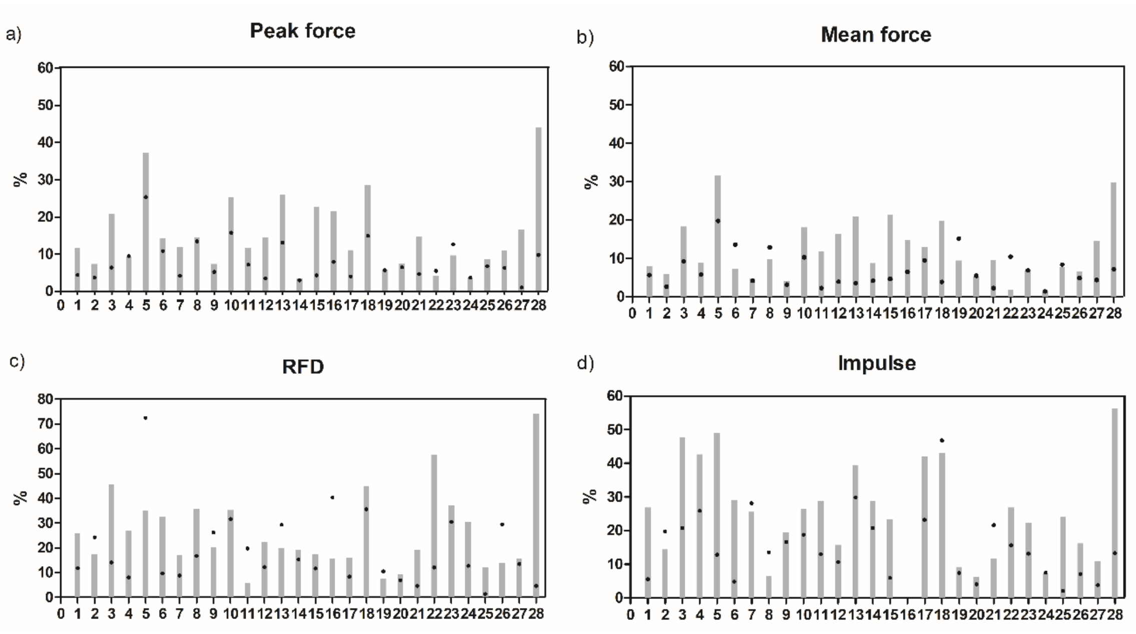

Figure 2. The grey bars are the asymmetries of each participant, while the black dots are the variable CV for each participant. Note 2: If a grey bar (asymmetry) has a higher % than a black dot (variable CV), then the asymmetry is considered real.

