Propulsive force symmetry generated during butterfly swimming

Simetria da força propulsiva gerada pelas mãos durante o nado borboleta

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Abstract – The aim of the study was to analyze the hand force symmetry in butterfly swimming. Fourteen male and female swimmers (18.4 ± 4.9 years old, 71.8 ± 14.6 kg of body mass, 1.78 ± 0.09 m of height and mean performance that corresponds to 74.9 ± 5.8% of the world record). Subjects performed three trials of 25 m of butterfly swimming at maximal speed. Mean and maximum forces were estimated for each hand using pressure sensors of the Aquanex System (Swimming Technology Research, USA). The comparisons between force values for dominant and non-dominant hands were made through Student's T test for dependent samples (p<0.05). In addition, the symmetry Index (SI) was calculated as a relative measure of the force applied by each hand. The mean and maximum force for the dominant hand corresponded, respectively, to 55.7 ± 14.7 N and 114.7 ± 39.6 N. For the non-dominant hand, values were 51.2 ± 14.7 N for mean force and 110.7 ± 36.7 N for maximum force. Significant differences were found between dominant and non-dominant hands for both variables (p<0.01). The symmetry index analysis showed mean values of 8.9% for mean force and of 12.6% for maximum force, and most swimmers presented values higher than 10% for mean and/or maximum forces. Further studies should be performed in order to investigate the relationship between hand force symmetry and swimming performance.

Key words: Arm; Functional laterality; Swimming.

Resumo – *O objetivo do estudo foi analisar a simetria da força dos membros superiores durante a braçada do nado borboleta. Quatorze nadadores de ambos os sexos (18,4 ± 4,9 anos, massa de 71,8 ± 14,6 kg, estatura de 1,78 ± 0,09 m e com média de desempenho correspondente a 74,9 ± 5,8% do recorde mundial) realizaram três execuções de 25 m máximas nadando borboleta. A força média e a força máxima de cada mão foram estimadas através de sensores de pressão do Sistema Aquanex (Swimming Technology Research, EUA). Comparações entre a força produzida pelos lados dominante e não dominante foram realizadas através do teste t de Student para amostras dependentes (p<0,05). Adicionalmente, foi calculado o índice de simetria como uma medida relativa da força aplicada em cada mão. A força média e a força máxima da mão dominante corresponderam, respectivamente, a 55,7 ± 14,7 N e 114,7 ± 39,6 N. Para a mão não dominante, os valores foram de 51,2 ± 14,7 N para a força média e 110,7 ± 36,7 N para a força máxima. Foram encontradas diferenças significativas entre a mão dominante e não dominante para ambas as variáveis (p<0,01). A análise do índice de simetria mostrou valores médios de 8,9% para a força média e de 12,6% para a força máxima, sendo que a maioria dos nadadores apresentou valores maiores do que 10%, para a força média e/ou máxima. Acredita-se que análises futuras devam ser feitas, buscando relações da assimetria com o desempenho de nado.*

Palavras-chave: *Braços; Lateralidade funcional; Natação.*

INTRODUCTION

The goal of competitive swimming is to swim the full distance of a race according to the rules in the shortest possible time[1]. The search for higher speed has led coaches, researchers and athletes to improve, among other things, the swimming technique.

The assessment of biomechanical indicators is an important resource in the search for better results. Studies using such analyses in butterfly swimming deal with factors such as coordination of the movement of arms with legs[2,3], torque characteristics of the propulsive phase of the stroke[4], variations of biomechanical and/or bioenergetic characteristics at different speeds[4-6] and influence of breathing on swimming-related characteristics[7,8].

In the correct technique of butterfly swimming, the swimmer remains in prone position, the more horizontal as possible, and performs the stroke with arms simultaneously[1,9], and the stroke is the movement that most contributes to propulsion[10]; thus analyzing and correcting this movement should be prioritized in training. The hand movement should be symmetrical, thus avoiding any rotation in the anterior-posterior axis of the body, preventing body misalignment and consequently loss of ideal position for swimming[11].

