Understanding Differences in Swimming Velocity and Propulsive Force in the Butterfly Stroke: A Comparison Between Male and Female Butterfly Swimmers Through Discrete and Continuous Variables

Mafalda P. Pinto,[1,2] Henrique P. Neiva,[1,2] Tatiana Sampaio,[1,2,3] João P. Oliveira,[1,2,3] Tiago M. Barbosa,[4,3] Daniel A. Marinho,[1,2] and Jorge E. Morais[4,3]

[1]Department of Sport Sciences, University of Beira Interior, Covilhã, Portugal; [2]Research Center in Sports, Health and Human Development (CIDESD), Covilhã, Portugal; [3]Research Centre for Active Living and Wellbeing (LiveWell), Instituto Politécnico de Bragança, Bragança, Portugal; and [4]Department of Sport Sciences, Instituto Politécnico de Bragança, Bragança, Portugal

Abstract

Pinto, MP, Neiva, HP, Sampaio, T, Oliveira, JP, Barbosa, TM, Marinho, DA, and Morais, JE. Understanding differences in swimming velocity and propulsive force in the butterfly stroke: A comparison between male and female butterfly swimmers through discrete and continuous variables. *J Strength Cond Res* XX(X): 000–000, 2026—The aim of this study was to verify differences in swimming velocity and propulsive force (PF) between male and female swimmers in the butterfly stroke based on discrete variables and Statistical Parametric Mapping (SPM—continuous variables). The sample comprised 20 young national-level swimmers (10 boys with 17.9 ± 1.2 years and 10 girls with 15.5 ± 1.4 years). Swimming velocity, intracyclic variation of swimming velocity, stroke frequency, stroke length, stroke index, and PF were measured as discrete variables. Swimming velocity and PF were also measured as continuous variables with SPM. As a discrete variable, swimming velocity presented significant differences between sexes with very large effect sizes ($p < 0.001$, $d = 2.46$). The average PF also presented significant differences between sexes with very large effect sizes ($p < 0.001$, $d = 2.01$). Male swimmers were faster and generated greater PF than female swimmers. As for SPM, velocity presented significant differences between sexes ($t = 3.355$, $p < 0.001$) between ~31 and ~56% of the stroke cycle. This corresponds mainly to the end of the pull and most of the push phase. PF followed the same trend, with differences in the same phase of the time series. SPM allowed for identification where, within the stroke cycle, differences between sexes occurred in velocity and PF. Being in the same phase of the time series highlights the existing velocity–PF relationship. SPM can allow researchers and coaches to pinpoint the exact moments within the stroke cycle where differences between swimmers may occur.

Key Words: swimming, biomechanics, statistical parametric mapping, propulsive force, butterfly

Introduction

As a time-based sport, competitive swimming places a premium on precise quantification of performance, because marginal differences in time often determine rankings. Swimming performance depends on complex interactions among several scientific areas, including biomechanics, physiology, motor control, and others (10,11). Beyond final race times, a comprehensive evaluation requires measuring and interpreting specific variables that underpin performance. At least in young and young adult swimmers, biomechanical factors (particularly those related to swimming technique) are considered to present a meaningful contribution to final performance (32,43).

In biomechanics, kinematics and kinetics are major determinants of performance because they are strongly associated with swimming technique (23). Considering kinematics, these include stroke length (SL), stroke frequency (SF), stroke index (SI), and intracyclic velocity variations (the latter 2 of which can also be considered proxies for swim efficiency) (8). As for kinetics, variables related to drag (water resistance) are often measured and used for further analysis (1,39). However, measuring propulsive force (PF) in swimming remains an ongoing topic, particularly through experimental methods (13). In the past, tethered swimming was used as an indirect method to estimate the swimmers' PF (27,38). However, several constraints were raised about this method, for instance, the absence of displacement could induce changes in the swimmer's stroke pattern, creating mechanical constraints (33). Nowadays, with the technological development of wearables (cabling or wireless devices), there is equipment that measures the PF exerted by the swimmer (13,26). Based on experimental methods, it was demonstrated that swimming velocity is positively and significantly associated with PF. That is, swimmers who generate the greatest values of PF are more likely to achieve the fastest velocities (15,37). However, most of these findings relate to the front crawl swimming stroke. Thus, the literature lacks information on this topic for the remaining swim strokes, including the butterfly stroke.

Most research on swimming performance treats velocity, or other time-curve data, as an average value. That is, without

Address correspondence to Jorge E. Morais, morais.jorgestrela@ipb.pt.

