Serbian Journal of Sports Sciences
2011, 5(3): 91-97
UDC 797.212.8.012.5

ISSN 1820-6301
ID 186014732

Original article
Received: 12 Oct 2010
Accepted: 14 May 2011

EFFECTS OF DIFFERENT HAND PADDLE SIZES ON BILATERAL PROPULSIVE FORCE DIFFERENCE IN FRONT CRAWL SWIMMING

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Abstract This study investigated the effect of different sizes of hand paddles on bilateral propulsive force difference (BFD) in the crawl stroke. Fourteen male swimmers (Age: 20.0 ± 3.7 years, 100-m best time: 53.70 ± 0.87 s) were submitted to the following test protocol: 2 x 10 s maximal efforts in the fully tethered swimming, repeated in five conditions: free swimming (FREE), with small (PP, 280 cm²), medium (PM, 352 cm²), large (PG, 462 cm²) and extra-large paddles (PGG, 552 cm²). Stronger (STR) and weaker (WKR) strokes were those which presented the higher and lower mean peak force values in four non-consecutive strokes, respectively. BFD was expressed by the percentage difference between STR and WKR. STR and WKR were significantly different in all the conditions (FREE: 296 x 249 N; PP: 310 x 264 N; PM: 323 x 285 N; PG: 339 x 298 N; PGG: 353 x 310 N). No specific paddle size changed BFD significantly. A significant reduction occurred when the lower individual values of BFD obtained with hand paddles, independently of their size, were compared to those found in FREE (14.9% x 7.4%). The present results showed that the artificial enlargement of hands can acutely reduce the bilateral force difference in competitive swimmers. However, the best size of paddles should be individually chosen.

Key words: Hand paddles, bilateral symmetry, propulsive force, tethered swimming

INTRODUCTION

As a cyclical modality, swimming performance becomes dependent, among others factors, on high stroke-to-stroke consistency [7], i.e., bilateral symmetry. Although it can be identified through spatial-temporal parameters [12], according to Havriluk [8], its potential impact on performance can be quantified and determined by monitoring the kinetic variables.

From a physical perspective, the swimmer's inability to coordinate propulsive forces could cause a greater intracyclic velocity variation due to a systematic break of inertia, which in turn would lead to greater energy expenditure [9]. So far, the bilateral force difference has been detected even in the world's fastest swimmers [6].

The main causes of bilateral force asymmetry are injuries [1, 17] and factors related to propulsive force generation, i.e., hand velocity and features which can change the hand path [8], such as the breathing pattern, body roll and others.

Some of these factors can be susceptible to situations present in a normal training session which include, among others, the use of implements for propulsive force development (i.e., hand paddles, parachutes, elastic tubes and others). Paddle swimming, particularly, is widely used and recognized by coaches and researchers due to its mechanical [5, 10, 11], metabolic [13] and neuromuscular similarities [10, 11] to free swimming. However, it is still unknown how artificial hand surface enlargement affects the bilateral propulsive force difference.

Thus, considering the potential impact of bilateral propulsive force symmetry on swimming performance and the lack of information about the effects of paddles on it, the main objective of the present study was to investigate the possible modifications caused by different sizes of hand paddles in the bilateral force difference during front crawl swimming.

MATERIALS AND METHODS

SUBJECTS

Fourteen well-trained and competitive national level male swimmers participated in this study (age - 20.0 ± 3.7 years; body mass - 76.3 ± 8.6 kg; fat percentage - 8.6 ± 2.6%; height - 1.84 ± 0.08 m; arm span - 1.88 ± 0.09

m; percentage from the 100-m freestyle world record - 87.4 ± 1.4%). They were short-distance crawl-stroke specialists (50, 100 and/or 200 m) and had more than four years of competitive swimming experience (9.0 ± 4.4 years), including training with paddles (7.3 ± 3.1 years). The subjects were fully informed about the procedures before giving their written consent to participate. The study had approval from the Campinas State University's Ethics Committee.

EXPERIMENTAL PROCEDURES

Prior to data acquirement, a hand paddle shape available in four sizes was selected; in the present study the sizes were marked as: small (280 cm²), medium (352 cm²), large (462 cm²) and extra-large (552 cm²), as shown in Figure 1. These models were chosen because they are nationally manufactured and widely used by Brazilian coaches.

Figure 1. Shapes and sizes of the hand paddles tested

During one testing session, the swimmers were submitted to a fully tethered swimming force evaluation. The test protocol adopted, which will be described below, was repeated in each condition analyzed: (1) free swimming (FREE), with small (PP), medium (PM), large (PG) and extra-large hand paddles (PGG).

All the tests were performed using the front crawl stroke, on the same day, in the week after the main competition of the season. The water temperature was 27 ºC. As warm-up, the swimmers performed 10-minute active stretching, 10-minute free swimming, and four 15 m sprints 90 seconds apart. After this, about five minutes were given to start the tests.

PROPULSIVE FORCE

Propulsive force was measured using fully tethered swimming. The system consisted of a load cell with four strain gages, 2000 N of maximum capacity and 30 g of maximum resolution. One of its extreme ends was fixed to a specially designed support attached to the starting platform, while the other was connected to an inextensible cable system, in which the swimmer was tethered (Figure 2).

Mechanical deformations in the load cell, generated by the swimmer's efforts, were recognized by an A/D interface, which converted the analog voltage into a digital signal. Data were stored in a data acquisition program at 600 Hz. Raw data were smoothed using a forth-order butterworth low pass digital filter [14]. The cut-off frequency of eight hertz was determined with a residual analysis [20]. The system was calibrated using increments of 20 kg until the maximum weight of 100 kg and the force values were obtained through the calibration straight line. Prior to the testing session, the calibration was checked using a weight of 9.4 kg.