Stroke asymmetry can be compromising for the swimming performance and its origin can be related to several factors related to the physical characteristics of the swimmer and training[12]. Sanders et al.[13] report that asymmetries in the application of propulsive force could cause unwanted body rotations, affecting hydrodynamic position and increasing the drag force and consequently reducing the swimming efficiency. In addition to the reduction of swimming efficiency, asymmetry of force production in stroke could cause the swimmer to perform arm movements in different paths by the water, thus recruiting different muscles so that the distance traveled by the swimmer is kept as aligned as possible[13]. This compensation, in turn, coupled with high repetition movement and training overload can cause undesired organic adaptation, causing muscle imbalance and increasing the prevalence of lesions[14].

Analysis of the force production symmetry in stroke has been investigated for crawl swimming, considering aspects such as the technical level of swimmers and the breathing technique[15-18]. These studies have used the method of tethered swimming, which impairs the analysis of symmetry in the case of swimming whose stroke is simultaneous. As an alternative to the traditional method for evaluating propulsive forces, an instrument that measures force produced during the stroke from pressure difference between the back and the palm has been used to measure the force applied on each of the hands independently[19]. Given the above context, this study aimed to analyze the symmetry of the force applied by hands during the stroke in butterfly swimming.

METHODOLOGICAL PROCEDURES

Subject

Study participants were fourteen swimmers, five women and nine men (18.4 ± 4.9 years of age, 71.8 ± 14.6 kg of body weight and 1.78 ± 0.09 m in height), specialists in butterfly or medley swimming (performance corresponding to 74.9 ± 5.8% of the world record in the 50 m butterflyrace), belonging to swim teams of Florianópolis, Brazil. All kindly agreed to voluntarily participate in the research by signing the Informed Consent Form; in the case of underage swimmers, consent was given by parents / guardians. The study procedures were approved by the Ethics Committee for Research Involving Human Beings of the Santa Catarina State University (No. 29/06). Participants met the following inclusion criteria: (1) have participated for at least two years of competitive training sessions; and (2) have regularly participated in 50 m butterfly race competitions in the year of the research performance. Involvement of any musculoskeletal injury was adopted as exclusion criterion.

Instruments

Anthropometric measurements (weight and height) were obtained using a digital scale (TechLine, BAL- model 150 PA) and a stadiometer with resolution of 0.01 m (WISO). Stroke force was measure using Aquanex data acquisition equipment (Swimming Technology Research, USA) composed of two independent pressure sensors, which are positioned between phalanges of middle and ring fingers of both hands of swimmers (Figure 1). Sensors that estimate force on the swimmer's hand were connected to an A / D converter connected to a laptop computer with the AQUANEX 4.1 data collection software (Swimming Technology Research, USA). The measurement error of the system is 0.2%[20]. Acquisition rate of 100 Hz was used to collect data.
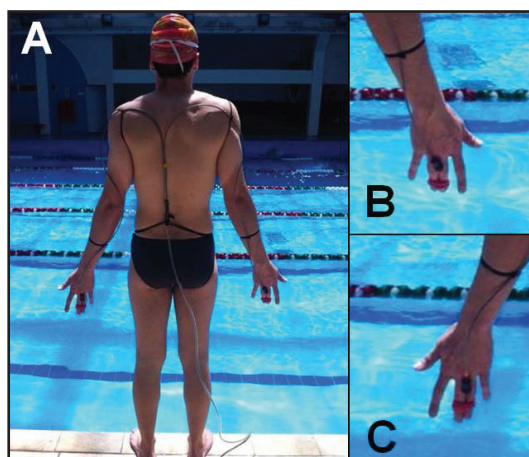

Figure 1. Photo of a research participant prepared for data collection (A). In detail, the positioning of the pressure sensor in the right hand (B) and left hand (C).