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a time dimension (0–D, discrete variables obtained from averaged values across the stroke cycle). In experimental studies, even when instantaneous velocity is measured, authors often report the average across the entire stroke cycle(s) (3,41). This approach yields information solely about the swimming velocity across a full stroke cycle or as an average for multiple cycles. Thus, information within the stroke cycle might be neglected. Being a periodically accelerated motion, swimming velocity presents intracyclic horizontal variations (6). Using swimming velocity as a discrete variable (0–D) will give only an overall perspective of the entire stroke cycle, disregarding the complexity of the swimming velocity pattern (2). In contrast, 1-D time-based analysis (where variables represent continuous time-series data across the stroke cycle) has proven advantageous, because it delivers more precise and sensitive information when continuous time series are considered (30). Statistical Parametric Mapping (SPM) is a statistical method that exploits random field theory. This performs topological inference by directly mapping the conventional Gaussian distribution to smooth n-dimensional data (measurements defined over points in an n-dimensional domain (e.g., time, space, or space–time), where each location is associated with a random variable) (30). SPM offers significant advantages for researchers by preserving the original time series. This is used in sports sciences in general (3) and swimming specifically, but mostly for the front crawl stroke (25,37). Consequently, the literature lacks information on the use of SPM and the insights it offers into the butterfly stroke (7,19). In addition, even less information is available about PF in the butterfly stroke using SPM (36,37). Thus, the use of SPM in the analysis of PF in swimming can provide a robust framework for detecting time-dependent variations across the stroke cycle. This enables a more comprehensive characterization of force production than traditional discrete measures. This approach becomes even more critical when analyzing both swimming velocity and PF concurrently, because these variables are inherently interdependent yet may vary dynamically throughout the stroke cycle. By applying SPM to both signals simultaneously, researchers can identify specific temporal regions within the stroke cycle where changes in PF directly translate into changes in swimming velocity.

Therefore, the main aim of this study was to examine sex-related differences in swimming velocity and PF in butterfly swimmers using both discrete variables and SPM. Rather than merely confirming overall performance differences, this study sought to identify where within the stroke cycle male swimmers and female swimmers differ. Based on discrete analysis, it was expected that male swimmers would exhibit higher or better values for selected discrete performance and stroke kinematics variables than female swimmers. As for SPM analysis, it was hypothesized that this would reveal phase-specific differences in velocity and PF across the stroke cycle, providing insights not detectable through traditional discrete analysis.

Methods

Experimental Approach to the Problem

This study investigated sex-related differences in swimming velocity and PF during the butterfly stroke. Rather than using discrete variables only, this aimed to identify where these differences occurred across the stroke cycle by specifically identifying their temporal locations through continuous analyses (SPM). It was also possible to examine whether differences in velocity and PF occurred within the same phase(s) of the stroke cycle. For this purpose, a sex comparison was done. Notwithstanding, this also allowed for a competitive level comparison as male swimmers were significantly faster than their female counterparts.

Regarding the in-water tests, the swimmers underwent previous familiarization sessions with the equipment used in a 25 m indoor swimming pool. Before the in-water data collection, the swimmers completed a warm-up session designed for sprint performance (29). Afterward, they were randomly instructed to perform 3 all-out trials in the butterfly stroke. To define the stroke cycles, the upper limbs' actions were used. These were expanded as follows: (a) hand entry and catch—this is the time between when the hands enter the water and when they begin moving backward, (b) pull—this is the time between when the hands begin moving backward and when they reach the vertical line of the shoulders, (c) push—this is the time between when the hands are positioned below the shoulders and when they exit the water, and (d) recovery—this is the time between the exit of the hands from the water and their following entry into the water (4). For the swimming velocity measurement, a stroke cycle was defined as the time interval between successive hand entries. For the PF measurement, the arm pulls (i.e., time gap between hands' entry and exit) were considered.

A set of variables related to kinematics and kinetics was measured. For ease of data processing or because of statistical limitations, researchers frequently rely on average values (i.e., without a time dimension; 0–D) by comprising multiple consecutive stroke cycles (41). However, such discrete measures, such as average swimming velocity, may lack the detail needed to fully capture individual differences among swimmers. However, continuous analysis (with a time dimension; 1–D), such as SPM, offers a clear advantage by preserving the integrity and sensitivity of time-series data, enabling a more comprehensive understanding of events across the entire time series (31). Thus, swimming velocity and PF (the main dependent variables) were measured as discrete and continuous variables. The remaining variables were measured only as discrete values.

