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Is There Any Effect of Symmetry on Velocity of the Four Swimming Strokes?

Raul Filipe Bartolomeu [1,2,3,*], Pedro Rodrigues [3,4], Catarina Costa Santos [3,4,5], Mário Jorge Costa [3,5] and Tiago Manuel Barbosa [1,3]

1 Department of Sport Sciences and Physical Education, Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Braganca, Portugal; barbosa@ipb.pt
2 Department of Sport Sciences, Exercise and Health, University of Trás-os-Montes and Alto Douro, 5000-801 Vila Real, Portugal
3 Research Center in Sports Sciences, Health and Human Development (CIDESD), 5001-801 Vila Real, Portugal; pedro.henrique.rodrigues@ubi.pt (P.R.); catarina.costa.santos@ubi.pt (C.C.S.); mario.costa@ipg.pt (M.J.C.)
4 Department of Sport Sciences, University of Beira Interior, 6200-209 Covilha, Portugal
5 Department of Sports Sciences, Polytechnic Institute of Guarda, 6300-559 Guarda, Portugal
* Correspondence: rbartolomeu@ipb.pt; Tel.: +351-273-330-850

Abstract: The different characteristics of the four swimming strokes affect the interplay between the four limbs, acting as a constraint to the force produced by each hand and foot. The purpose of this study was to analyze the symmetry of force production with a varying number of limbs in action and see its effect on velocity. Fifteen male swimmers performed four all-out bouts of 25-m swims in the four strokes in full-body stroke and segmental actions. A differential pressure system was used to measure the hands/feet propulsive force and a mechanical velocity meter was used to measure swimming velocity. Symmetry index was calculated based on the force values. All strokes and conditions presented contralateral limb asymmetries (ranging from 6.73% to 28% for the peak force and from 9.3% to 35.7% for the mean force). Backstroke was the most asymmetric stroke, followed-up by butterfly, front crawl, and breaststroke. Kicking conditions elicited the higher asymmetries compared with arm-pull conditions. No significant associations were found between asymmetries and velocity. The absence of such association suggests that, to a certain and unknown extent, swimming may benefit from contralateral limb asymmetry.

Keywords: hand force; asymmetry; velocity; segmental actions

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1. Introduction

In human swimming, segmental actions act as propellers producing propulsive forces. When swimming the full stroke, the upper-limbs produce propulsion by doing arm-pulls; whereas, the lower-limbs by kicking. Propulsive force is related to limbs' velocity, stroke frequency, stroke length, and therefore, to performance [1]. Each swim stroke presents its unique set of coordination constraints between the four limbs [2], plus unique trajectories under and above the water [3]. These features affect the production of propulsive forces, and therefore affect thrust, velocity, and complexity, thus making some strokes faster and more complex than others [4].

In the past years, thrust has been studied mainly using tethered swim techniques [5–7]. Despite the practical applications of this method and the useful data it provides, it cannot quantify for example, the force produced by each hand/foot separately during the full-body stroke [8]. Different underwater limbs' phases and angles, inherent to each swimming stroke, are constraints affecting coordination [2] and muscle activation [9]. This will have an impact on the magnitude of the hands/feet forces produced [3] which will lead to different force–time time-series [10] and therefore, different velocities. To measure the force produced more ecologically (i.e., during actual free swimming) would bring further insight on interlimb asymmetry and its effect on velocity.

From a theoretical perspective, one could expect that both arms and legs would need to generate similar propulsive forces in order to maximize thrust, diminish drag, and achieve top-performances [11]. However top-tier swimmers keep improving their performances although several studies have reported contralateral limbs asymmetries in a wide range of swimmers, from non-expert to elite counterparts [12–14]. Asymmetries have been said to have their origins on numerous physical or training characteristics [11], and the presence of asymmetries in the force production can lead to unwanted body rotations that affect drag and unequal contribution of each body side to the propulsion [15,16].