Data Collection

Samples were collected in a heated pool (28°C) with 25 m in length. Swimmers were evaluated at the scheduled day and time, wearing appropriate clothing for practice. After verification of anthropometric data, participant was taken to the swimming pool to perform a 10-minute warm-up exercise proposed by the athlete's coach, simulating warm-upper formed in competition. Then, the pressure sensors were placed in the fingers of the participant's hands and a period for familiarization with the equipment was respected. After the preparatory phase, each subject performed three repetitions of 25 m of butterfly swimming at full speed, with free exit from water. Both breathing and underwater ripple were not controlled.

At the beginning of each repetition, just before the beginning of exercise itself, the participant was asked to keep his hands horizontally immersed at the waistline for 10 seconds in order to reset the system with the hydrostatic pressure values. A passive recovery period of at least five minutes was respected between each repetition. The distance of 25 m was chosen to analyze the force used by the subject without any effect of fatigue or loss of efficiency.

Data Analysis and Processing

Force curves, acquired by the Aquanex system, were exported in *.txt format and analyzed through a processing routine in Matlab 7.1 environment (Mathworks Inc., USA). Initially, curves were smoothed using a low-pass 3rd order Butterworth digital filter with 10 Hz cutoff frequency. Then, six intermediate curves (corresponding to six stroke cycles) were manually selected, discarding the first two and the last two cycles in order to reduce the effect of initial acceleration after start and fatigue at the end of exercise. The beginning of the propulsive phase was determined when the curve began its ascending phase. In each of the curves, the following variables were recorded:

- Mean Force (F_{mean}): mean value of the force applied during the propulsive phase of each stroke cycle, expressed in Newton (N);
- Maximum force (F_{max}): highest value of force applied during the propulsive phase of each stroke cycle, expressed in Newton (N).

Based on the above variables, the following variable was calculated:

- Symmetry Index (SI%) proposed by Robinson et al.[21] for analysis of gait in individuals with lesions in the lower limbs and assesses difference between body sides, given from the equation below:

$$SI(\%) = \frac{X_d - X_{nd}}{\frac{1}{2}(X_d + X_{nd})} \times 100$$

Where Xd is the force produced by the dominant hand, which was considered hand that produced the highest Maximum Force value and Xnd is the force produced by the non-dominant hand, defined as the hand that generated the lowest Maximum Force, thus a positive value of this index indicates greater force produced by the dominant hand, while a negative value shows greater force produced by the non-dominant side of the swimmer.

The individual values of each subject for each of the variables were acquired from the mean value of cycles analyzed of three runs, totaling 18 cycles analyzed for each swimmer.

Based on individual data, a spreadsheet was used to calculate the mean values and standard deviation of each variable. Data normality was confirmed by the Shapiro-Wilk test. Student's t test for dependent samples was used in order to compare the means of variables between hands. All procedures were performed using the SPSS 20.0 software (IBM Inc., USA) with confidence level of 95% (p <0.05).

RESULTS

Figure 2 is an example of the force curve during 25 m butterfly swimming performed by one of the study participants.
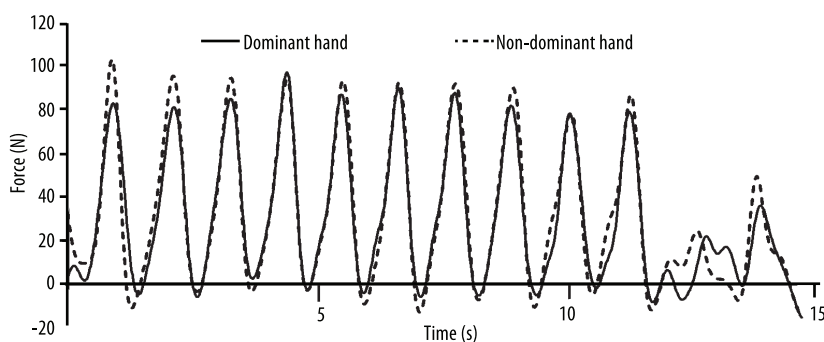

Figure 2. Force versus time curve generated by dominant hand (solid line) and non-dominant (dashed line) of one of the study participants during a 25 m repetition.