Subjects

The sample comprised 20 young swimmers (10 boys: 17.9 ± 1.2 years, 77.0 ± 9.6 kg of body mass, 184.5 ± 8.7 cm of height, 187.4 ± 7.2 cm of arm span, 592.2 ± 62.7 World Aquatic Points in the 50 m butterfly event; 10 girls: 15.5 ± 1.4 years, 60.6 ± 6.3 kg of body mass, 169.3 ± 7.1 cm of height, 171.4 ± 6.6 cm of arm span, 489.2 ± 62.6 World Aquatic Points in the 50 m butterfly event). These swimmers regularly competed at regional and national events, and were under the supervision of the national team staff—Tiers 2 and 3 athletes (21). The swimmers followed a training regimen of 6 to 9 sessions per week, typically completing 1 water-based session per day, with additional double sessions on some days. They also performed complementary strength and conditioning training between 2 to 3 times per week. This strength and conditioning training was monitored by a certified coach. As inclusion criteria, they had to be butterfly experts, free of injuries, and have been training regularly for the past 6 months. Coaches and/or parents and the swimmers gave their consent/assent to participate in this study. All human research procedures were conducted in accordance with the Helsinki Declaration. The Polytechnic Ethics Committee approved the study design (P547664-R678573-D2082555).

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Procedures

An expert evaluator collected anthropometric data on the swimmers' demographics before in-water testing. As for the in-water testing, each swimmer performed 3 maximal-effort 25 m butterfly trials with a wall push-off start. A 30-minute rest period was provided between trials to ensure full recovery. The fastest trial, determined by the fastest swimming velocity, was selected for analysis. Three consecutive stroke cycles were measured and analyzed between the 10th and 20th meters. The average of the 3 was used for further evaluation. Between such markers, swimmers were instructed to perform stroke cycles while holding their breath to minimize disruptions in stroke coordination or technique that might influence swimming velocity (20). The swimming velocity, intracyclic variation of swimming velocity (dv), SF, SL, SI, PF, and intracyclic variation of propulsive force (dF) were used for analysis.

Swimming velocity (in m/s) was measured with a speedometer (SpeedRT, ApLab, Rome, Italy). The device recorded displacement and velocity data at a sampling frequency of 100 Hz. The velocity–time data series were thereafter imported into signal processing software (AcqKnowledge v. 3.9.0, Biopac Systems, Santa Barbara, CA). After residual analysis, the signal was processed using a fourth-order Butterworth low-pass filter with a cutoff frequency of 5 Hz. A video camera (GoPro Hero Black 7, GoPro, San Mateo, CA) was positioned at a fixed location along the mid-section of the swimming pool (between the 10th and 20th meter) to identify the stroke cycles. This was synchronized with the speedometer to capture video recordings of the swimmers in the sagittal plane, identifying the swimmers' hand entry to set the beginning and end of the stroke cycle. The video camera and the speedometer were synchronized using a luminous signal visible in the camera's field of view, which was simultaneously recorded by the acquisition system. The dv (in %) was calculated as the coefficient of variation (CV = SD/mean × 100). The SF (in Hz) was calculated as the number of cycles per unit of time from the time taken to complete a full cycle (f = 1/P; where P is the period), then converted to Hz. The SL (in m) was calculated as the ratio between swimming velocity and SF. The SI (in m^2/s) was calculated as the product of swimming velocity and SL.

Propulsive force (in N) of the arm pulls was measured using a set of wearable paddles (Pool Shark, Tampere, Finland) (16). Afterward, the dF (in %) was calculated as the coefficient of variation (CV = standard deviation/mean × 100). These paddles are a system that includes 3 primary components: the wearable sensors, the PoolShark Session Manager mobile app for data acquisition, and the Analysis Center (https://sharksensors.com/), which handles data storage and postprocessing. The wearable units are affixed to the swimmer's hands with silicone straps. They feature 2 pressure sensors to measure water-applied force and a 9-axis inertial measurement unit to monitor motion, all sampled at 100 Hz. The session manager serves as a bridge between the wearables and a mobile device, enabling both data collection and transmission to the analysis center. Once the data are uploaded, they are processed within the analysis center, which provides visual performance feedback. Users can also export the processed data for external analysis. The underlying algorithm responsible for data processing is proprietary and implemented within a closed MATLAB-based graphical user interface. This means that the raw data and internal constants used in the calculations are not accessible for common user modification. This system has demonstrated excellent consistency and agreement with other validated in-water force measurement tools referenced in existing research (18) and with a strain-gauge system (tethered or semitethered procedures with load cells) used to measure force in water (16). The PF of the right (PF_R) and left (PF_L) upper limbs and the intracyclic variation of the PF (dF_R and dF_R) were analyzed. Afterward, the average PF and dF of both upper limbs were calculated (PF_{AV} and dF_{AV}).