Ultimately, asymmetries in hand–feet forces may end up being a constraint for the propulsive force production affecting the velocity and performance. There is a trend for a less complex pattern of velocity in segmental stroke conditions (only the arm-pull and only leg kicking) comparing to the full-body stroke [4], which seems to point out that those asymmetries may vary between segmental and full-body conditions. Thus, identifying swimming constraints (i.e., swim strokes or swim conditions, such as arm-pull or kicking) that might elicit wider asymmetries in hand/feet forces may aid end-users (i.e., practitioners, such as coaches, teachers, and physiotherapists) designing evidence-based learning processes and motor control strategies that can assist humans to learn in a more effective way and also enhance their performance in water. Therefore, the aims of the present study were twofold: (a) to assess the symmetry of the force produced by the hand/feet force of the four competitive swimming strokes, in the full and segmental stroke conditions, in an ecological environment, and (b) to analyze the influence of asymmetries in the swimming velocity.

It was hypothesized that swimming the full stroke, swimmers would exhibit contralateral limbs asymmetries, as literature reports. In the segmental stroke conditions, as they tend to have less complex force production patterns, asymmetries are also hypothesized to exist but in a lower extent. At last, it was hypothesized that asymmetries would negatively affect velocity.

2. Materials and Methods

2.1. Participants

Fifteen male swimmers took part of this research (16.00 ± 2.88 years-old, 1.69 ± 0.08 m of height and 62.46 ± 14.61 kg of body mass). The participants were swimmers with training volumes of approximately 16,000 m per week, from regional to national level, with personal records of 82%, 75%, 72%, and 70% of the front crawl, backstroke, breaststroke, and butterfly world records, respectively. As inclusion criteria it was set that all participants should be males, local and/or national level competitors on the two previous competitive seasons at least. Conversely, exclusion criteria included having any musculoskeletal injury or neurologic condition diagnosed in the past 6 months. Also excluded were those who reported beforehand to be unable to attend the four scheduled sessions of this study.

All procedures were in accordance with the Helsinki Declaration regarding human research, and the University's Institutional Review Board approved the research design. All coaches, parents/guardians, and swimmers gave their informed written consent/assent for participation in this study.

2.2. Protocol

All swimmers performed a standard warm-up at moderated pace followed-up by a few sprints as described elsewhere [17]. Swimmers were randomly assigned to perform 4 all-out bouts of 25 m in each swim stroke (front crawl, backstroke, breaststroke, and butterfly) at three different conditions: (i) full stroke (i.e., arm-pull plus kicking); (ii) arm-pull (i.e., only the arm stroke; AO); and (iii) kicking (i.e., only the leg kicking; KO). The full stroke condition was performed twice due to the availability of only two sensors that only allows the collection of both arms (i.e., full stroke with sensors on the hands; FA) or both legs (i.e., full stroke with sensors on the feet; FK) force data at the time (Table 1). All bouts started with an in-water push-off and swimmers were instructed to start swimming immediately (i.e., no gliding or underwater dolphin kicking was allowed). Nonetheless, to avoid the high variance in the motor behavior that are not caused by the swim stroke, the first five meters (push-off from the wall) and the last meter (finish) were discarded from the analysis. To ensure full recovery, each swimmer rested for 30 min prior to next bout. The lanes beside where the test was conducted were empty to minimize drag, drafting, and other confounding factors. Each swimmer performed 16 bouts over 4 testing sessions, with a maximum of 4 bouts per session (total number: 15 participants × 16 bouts = 240 trials).

Table 1. Stroke variant, correspondent acronym, and sensor placement for each of the four swimming strokes.