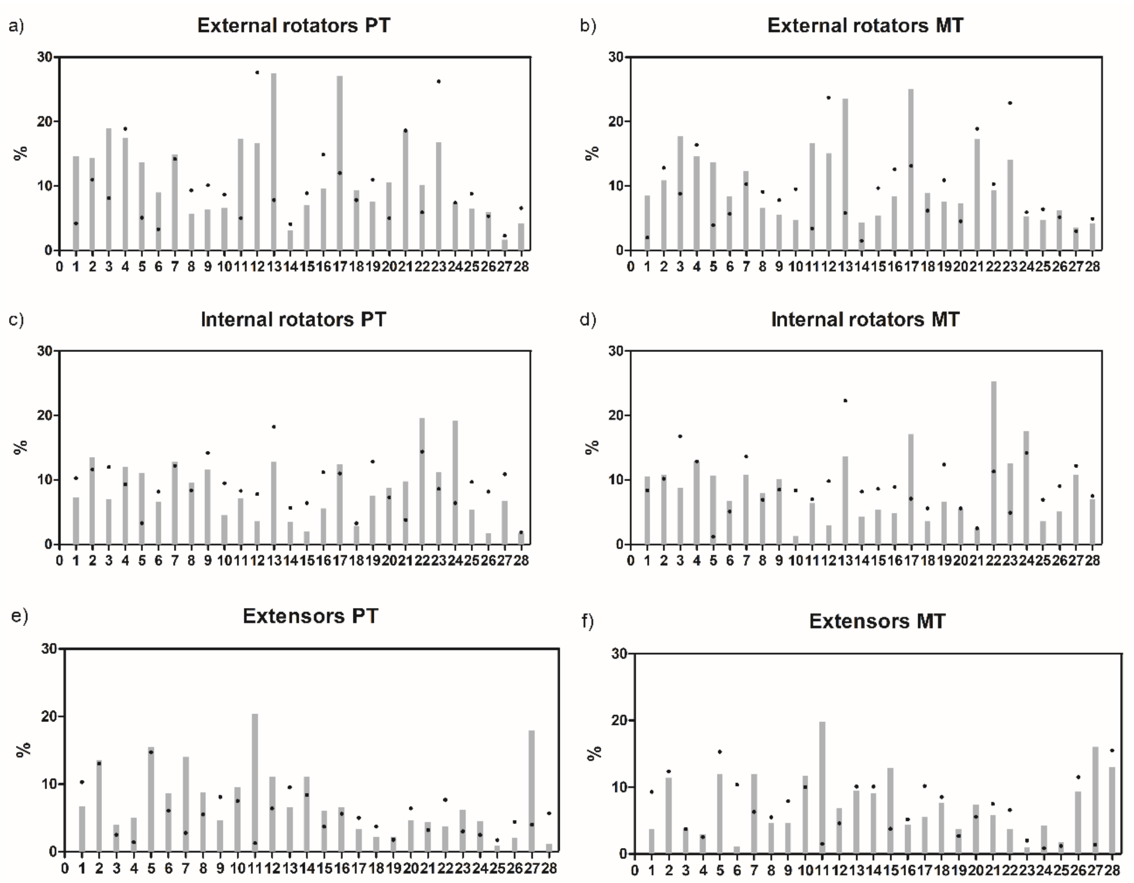

Figure 3. The grey bars are the asymmetries of each participant, while the black dots are the variable CV for each participant. Note 2: If a grey bar (asymmetry) has a higher % than a black dot (variable CV), then the asymmetry is considered real.

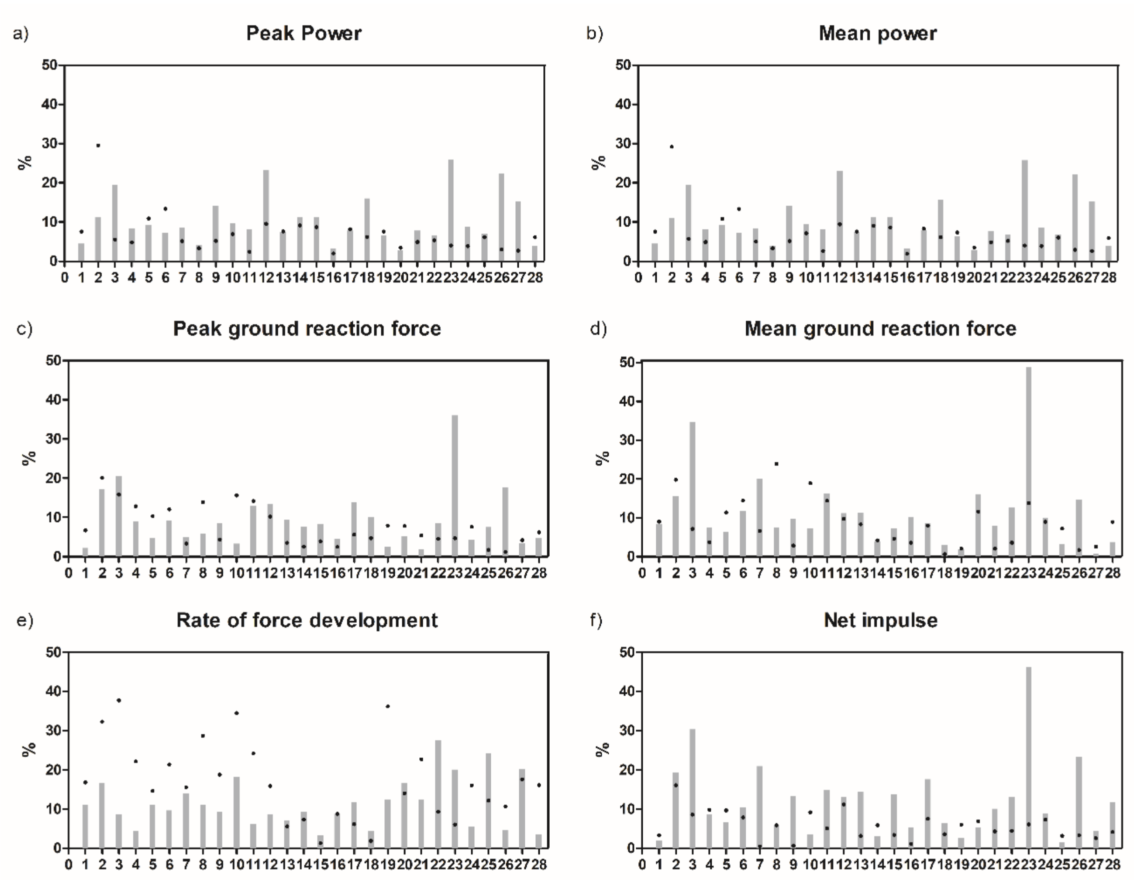

Figure 4. The grey bars are the asymmetries of each participant, while the black dots are the variable CV for each participant. Note 2: If a grey bar (asymmetry) has a higher % than a black dot (variable CV), then the asymmetry is considered real.