Statistical Analysis

For discrete analysis, data distribution and homoscedasticity were analyzed with the Shapiro–Wilk and Levene tests, respectively. The mean plus 1 SD was calculated as descriptive statistics. An independent samples t test was used to compare all kinematic variables as discrete variables ($\alpha = 0.05$). Cohen's d was used to estimate the standardized effect sizes between pairs: (a) trivial if $0 \le d < 0.20$, (b) small if $0.20 \le d < 0.60$, (c) moderate if $0.60 \le d < 1.20$, (d) large if $1.20 \le d < 2.00$, (e) very large if $2.00 \le d < 4.00$, (f) nearly distinct if $d \ge 4.00$ (12). A 2-way ANOVA ("sex" effect, "side" effect, and respective interaction) was used to understand the PF's and dF's variance. The eta square (η^2) was used as an effect size index interpreted as (a) without effect if $0 < \eta^2 \le 0.04$, (b) minimum if $0.04 < \eta^2 \le 0.25$, (c) moderate if $0.25 < \eta^2 \le 0.64$, and (e) strong if $\eta^2 > 0.64$ (5). These statistical analyses were performed with SPSS software (Version 26, IBM, Chicago, IL). An SPM 2-tailed independent sample t test was used to compare the swimming velocity as a continuous variable between groups, and a 2-way ANOVA ("sex" effect, "side" effect, and respective interaction) for the PF_{av}. SPM analyses were implemented using the open-source spm1d code (v. M0.1, www.spm1d.org) and performed in MATLAB (v. 2019b, MathWorks, Inc., Natwick, WY). Before these analyses, each stroke cycle was normalized to its duration using R software. Afterward, the average of the 3 consecutive time-normalized stroke cycles for each swimmer was used.

Results

Table 1 presents the descriptive statistics of all variables measured per sex. As a discrete variable, swimming velocity showed significant differences between sexes, with a very large effect size ($p < 0.001$, $d = 2.46$), with male swimmers being faster. Figure 1 (Panel A) depicts the velocity–time curve of both sexes. The SI ($p < 0.001$, $d = 2.36$) and SL ($p = 0.004$, $d = 1.35$) followed the same trend, but the latter one with a larger effect size. The dv and SF showed nonsignificant differences between sexes. Nonetheless, dv was smaller in female swimmers than in male swimmers, and SF was faster in male swimmers than in female swimmers (Table 1). As a discrete variable, PF_{AV} ($p < 0.001$, $d = 2.01$) showed significant differences between sexes, with very large effect sizes: male swimmers were faster and generated greater PF than female swimmers. Figure 1 (Panel B) depicts the PF–time curve of both sexes. The dF_{AV} was also significantly larger in male swimmers than in female swimmers ($p = 0.027$, $d = 0.92$) with a moderate effect size. As for the PF ($F = 31.96$, $p < 0.001$, $\eta^2 = 0.47$) and dF ($F = 4.27$, $p = 0.046$, $\eta^2 = 0.11$) of each upper limb, only a significant "sex" effect was noted with a moderate and minimum effect size, respectively (Table 1). This was noted in the pairwise comparison. A nonsignificant side and sex × side interaction were noted. However, for both upper limbs, male swimmers generated significantly more PF than female swimmers with large effect sizes (right: mean difference = 10.11 N, $p <$

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Table 1

Descriptive statistics (mean ± SD) of all variables measured per sex.

	Mean ± SD		Independent samples *t* test		
	Males	Females	*t* test (*p*)	MD (95% CI)	d [descriptor]
Velocity [m/s]	1.58 ± 0.09	1.35 ± 0.10	−5.50 (<0.001)	−0.24 (−0.33 to −0.15)	2.46 [very large]
dv [%]	23.28 ± 9.52	19.38 ± 10.46	−0.87 (0.197)	−3.90 (−13.30 to 5.50)	0.39 [small]
SF [Hz]	0.96 ± 0.07	0.91 ± 0.09	−1.46 (0.081)	−0.05 (−0.12 to 0.02)	0.65 [moderate]
SL [m]	1.65 ± 0.11	1.48 ± 0.13	−3.02 (0.004)	−0.16 (−0.28 to −0.05)	1.35 [large]
SI [m²/s]	2.61 ± 0.26	2.00 ± 0.26	−5.28 (<0.001)	−0.61 (−0.85 to −0.37)	2.36 [very large]
PF_{AV} [N]	43.41 ± 5.50	32.37 ± 5.49	−4.49 (<0.001)	−11.04 (−16.21 to −5.87)	2.01 [very large]
dF_{AV} [%]	59.10 ± 7.17	53.10 ± 5.74	−2.07 (0.027)	−6.00 (−12.10 to 0.10)	0.92 [moderate]