Trial Number (Randomly Assigned)	Stroke Variant	Sensor Placement	Condition Acronym
1	Full Stroke	Right and left hands	FA
2	Full Stroke	Right and left feet	FK
3	Arm-pull only	Right and left hands	AO
4	Leg-kicking only	Right and left feet	KO

2.3. Data Collection

A differential pressure system (Aquanex System, v.4.1, Model DU2, Swimming Technology Research, Inc., Tallahassee, FL, USA) was used to measure the hand/feet force (Figure 1a). The system features two independent differential pressure sensors (Type A) connected by cabling to a two-sensor interface that processes the signal (f = 100 Hz). Each sensor measures the pressure component acting perpendicular to it. Accuracy of the system was reported elsewhere [18]. Although there are other force components that may come into play, it was reported that the pressure component is the main contributor to the propulsive force [19]. Therefore, the pressure component was assumed to be represented by the hands/feet forces. Before each bout, swimmers were asked to keep their hands underwater at the waistline for 10 s in order to calibrate the system with the hydrostatic pressure values. Force–time data was streamed in real time on a visual interface on a laptop. In the AO condition, sensors were placed in both hands, between the proximal phalanges of the 3rd and 4th fingers. In the KO condition, the sensors were placed in both feet between the 2nd and 3rd toes. Concurrently, swimming velocity was measured. A string was attached from the swimmer's hip to a mechanical system (Swim speedo-meter, Swimsportec, Hildesheim, Germany) placed on a starting block in the head-wall of the swimming pool (Figure 1b). The signal was acquired at a frequency of 50 Hz and transmitted by a 12-bit acquisition card (USB-6008, National Instruments, Austin, TX, USA) to a software interface in LabView (v.2010, National Instruments, Austin, USA), which displays the speed-time data in real time. Data from both systems were then transferred to a signal-processor software (AcqKnowledge v.3.7.3, Biopac Systems, Santa Barbara, CA, USA). Upon residual analysis, data was filtered with a 5-Hz cut-off low-pass 4th order Butterworth filter.

(**a**) (**b**)

Figure 1. (**a**) Differential pressure sensor being put in between the proximal phalanges of the 3rd and 4th fingers; (**b**) velocimeter, placed on the head-wall of the swimming pool, with a string attached from it to a belt placed on the swimmer's hip.

2.4. Kinetic and Kinematic Variables

Peak and mean forces were calculated as propulsive force outcomes in the signal processing software. Peak force was defined as the maximum value achieved during the bout. Mean force was defined as the mean of the values measured over the whole bout. In front crawl and backstroke, the kicking comprises two distinct phases (downward and upward beats). The differential pressure sensors note these phases with positive and negative values, imposing a bias in the mean force. Hence, the Root Mean Square of the time-series was calculated for these strokes in the FK and KO conditions as [20]:

$$RMS = \sqrt{\frac{1}{N}}\sum_{k=1}^{N}(x_k) \quad k = 1, 2, \ldots, N \tag{1}$$

The highest velocity peak obtained in every bout was deemed as the peak velocity (V_{pk}) and the mean of all values measured throughout the bout, the mean velocity (V_m).

2.5. Motor Control Variable

Symmetry Index (SI, %) was selected as a symmetry measure. It enables the quantification of the difference between the forces produced by contralateral limbs. SI, was calculated for the peak force (SI_F_{pk}) and the mean force (SI_F_m). Both (SI_F_{pk} and SI_F_m) were calculated as proposed by [21]:

$$\text{SI}\ (\%) = \frac{|X_d - X_{nd}|}{0.5 \times (X_d + X_{nd})} \times 100 \tag{2}$$

where X_d is the force produced by the dominant limb, X_{nd} is the force produced by the non-dominant limb. Each participant reported which were their dominant and non-dominant limbs. Although other random cut-off values may be occasionally found in the literature, we went by Herzog et al. [22] who defined symmetry as the "perfect agreement of the external kinetics and kinematics of the left and right leg". Thus, SI was interpreted as perfectly symmetric if SI = 0% and asymmetric if SI > 0% [21]. As the goal was to assess the presence of asymmetries and not the direction of that asymmetry (i.e., asymmetry at left or right), the SI values were presented in absolute values.