Table 1 shows the mean values and standard deviations for variables F_{mean}, F_{max}, and SI (%) and p-value obtained by the Student t test for comparison between dominant and non-dominant hand.

Table 1. Mean and standard deviation of the mean force (F_{mean}) and maximum force (F_{max}) for dominant and non-dominant hand, symmetry index (SI%) and p-value obtained from the Student t test for dependent samples.

Variables	Dominant hand	Non-dominant hand	SI%	p-value
F_{mean} (N)	55.7 ± 14.7	51.2 ± 14.7	8.9 ± 9.7	<0.01
F_{max} (N)	124.8 ± 39.6	110.7 ± 36.7	12.6 ± 10.1	<0.01

Statistically significant differences were found between dominant and non-dominant hands both for mean force and maximum force. Analyzing data individually, it is possible to observe that in some cases, asymmetries found were greater than 30% (Table 2).

The repeatability of data using the Aquanex system was previously analyzed by Havriluk[19] for competitive swimmers, analyzing two runs of 15 m in crawl swimming, and can be considered high (intraclass correlation coefficient of 0.915). In this study, the intraclass correlation coefficient values calculated are also considered high, and correspond to 0.991 for F_{max} of the dominant hand, 0.981 for F_{max} of the non-dominant hand, 0.964 for F_{mean} of the dominant hand; and 0.969 for F_{mean} of the non-dominant hand.

Table 2. Mean and standard deviation of mean force (F$_{mean}$) and maximum force (F$_{max}$) for each swimmer and percentage difference between dominant and non-dominant hands

	F$_{mean}$			F$_{max}$		
	Dominant hand	Non-dominant hand	SI(%)	Dominant hand	Non-dominant hand	SI(%)
1	51.5 ± **2**.9	43.3 ± **2**.6	17.3	107.9 ± 7.1	94.0 ± 6.4	13.8
2	39.1 ± 2.7	33.9 ± 3.4	14.2	75.1 ± 6.0	60.4 ± 5.9	21.7
3	60.3 ± 5.2	58.± 5.2	3.7	135.2 ± 8.8	133.2 ± 9.3	1.6
4	43.0 ± 3.9	41.8 ± 3.0	2.8	94.4 ± 6.3	84.8 ± 7.1	10.7
5	37.1 ± 4.3	37.4 ± 5.6	-0.8	90.3 ± 8.7	86.3 ± 11.5	4.5
6	44.4 ± 6.3	45.5 ± 7.9	-2.5	98.83 ± 9.9	94.3 ± 6.7	4.7
7	74.6 ± **9**.0	75.1 ± **5**.7	-0.6	155.2 ± **23**.2	152.1 ± **18**.2	2.0
8	80.6 ± 8.8	69.0 ± 5.0	15.5	174.9 ± 20.2	151.8 ± 8.6	14.1
9	63.3 ± **3**.2	60.7 ± 3.8	4.2	137.5 ± 10.7	123.8 ± **9**.5	10.5
10	50 ± 6.6	46.4 ± 6.6	7.5	92.0 ± 11.0	88.3 ± 11.0	4.1
11	55.7 ± 11.6	39.9 ± 10.3	33.1	120 ± 13.9	86.3 ± 13.7	32.7
12	80.3 ± 8.0	76.9 ± 5.1	4.4	223.5 ± 15.4	193.7 ± 25.1	14.3
13	55.2 ± 6.6	55.2 ± 6.9	0.2	132.3 ± 19.7	121.0 ± 16.6	8.9
14	42.4 ± 7.9	34.8 ± 5.2	19.6	109.4 ± 6.3	79.1 ± 13.5	32.1

DISCUSSION

This study aimed to compare the force applied by hands in relation to the dominance of swimmers while performing 25 meters of butterfly swimming at full speed. Considering the results, it was observed that the mean values obtained showed significant differences between dominant and non-dominant sides. In individual analysis, asymmetry values of up to 33.1% between sides were found.