	Mean ± *SD*		"Sex" effect		"Side" effect		Interaction	
	Males	Females	F-ratio (*p*-value)	η^2	F-ratio (*p*-value)	η^2	F-ratio (*p*-value)	η^2
PF_R [N]	43.07 ± 5.31	32.96 ± 5.53	31.96 (<0.001)	0.47	0.002 (0.969)	0.00	0.161 (0.690)	0.01
PF_L [N]	43.76 ± 7.13	32.11 ± 6.21						
dF_R [%]	61.48 ± 6.92	56.61 ± 7.72	4.27 (0.046)	0.11	0.96 (0.335)	0.03	0.07 (0.787)	0.00
dF_L [%]	59.57 ± 12.19	53.22 ± 6.26						

It also presents the independent-samples *t* test comparisons between sexes and the respective effect sizes, and ANOVA tests for propulsive force (PF) and intracyclic variation of propulsive force (dF).
*dv = intracyclic variation of swimming velocity; SF = stroke frequency; SL = stroke length; SI = stroke index; PF = propulsive force; dF = intracyclic variation of propulsive force. Suffixes: AV = average of both upper limbs; R = right upper limb; L = left upper limb. MD = mean difference; 95% CI = 95% confidence intervals; *d* = Cohen's effect size; η^2 = eta square (effect size).

0.001, $d = 1.86$; left: mean difference = 11.65 N, $p < 0.001$, $d = 1.74$).

SPM results are depicted in Figure 2. Once again, for the swimming velocity, a stroke cycle was considered the consecutive entry of the hand into the water. The in-water phase (i.e., pull and push—propulsion) accounted for 68.7 ± 3.1% and the recovery 31.3 ± 3.1%. Swimming velocity showed significant differences ($t = 3.355$, $p < 0.001$) across ~31% to ~56% of the stroke cycle, corresponding mainly to the end of the pull and most of the push phase (Panel A). As for the PF, a significant "sex" effect was noted ($F = 9.71$, $p < 0.001$) between ~46 and ~81% of the arm pull (Panel B). As with the swimming velocity, these corresponded to the same phases, that is, the end of the pull and most of the push. After rescaling the axis (i.e., synchronizing the x- and *y*-axis of the PF into the swimming velocity output), it is possible to note that the PF and swimming velocity differences mainly overlap. A nonsignificant "side" effect (Panel C) or a sex × side interaction (Panel D) was noted. This indicates that both sexes did not present a significant imbalance in the upper limbs, indicating symmetry.

Discussion

The main aim of this study was to examine sex-related differences in swimming velocity and PF in butterfly swimmers using both discrete variables and SPM. Comparisons between the sexes regarding other discrete variables related to stroke kinematics were also made. As expected, based on discrete variables, male swimmers were faster and generated greater PF than their female counterparts. They also presented the largest SI, SL, and dF. Our hypothesis related to SPM was also confirmed. Unlike analyses of discrete variables, SPM allowed identification of where, within the stroke cycle, male swimmers were faster and had greater PF than female swimmers. At the same time, it was possible to verify that these differences coincided with the stroke cycle/arm pull: at the end of the pull and during most of the push. Both male and female swimmers exhibited a symmetrical profile between their right and left PF.

Most research on swimming uses discrete variables (8,41). From an overall perspective, across the 4 swim strokes, there is solid evidence of kinematic differences between sexes or competitive levels in experimental (12) and observational (4) settings. The present findings for the butterfly stroke are consistent with previous research, which indicates that male swimmers are faster and exhibit better overall stroke kinematics than their female counterparts (7). This highlights and supports the rationale for conducting sex-specific analyses. The present findings indicated nonsignificant differences between sexes by the SF's and dv's. But it must be mentioned that, despite the absence of statistical differences, male swimmers (best performers) did present the fastest SF's. In a study by Seifert and coworkers, the authors reported