2.6. Statistical Analysis

The normality of the data distribution was tested by Shapiro–Wilk test. Mean ± 1 SD and 95% confidence intervals (95CI) are reported for all dependent variables. Data variation across swimming strokes and conditions were analyzed resorting a two-way repeated measures ANOVA (α set to 0.05). Whenever needed, a repeated measures ANOVA followed-up by Bonferroni post-hoc test was carried out (α set to 0.05). The assumptions for a two-way ANOVA were tested. Every time the assumption of sphericity was violated, the Greenhouse–Geisser correction was used to adjust the degrees of freedom of the F-ratio. Partial Eta-Squared (η_p^2) was selected as the standardized effect size index of the variance and deemed as: (1) minimum effect size if $0.02 < \eta_p^2 \leq 0.13$; (2) moderate effect size if $0.13 < \eta_p^2 \leq 0.26$; and (3) strong effect size if $\eta_p^2 > 0.26$ [23]. Pearson's correlation was also carried out to assess the association between SI and velocity (α set to 0.05). Correlation effect sizes were deemed as: $0 < |R| \leq 0.1$ null; $0.1 < |R| \leq 0.3$ small; $0.3 < |R| \leq 0.5$ moderate; and $|R| > 0.5$ strong. All statistical procedures were performed in the IBM Statistical Package for The Social Sciences (SPSS) (v.21, IBM, New York, NY, USA).

3. Results

Descriptive and Main Effects

All strokes and variants presented contralateral limb asymmetries. Backstroke was the most asymmetric stroke, followed-up by butterfly stroke, front crawl, and breaststroke. KO condition elicited the highest asymmetry, followed by the other kicking condition, FK, FA, and, finally, AO (Tables 2 and 3).

Table 2. Mean (M), standard deviation (SD), and confidence intervals (CI) of peak (F_{pk}) and mean (F_m) propulsive force of the dominant (DL) and non-dominant (NDL) limbs and Symmetry Index (SI), across conditions in front crawl and backstroke.

		Front Crawl			Backstroke		
		DL [N] M ± 1 SD (95CI)	**NDL [N] M ± 1 SD (95CI)**	**SI [%]**	**DL [N] M ± 1 SD (95CI)**	**NDL [N] M ± 1 SD (95CI)**	**SI [%]**
FA	peak	101.6 ± 38.3 (79.4−123.7)	104.9 ± 45.3 (78.7−131.0)	10.6 ± 5.9 (7.2−14.0)	86.6 ± 29.5 (69.6−103.7)	88.6 ± 31.1 (70.6−106.6)	13.5 ± 8.4 (8.6−18.4)
	mean	34.9 ± 14.2 (26.7−43.1)	36.2 ± 18.0 (25.8−46.6)	9.3± 5.1 [a] (6.3−12.2)	29.3 ± 11.7 (22.5−36.1)	31.0 ± 11.7 (24.2−37.7)	12.9 ± 6.9 [a] (8.9−16.2)
FK	peak	120.4 ± 74.6 (77.3−163.5)	132.3 ± 63.1 (95.8−168.7)	18.8 ± 12.1 (11.8−25.8)	156.3 ± 73.1 (114.1−198.5)	144.9 ± 68.1 (105.6−184.3)	25.8 ± 15.0 (17.1−34.4)
	mean	41.6 ± 29.8 (24.4−58.8)	46.2 ± 31.0 (28.3−64.1)	17.1 ± 12.4 [a] (9.98−24.3)	57.4 ± 35.8 (36.7−78.0)	53.0 ± 34.1 (33.3−72.8)	20.2 ± 14.3 [ab] (11.9−28.4)
AO	peak	107.1 ± 42.2 (82.8−131.5)	102.5 ± 39.5 (79.7 −125.3)	10.7 ± 6.2 (7.1−14.2)	85.7 ± 32.5 (66.9−104.4)	86.3 ± 33.7 (66.9−105.8)	13.3 ± 14.3 (5.1−21.6)
	mean	33.7 ± 13.3 (26.0−41.4)	34.2 ± 16.7 (24.6−43.8)	11.2 ± 7.0 [a] (7.2−15.3)	28.9 ± 13.0 (21.4−36.4)	29.4 ± 15.0 (20.7−38.1)	10.4 ± 7.9 [a] (5.8−14.9)
KO	peak	120.4 ± 52.7 (89.9−150.8)	123.8 ± 52.3 (93.6 −154.0)	14.6 ± 14.8 (6.1−23.2)	147.3 ± 65.2 (109.7−184.9)	136.5 ± 57.7 (103.2−169.9)	28.1 ± 25.2 (13.6−42.6)
	mean	40.9 ± 27.8 (24.9−56.9)	39.2 ± 25.3 (24.6−53.8)	15.7 ± 13.6 [a] (7.9−23.6)	52.6 ± 30.7 (34.9−70.4)	45.7 ± 28.9 (29.1−62.4)	35.0 ± 34.1 [b] (15.3−54.7)