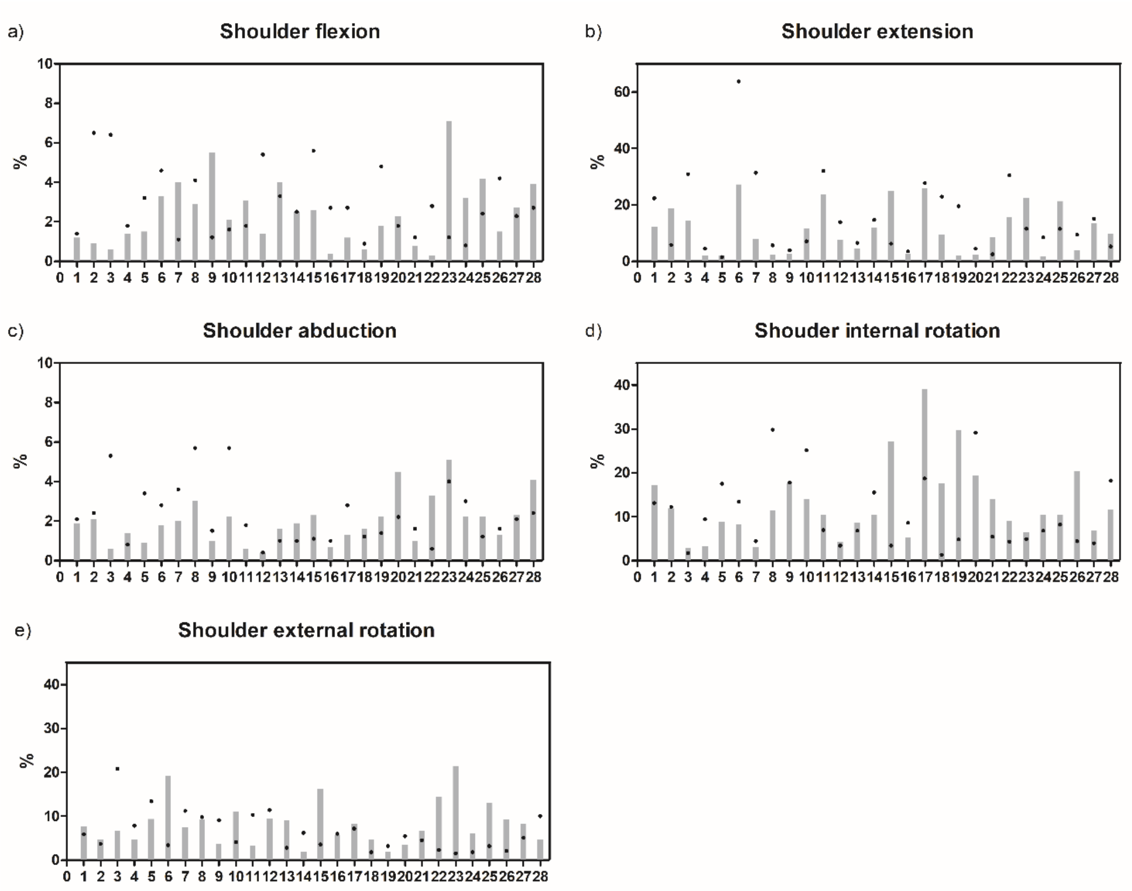

Figure 5. The grey bars are the asymmetries of each participant, while the black dots are the variable CV for each participant. Note 2: If a grey bar (asymmetry) has a higher % than a black dot (variable CV), then the asymmetry is considered real.

Figure captions

Figure 1. Initial (top line) and final (bottom line) positions of the shoulder abduction (a), flexion (b), extension (c), internal rotation (d) and external rotation (e) ROM measurements.

Figure 2. Between-session individual asymmetry (grey bars) and coefficient of variation (black dots) values of the swimming test variables.

Figure 3. Between-session individual asymmetry (grey bars) and coefficient of variation (black dots) values of the shoulder torque test variables.

Figure 4. Between-session individual asymmetry (grey bars) and coefficient of variation (black dots) values of the countermovement jump test variables.

Figure 5. Between-session individual asymmetry (grey bars) and coefficient of variation (black dots) values of the range of motion test variables.