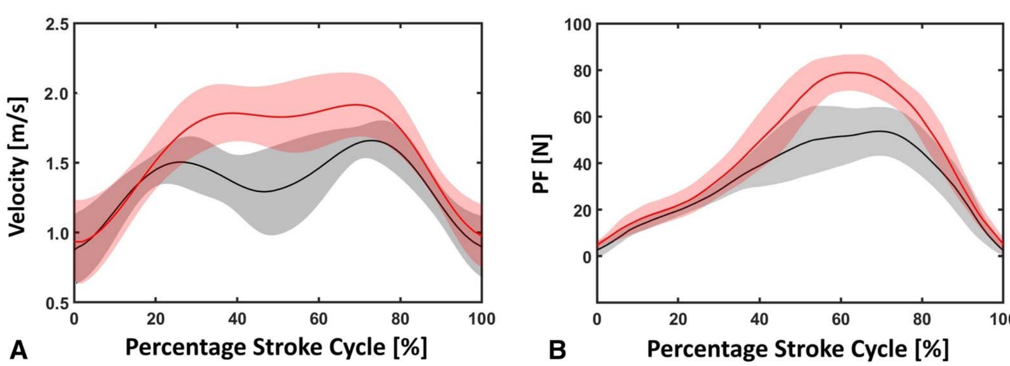

Figure 1. Panel A—velocity profile of male (red) and female (black) swimmers. Panel B—propulsive force (PF) profile of male (red) and female (black) swimmers. The shaded phase refers to the 95% confidence intervals (95% CI).

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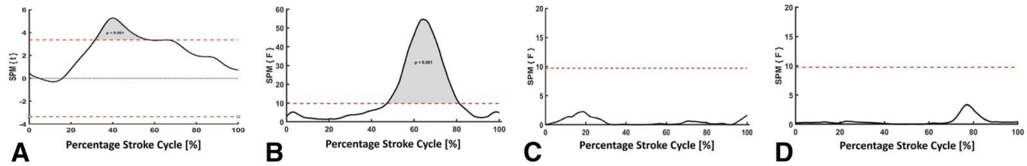

Figure 2. Statistical Parametric Mapping (SPM) tests. Panel A—this refers to the swimming velocity comparison between sexes. Panel B—this refers to the propulsive force comparison— "sex" effect. Panel C—this refers to the propulsive force comparison— "side" effect. Panel D—this refers to the propulsive force comparison—sex × side interaction. SPM {t}—*t* test for an independent sample. SPM {F—2-way ANOVA. The gray area indicates significant differences ($p < 0.001$). Dash red lines represent the 95% confidence intervals (95% CI).

a nonsignificant sex-by-skill interaction in butterfly swimmers for the SF (40). This indicates that male and female swimmers did not differ in the SF pattern, and the same was observed for the more and less skilled swimmers. However, when comparing elite and highly trained male versus female swimmers, it was noted that male swimmers presented the fastest SF's (14). It must be noted that this comparison was not limited to the butterfly stroke, but rather to their preferred stroke (14). For elite versus national level butterfly swimmers (after adjusting for the sex effect) (7), and for competitive versus recreational level female swimmers only (42), it was noted that the fastest swimmers were characterized by presenting the fastest SF's. As for the dv in the butterfly stroke, contradictory reports can be found. A study by Fernandes and coworkers noted that the fastest performers delivered the smallest dv's (7). Others noted that the fastest performers (male swimmers) showed the largest dv's in comparison with their poorest counterparts (female swimmers) (22). However, the authors also noted that the dv entered as a predictor of swimming velocity, with the smallest dv's associated with the fastest velocities (22). Indeed, recent trends in dv research have been claiming that this variable may be an individual swimming behavior, that is, it may not be a cause of a given behavior, but rather a consequence (8). Overall, even in the absence of consistent statistical differences, a clear tendency is observed: fastest performers deliver the highest SF's. Across sex, skill, and competitive level comparisons, the best swimmers were characterized by faster SF values, confirming this variable as an important performance-related characteristic at least in maximal trials. Regarding the dv, this variable can be related to the swimmer's profile or pacing strategy (8). Swimmers may choose to increase velocity by increasing the PFs in a more aggressive and less efficient technique (larger dv's) or by smoother patterns (smaller dv's).