%—percentage; N—Newton; FA—Full-stroke arm-pull; FK—Full-stroke kicking; AO—Arm-pull only; KO—Kicking only; DL—Dominant limb; NDL—Non-dominant limb; SI—Symmetry index Vertically, conditions with the same superscript letter aren't statistically different ($p < 0.05$).

Table 3. Mean (M), standard deviation (SD), and confidence intervals (CI) of peak (F_{pk}) and mean (F_m) propulsive force of the dominant (DL) and non-dominant (NDL) limbs and Symmetry Index (SI), across conditions in breaststroke and butterfly stroke.

		Breaststroke			Butterfly Stroke		
		DL [N] M ± 1 SD (95CI)	NDL [N] M ± 1 SD (95CI)	SI [%]	DL [N] M ± 1 SD (95CI)	NDL [N] M ± 1 SD (95CI)	SI [%]
FA	peak	121.8 ± 35.3 (101.4−142.1)	118.9 ± 35.3 (98.5−139.3)	14.06 ± 10.8 (7.8−20.3)	107.3 ± 38.2 (85.2−129.3)	97.1 ± 36.1 (76.2−117.9)	17.3 ± 10.2 (11.4−23.2)
	mean	33.3 ± 9.6 (27.7−38.8)	31.4 ± 11.2 (24.9−37.9)	16.1 ± 11.3 [a] (9.7−22.6)	34.8 ± 11.2 (28.3−41.3)	32.5 ± 13.2 (24.8−40.1)	14.8 ± 7.4 [a] (10.5−19.0)
FK	peak	198.1 ± 50.9 (168.7−227.5)	192.0 ± 46.4 (165.2−218.8)	7.36 ± 7.5 (3.0-11.7)	71.2 ± 26.6 (55.8−86.5)	76.0 ± 28.3 (59.67−92.3)	17.6 ± 17.9 (7.2−27.9)
	mean	30.2 ± 8.0 (25.6−34.8)	27.87 ± 7.76 (23.4−32.3)	10.2 ± 5.8 [a] (6.9−13.6)	12.1 ± 5.9 (8.6−15.5)	12.2 ± 5.4 (9.08−15.3)	25.2 ± 24.3 [ab] (11.2−39.27)
AO	peak	111.9 ± 36.5 (90.8−133.0)	107.1 ± 40.5 (83.7−130.7)	6.7 ± 5.9 (3.3−10.1)	101.7 ± 37.3 (80.1−123.3)	90.0 ± 37.1 (68.6−111.4)	19.5 ± 12.3 (12.4−26.6)
	mean	32.2 ± 10.1 (26.3−38.0)	32.2 ± 11.1 (25.7−38.6)	11.0 ± 8.6 [a] (6.0−15.9)	34.0 ± 10.0 (28.2−39.7)	31.6 ± 11.8 (24.8−38.4)	14.3 ± 7.0 [a] (10.3−18.3)
KO	peak	201.7 ± 51.12 (172.1−231.2)	184.5 ± 49.3 (156.1−213.0)	9.4 ± 9.09 (4.1−14.6)	104.4 ± 46.3 (77.7−131.1)	96.3 ± 37.5 (74.5−117.9)	22.1 ± 18.5 (11.4−32.8)
	mean	32.0 ± 7.7 (27.5−36.4)	28.4 ± 7.2 (24.2−32.6)	14.9 ± 9.1 [a] (9.6−20.1)	21.8 ± 14.5 (13.4−30.2)	17.3 ± 9.0 (12.0−22.5)	35.7 ± 24.6 [b] (21.5−49.9)