Using a force analysis system based on the pressure exerted by water on the palm similar to the present study, Kudo et al.[22] found higher mean force values generated by hands. The instrument used by the authors was synchronized to a camera that allowed the analysis of forces at different stroke phases (insweep and upsweep), excluding the support phase. The replication of this situation was not possible in this study, since analyses were performed using only force curves.

Studies involving force symmetry in crawl swimming demonstrate a tendency to asymmetry of limbs. Dos Santos et al.[17] analyzed maximum execution lasting two minutes in tethered swimming without the use of propulsion legs. The authors found significant differences between forces produced by arms at all times of execution. Morouço et al.[18], analyzed force performed by the upper limbs using tethered crawl swimming and found differences between right and left sides for maximum force produced during the first 19 strokes during a 30-secondexecution.

Significant differences were found between mean and maximum force applied by the hands. Due to the large inter-subject variability (Table 1), this result needs to be interpreted with caution, since the mean values of

the study group can hide individual aspects. Thus, individual analysis of data was more appropriate to observe asymmetry in subjects.

In the individual analysis (Table 2), it was observed that mean and maximum forcevalues produced during cycles for each subject varied considerably. The lowest mean difference for F_{mean} was presented by subject 13 (0.2%); however, the same subject presented slightly larger difference for F_{max} (8.9%). For some swimmers, the difference in forces applied by both hands is considerable and close to 30% for F_{mean} and F_{max} (subject 11).

When it comes to threshold values shown in literature for asymmetries, Robinson et al.[21] reported for gait analysis value of 10%, using SI (%). The same index is also used in studies on swimming aiming at the analysis of coordination, in force applied to the swimming ergometer and tethered swimming[15,18,23,24]. In this study, eight of the 14 swimmers analyzed showed asymmetry values above 10% for F_{mean} and / or F_{max}, which demonstrates the importance of individual analysis for the identification of force asymmetries during butterfly swimming.

Sanders[13] presents three adverse effects in relation to imbalance in the production of forces between both sides of the body during swimming: (1) the production of undue rotations that can be detrimental to the technique and increase drag; (2) the loss of swimming efficiency, since one of the upper limbs produces less force than it could; and (3) the onset of muscle fatigue in the limb that produces more force, thus reducing the propulsive efficiency of the stroke and restricting the swimmer's ability to better remain aligned with the water.

This study was pioneer in analyzing the symmetry of swimmers using the Aquanex data acquisition system. It was decided to use this system for two reasons: (1) the possibility of measuring arm force values separately, as tethered swimming does not allow this situation for simultaneous swimming, since it analyzes forces from the tension generated in the cable holding the swimmer; and (2) it is believed that the system interferes in the swimming mechanics compared to tethered swimming, since it enables the swimmer to move in the water. On the other hand, knowing the importance of hand positioning during propulsive phase of the stroke[25], the placement of sensors may have influenced the efficiency of strokes. There is also recognition that this is an initial exploratory study, which has limitations such as the small number of subjects, the fact of breath (type and occurrence) and the submerged phase of swimmers were not controlled and the high sample variability. Future studies should be carried out to analyze the force symmetry considering other ways for determining dominant hand, for example, the preferential breathing side in crawl swimming or the analysis of the highest concentric unilateral force held in isokinetic device. Such approaches could also help understanding the possible causes of asymmetries observed during stroke in butterfly swimming. In addition, the relationship of SI values with some indicator of swimming performance should be investigated to obtain greater understanding of the real effect of asymmetry on the swimmer's performance

CONCLUSION

This study has allowed, from the analysis of the stroke kinetics in butterfly swimming, observing that the sample showed different values of force applied by the dominant and non-dominant hands for variables maximum force and mean force. Most swimmers analyzed showed asymmetry higher than 10% and some reached values close to 30%. Future analyses should investigate the relationship between asymmetry values and performance and with the possible occurrence of lesions, also analyzing and comparing swimmers of different performance levels.

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