Regarding PF (as a discrete variable), few studies have been conducted in the butterfly stroke (22,37). The predictors of swimming performance in young swimmers, including PF, were investigated (22). Overall, it was noted that boys had greater PF than girls, and that PF and sex were the final predictors of swimming performance (22). This indicated that the fastest velocities were achieved with the greatest PFs, and with a sex effect. Others also noted that the fastest swimmers delivered the greatest PFs (with boys and girls plotted together, and thus, no sex effect was considered) (37). As aforementioned, most studies about PF used the tethered or semitethered methods (which in the past could be considered as a good proxy of PF—considering PF with displacement). For instance, Morouço et al. noted that the average PF was significantly correlated with butterfly stroke swimming performance (28). However, the authors plotted male swimmers and female swimmers together, so it was not possible to assess a hypothetical sex effect. More recently, a study investigated the relationship between sprint performance and PF outputs derived from fully tethered and semitethered assessments in elite and highly trained male and female swimmers (14). It was noted that, in both fully and semitethered conditions, PF was significantly greater in male swimmers than in female swimmers, and that, overall, PF measured with the semitethered protocol was significantly correlated with swimming performance (14). Nonetheless, the authors did not clearly specify these outputs for each swim stroke. They measured male and female swimmers in their preferred stroke, including butterfly. Thus, it can be argued that few studies compare male and female swimmers in the butterfly stroke, and even fewer examine a PF comparison.

Considering the SPM findings, few studies have examined swimming (5,7,31), and even fewer have examined the butterfly stroke (7,36). The present results showed that swimming velocity was significantly higher in male swimmers than in female swimmers during the end of the pull and most of the push phase. This is a main advantage of SPM analysis over discrete analysis. By treating time series continuously, it is possible to identify where, within the stroke cycle, differences occur. As far as we understand, no studies were found that clearly compare swimming velocity between sexes in the butterfly stroke using SPM. Although 1 study compared competitive levels, in which both groups included male and female swimmers (7). The authors reported that the best performers' mean velocity was higher than their poorest counterparts between 25 and 45% of the time curve. This corresponded to the upper-limb release and recovery and the outsweep phases (7). Considering that this outsweep phase may correspond to a subphase of the pull, Fernandes and coworkers (7) noted differences earlier in the stroke cycle than those observed in this study. Despite the lack of information about SPM in the butterfly stroke, other topics are available. For instance, Gonjo et al. aimed to investigate the differences throughout 100 m breaststroke trials between elite and subelite male swimmers using SPM (9). The authors reported that elite swimmers were significantly faster than their subelite counterparts in most of the clean swim phase. Others noted that targeted training enabled young swimmers (boys and girls together) to improve their underwater undulatory velocity. This was noted from the beginning to approximately 15% of the cycle time, and from approximately 50% to the end of the cycle time (35). Once again, in this study, significant differences were noted from the end of the pull and most of the push phase. Despite scarce information about this topic in the butterfly stroke, it was noted that these phases are responsible for the fastest swimming velocities (17). Throughout SPM, this assumption can be confirmed, because the velocity time series showed that male swimmers (fastest) exhibited the highest velocities during these phases of the stroke cycle.

As for the PF, significant differences between the sexes were also observed at the end of the pull and most of the push phase. Once the axes were rescaled (that is, the x and y axes of the PF are synchronized with the swimming velocity output—remembering that for the velocity, complete stroke cycles were used; and for the

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PF, only the arm pull phase), the differences between the PF and swimming velocity seem to overlap substantially. This indicates that the differences in velocity and PF were noted in the same phase of the time series (both variables were measured with different equipment). Once again, if literature is scarce about SPM in the butterfly stroke, it is even scarcer when reporting to PF. In addition, to the best of our knowledge, no sex differences in the PF were tested using SPM. However, information can be found in the front crawl stroke. For example, Morais et al. aimed to test an interaction between time (repeated measures of PF) and side (dominant versus nondominant upper limbs) in young male swimmers performing the front crawl stroke (24). The authors noted a significant interaction between the 2 factors (time and side) in ~34 and ~42% of the arm pull. This was mainly because of a significant decrease in PF in the dominant upper limb, from ~32 to ~43% of the arm pull. Others investigated PF in young swimmers across different performance tiers within the same age group and compared dominant and nondominant PF within the same tier (37). For this, 52 young boys and girls were recruited. The authors reported significant differences between the fastest and slowest swimmers, between ~64 and ~74% of the arm pull for the dominant upper limb, and between ~60 and ~90% for the nondominant upper limb. The fastest swimmers exhibited the greatest PF (37). However, a sex effect (differences between sexes) was not tested. Thus, one can only assume that, regardless of sex, swimmers who generate more PF are more likely to achieve faster performances/velocities. It should also be pointed out that nonsignificant differences were noted in the PF between the upper limbs. This was also shown by others in the butterfly stroke (36). In butterfly swimming, it should be expected to observe nonsignificant differences between the upper limbs, because the stroke is characterized by high bilateral symmetry and coordinated motion (36). Therefore, the absence of significant asymmetries detected by SPM reflects the natural biomechanical consistency inherent in this symmetrical swimming stroke.