%—percentage; N—Newton; FA—Full-stroke arm-pull; FK—Full-stroke kicking; AO—Arm-pull only; KO—Kicking only; DL—Dominant limb; NDL—Non-dominant limb; SI—Symmetry index; Vertically, conditions with the same superscript letter aren't statistically different ($p < 0.05$).

There was a significant and strong effect of swimming stroke in SI_F_{pk} ($F_{3,39} = 6.802$, $p = 0.001$, $\eta_p^2 = 0.343$), with post-hoc test showing breaststroke to be significantly different from backstroke and butterfly stroke ($p < 0.05$) (Table 4).

Table 4. Interactions and main effects of swimming stroke and condition on the Symmetry Index (SI) of both peak and mean propulsive force.

	Symmetry Index of F_{pk} (SI_F_{pk})				Symmetry Index of F_m (SI_F_m)			
	df	F-Ratio	*p*-Value	η_p^2	df	F-Ratio	*p*-Value	η_p^2
Stroke	2.1, 27.5	6.802	0.003	0.343	3, 39	4.93	0.005	0.275
Condition	1.9, 25.3	2.955	0.071	0.185	1.8, 23.2	7.777	0.003	0.374
Stroke × condition	4.2, 54.4	1.908	0.119	0.128	3.7, 48.5	2.569	0.053	0.165

Regarding SI_F_m, it was observed a significant and strong effect of both stroke and condition ($F_{3,39} = 4.93$, $p = 0.005$, $\eta_p^2 = 0.275$ and $F_{3,39} = 7.777$, $p < 0.001$, $\eta_p^2 = 0.374$, respectively) (Table 4). Butterfly stroke was the most asymmetric stroke, followed-up by backstroke, front crawl, and breaststroke. Both kicking conditions were more asymmetrical than arm-pulls. Post-hoc test showed that breaststroke was significantly different from butterfly ($p < 0.05$) and that KO condition was significantly more asymmetrical than FA and AO conditions ($p < 0.05$).

Asymmetries in peak force (SI_F_{pk}) were positively and strongly correlated to asymmetries in mean force (SI_F_m) in every controlling condition ($0.677 < r < 0.680$). No significant correlations were found between any SI (SI_F_{pk} and SI_F_m) and any velocity variables.

4. Discussion

The aims of the present study were to assess the symmetries of the propulsive force and check their influence on swimming velocity. All strokes and conditions showed a contralateral asymmetry in the force production which were not correlated to swimming velocity.