Regardless of the statistical procedure used, studies also aimed to understand muscle activation during arm pulls (34,42). In the study by Qi and coworkers, the authors evaluated young female swimmers at different velocities (70, 80, and 90% of maximal velocity). It was noted that velocity increase relied on a stable, phase-specific muscle activation pattern. Increases in velocity were achieved mainly through greater activation of key muscles and enhanced trunk stabilization, rather than through changes in muscle coordination strategy (34). Specifically, increased velocity was primarily achieved through greater latissimus dorsi activation during the pull phase and greater triceps brachii and trunk muscle activation during the push phase (34). Others aimed to investigate differences in muscle activation during the butterfly stroke between the best- and poorest-performing female swimmers (42). It was reported that the key differences in muscle activation between competitive levels are not about how many muscle synergies (groups of muscles that are consistently activated together as a functional unit) they use, but how those muscles are coordinated and timed. The authors observed that the best performers confine propulsion during pull and push phases mainly to the latissimus dorsi, pectoralis major, biceps brachii (pull), and triceps brachii (push) (42). By contrast, the poorest counterparts recruit lower-limb and trunk muscles concurrently, indicating a compensatory strategy aimed at body stabilization rather than propulsion increase (42). Thus, considering these findings, propulsion during the arm pull primarily relies on the latissimus dorsi during the pull phase and on the triceps brachii during the push phase.

In summary, SPM provides a more comprehensive and statistically robust framework for analyzing swimming performance time series than traditional discrete-variable methods. Whereas discrete analyses focus on isolated phases of the stroke cycle/arm pull, SPM treats, the data as a continuous function, enabling the evaluation of temporal patterns across the entire stroke cycle/arm pull. This approach maintains the inherent temporal and biomechanical structure of the movement, thereby avoiding information loss and potential selection bias associated with discrete-point extraction. Whereas other studies based on discrete variables showed significant associations between swimming velocity and PF (despite swim stroke and sex) (12,13), the present SPM data showed that differences in velocity and PF occurred at the same time-series phases. This not only shows that the greatest PFs are associated with the fastest velocities, but also were within the stroke cycle. This study compared the sexes and allowed for a performance comparison (best versus poorest performers). However, researchers and practitioners are also advised to compare swimmers of the same competitive level. This will allow them to identify where, within the stroke cycle/arm pull, swimmers who compete at the same level differ. As main limitations, these findings are limited to national-level butterfly swimmers and maximal trials, and a larger sample size could yield more robust results. Therefore, future studies could recruit high-level swimmers to better test or confirm these assumptions and to compare these effects across different competitive levels, paces, and swim strokes to gain additional insights. By adding different physical capacities (e.g., endurance, dry-land strength, power, and flexibility) to the analysis, relationships between these physical attributes and the variables analyzed in this study (velocity and PF) might be tested.

In conclusion, significant differences in butterfly swimming velocity and PF were found between sexes across discrete variables and in SPM (continuous time-series analysis). Based on discrete variables, male swimmers were not only faster, but also presented a meaningfully larger SL and higher SI than their female counterparts. Based on SPM, it was possible to identify where, within the stroke cycle/arm pull, these differences occurred (at the end of the pull and throughout most of the push phase). In addition, as SPM analyzes time series, it was observed that the differences in velocity and PF occurred at the same phase of the stroke cycle. These findings provide researchers and coaches with deeper insights into the PF–velocity relationship.

Practical Applications

The findings of this study provide valuable insights for coaches and sport scientists aiming to optimize butterfly stroke performance. By combining discrete variables with SPM, this study not only confirms sex-related differences in swimming velocity and PF but also identifies the stroke cycle phases at which these differences occur. Specifically, male swimmers exhibited higher velocity and greater PF during the late pull and most of the push phases of the arm pull, with both variables differing concurrently within the same phases of the stroke cycle. Given that the latissimus dorsi and triceps brachii are the primary contributors to propulsion during these phases, these differences likely reflect variations in the ability to effectively recruit and apply force through the upper limbs rather than differences in overall strength alone. From a practical standpoint, these results suggest that training interventions for female butterfly swimmers should place greater emphasis on enhancing force production during the end of the pull and push phases. This rationale can

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also be used when comparing swimmers of the same competitive level. By identifying differences in velocity and PF across specific phases of the stroke cycle/arm pull, coaches will get important information for their training designs and interventions. Thus, coaches may prioritize targeted dry-land strength exercises (e.g., upper-body pulling and pushing) alongside in-water drills to improve phase-specific force application.

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