4.1. Asymmetries and Symmetry Index

The SI used in the present study, originally proposed by Robinson et al. [21] has been widely used over the years to assess contralateral asymmetries in several sports and settings [24–27]. Concurrently, the 10% cut-off criteria arbitrarily proposed originally by the same authors has gained traction and is used on a regular basis to note a significant contralateral asymmetry. In the literature, asymmetries are reported in a variety of activities such as jumping [28,29], landing [30], change of direction [28,29], running [31,32], or rowing [33] in numerous selected variables of interest, often below or around 10%. It is often reported that scores of SI above 10–15% affect performance [34–37] and may increase the likelihood of musculoskeletal injury [34,38]. However, some authors have forewarned that in tasks where the mean asymmetries are low, a value of 10% could already represent a red flag [39]. In swimming, on the other hand, studies consistently report higher SI values from low-experts all the way up to elite swimmers, regardless of being measured by differential pressure system [13], tethered tests [12,40], or computational simulations [41]. The present study, in tandem to literature, found asymmetries in every stroke and condition; while SI_F_{pk} ranged from 6.73% to 28%, SI_F_m ranged from 9.3% to 35.74% (Tables 2 and 3). Only three cases fell below the 10% threshold guidance. E.g., the averaged mean for all the asymmetries of all strokes and conditions were 15.60 ± 6.22% for SI_F_{pk} and 17.14 ± 8.20% for SI_F_m (i.e., above 10%). As such, in activities with high prevalence of asymmetries even in elite athletes (such as swimming) they may be a sign of usefulness. Thus, one may wonder if the mainstream 10% cut-off should be kept as a standard criterion to classify asymmetries, at least in swimming. Interestingly, some authors have been raising the same question at least for on-land human motor skills [28,42].

4.2. Symmetry, Velocity, and Performance

Aside from the asymmetry values, it can be seen in Tables 2 and 3 the high range of standard deviations found in both SI_F_{pk} and SI_F_m in every stroke and condition. Overall, SDs are equal or above the mean values, denoting a substantial range of individual contralateral asymmetry. Furthermore, the present results showed that SI_F_{pk} was positively and significantly related to SI_F_m with large effect size, in every controlling condition. This means that asymmetries, while highly individual, are also somewhat chronic, i.e., those whose peaks are more asymmetrical will also produce the highest asymmetrical force throughout the swimming bout. Even in breaststroke and butterfly, where one would expect a small SI given the simultaneous nature of both the stroke-pull and leg kick, there were asymmetries in the hands/feet force production.

Both slight contralateral kinematic differences in the underwater pathway and orientation of the limbs due to motor control singularities may justify the asymmetries in the propulsive force production. Also, poor coordination can drive to asymmetrical kicking that leads to asymmetric arm-pulls [43]. Literature suggests that asymmetries in propulsive force may affect body alignment and drag [15,16], thus, at the light of the present results, one might consider that correcting the asymmetries in the peak propulsive force would reduce the asymmetries throughout the swimming bout. However, elite swimmers seem able to offset their asymmetries and still reach fast velocities and deliver better performances [12,44,45]. Thus, one might wonder about the need of correcting such asymmetries and even more, about the usefulness of those asymmetries.

In the present study, there was no significant association between SI_F_{pk} and SI_F_m and V_{pk} and V_m (Table 5), thus, despite each individual has relatively pronounced asymmetries, there is no clear influence on velocity. Literature suggests that in the presence of asymmetry, there is a requirement for compensatory movement that changes the body position [46]. Theoretically, in swimming this may be translated into unwanted body rolls and inclinations that will change the projected frontal area, affect drag [47], and thus speed fluctuation and velocity [48]. However, literature does not quantify the amount of asymmetry needed to elicit such trade-off. Thus, at least for values under those found on the present study, asymmetries do not seem to be a constraint to velocity itself. Hence, one could hypothesize that swimming may be a sport that would benefit, to a certain extent, from some amounts of asymmetry, probably above 10%. Interestingly, the same reasoning has been put forward in human gait on land [49–51]. In a study of elite runners, Ueberschär et al. [51] found asymmetries in key biomechanical parameters. The authors questioned if the observed asymmetries should be regarded as functional and physiological and not as to be "corrected". They put forward that contralateral asymmetry might reflect a sensible and effective measure of the athlete to compensate for individual anatomic and/or orthopedic conditions (e.g., scoliosis or a congenital/acquired articular malalignment). Interestingly, the same reasoning has been put forward in human gait on land. Longman [49] in a piece about Usain Bolt's lower limb asymmetry, citing an ongoing research from the Southern Methodist University's Locomotor Performance Laboratory [52], referred to a 13% higher peak impact force in the right leg than the left leg. Conversely, the left leg remained on the ground about 14% longer than the right leg. The authors on the study about the asymmetry, cited by Longman [49], put forward that Usain Bolt probably has naturally settled into his stride to accommodate his scoliosis, optimizing his speed. Moreover, correcting his asymmetry would not speed him up and might even slow him down. If he were to run symmetrically, it could be an unnatural gait for him.

Table 5. Pearson's product–moment correlation between Symmetry Index, kinematics and kinetics.

		SI_F_{pk} (%)			**SI_F_m (%)**			**V_{pk} ($m{\cdot}s^{-1}$)**		
		df	*r*	*p*	*df*	*r*	*p*	*df*	*r*	*p*
No Control	SI_F_{pk} (%)	—	—	—						
	SI_F_m (%)	224	0.677	<0.001 †	—	—	—			
	V_{pk} ($m{\cdot}s^{-1}$)	156	−0.137	0.088	156	−0.062	0.438	—	—	—
	V_m ($m{\cdot}s^{-1}$)	156	−0.030	0.709	156	−0.075	0.354	156	0.551	0.000 †
Controlling for stroke	SI_F_{pk} (%)	—	—	—						
	SI_F_m (%)	221	0.678	<0.001 †	—	—	—			
	V_{pk} ($m{\cdot}s^{-1}$)	153	−0.129	0.132	153	−0.109	0.175	—	—	—
	V_m ($m{\cdot}s^{-1}$)	153	−0.029	0.723	153	−0.065	0.424	153	0.586	0.000 †
Controlling for condition	SI_F_{pk} (%)	—	—	—						
	SI_F_m (%)	221	0.678	<0.001 †	—	—	—			
	V_{pk} ($m{\cdot}s^{-1}$)	153	−0.119	0.141	153	0.048	0.556	—	—	—
	V_m ($m{\cdot}s^{-1}$)	153	0.008	0.921	153	0.041	0.612	153	0.385	0.000 ‡
Controlling for stroke × condition	SI_F_{pk} (%)	—	—	—						
	SI_F_m (%)	220	0.680	<0.001 †	—	—	—			
	V_{pk} ($m{\cdot}s^{-1}$)	152	−0.131	0.106	152	−0.002	0.979	—	—	—
	V_m ($m{\cdot}s^{-1}$)	152	0.010	0.904	152	0.056	0.494	152	0.426	0.000 ‡

SI_F_{pk}—Symmetry index of peak force; SI_F_m—Symmetry index of mean force; V_{pk}—peak velocity; V_m—mean velocity; ‡—moderate effect size; †—strong effect size.

In swimming, Formosa et al. [53] suggested that that upper-limbs may have different functions in human swimming; one limb may be responsible for the production of large forces; whereas, the other limb has the secondary role of stabilizing the direction of the displacement. Our results, alongside to those reported in the literature on swimming propulsive force asymmetry, seems to back up this reasoning.

As a take-home message, all strokes and conditions presented asymmetries with hands/feet force production. Furthermore, the conditions with higher asymmetries in peak force production will likely have higher mean force production. However, those asymmetries might not need to be corrected. Neither the literature nor our results set a target for an asymmetry value beyond which performance is affected, but at the light of the present results, more than 10% might not be worrying as it did not affect performance (velocity).

5. Conclusions

All swimming strokes and conditions elicited asymmetries in peak and mean force. Leg kicking was the condition which elicited wider asymmetries.

There was no effect of asymmetries on the velocity behavior suggesting that the motor control in swimming would beneficiate from a certain amount of asymmetry.

The use of the 10% cut-off criteria to identify asymmetries seems unsuitable for the sports of swimming. Hence, the results of this study can serve as guidance regarding the expected values and ranges of contra-lateral asymmetries in different swim strokes and conditions in competitive swimming.

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