Even though most of the swimmers were used to the equipment, a specific procedure, described earlier [3], was conducted for familiarization.

The test protocol consisted of two 10-s maximal swimming with a 4-minute rest, adopted according to ATP-CP resynthesis, which can last between three to five minutes [4]. The beginning (after approximately five seconds of moderate swimming) and the end of the test protocol were signaled by a whistle. In order to minimize the effects of changing swimming intensities, the first second swum maximally was discarded. During the test, swimmers were instructed to hold their breath and the leg kick was allowed. The cycle frequency was self-chosen. A typical force-time curve obtained in a 10-s test protocol is shown in Figure 3. Each peak represents one single stroke.

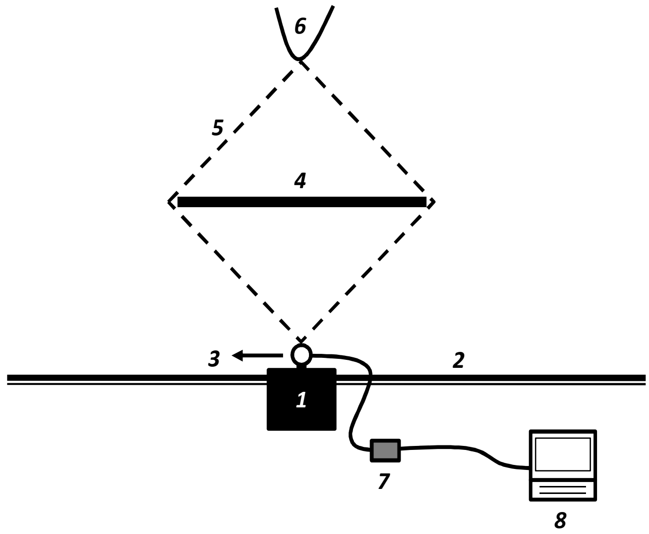

Figure 2. Top view of tethered swimming: (1) starting platform, (2) wall, (3) load cell, (4) floating bar, (5) inextensible cables, (6) belt, (7) interface and (8) computer

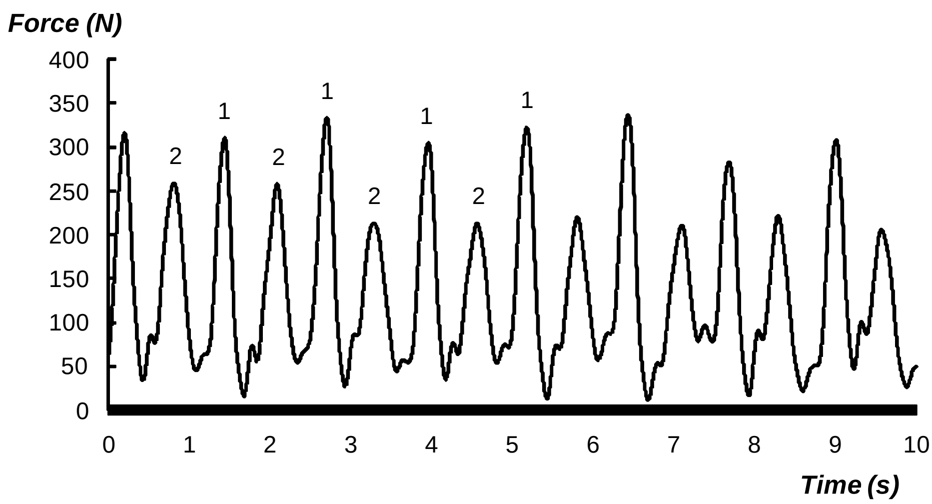

Figure 3. Typical crawl-stroke force-time curve during a 10-s test; 1 = Force peaks of the stronger stroke, 2 = Force peaks of t he weaker stroke

The test protocol was repeated five times, i.e., in the conditions FREE, PP, PM, PG and PGG. In an intent to attenuate any possible influence of the previous paddle size on the swimmers' stroke sensitivity, an intermission of 100 m swimming freely plus two passive minutes were adopted.

The bilateral difference in each condition was detected through the peak force analysis obtained in eight consecutive strokes. Considering the alternated characteristic, the stroke defined as stronger (STR) was the one which presented the higher mean peak force value found in four non-consecutive strokes. Consequently, the lower mean peak force value found in four non-consecutive strokes determined the weaker stroke (WKR) (Figure 3). The STR and WKR force values obtained in the first and second efforts, in each condition, were averaged for statistical analysis. Bilateral difference was expressed by the percentage difference between STR and WKR.

Statistical Analysis

All statistical analysis was conducted using SPSS for Windows (Version 16.0; SPSS, Inc., Chicago, IL). Normality and homogeneity were tested by Shapiro-Wilk's and Levene's tests, respectively. The comparison between STR and WKR was made using Student's t test for independent samples. In this case, variables were described using mean and standard deviation.

Due to a non-parametric distribution detected in FREE, the bilateral differences of all conditions were described through a box-plot graph and the comparisons among the situations were made using the Kruskal-Wallis test. The Mann-Whitney test, with the Bonferroni adjustment, was used to detect any possible significant difference. Due to great inter-participant variability, the lower individual values of the bilateral difference obtained with hand paddles, independently of the size, were grouped and compared to those found in FREE. For this, Mann-Whitney test was used. The significance level was set at $p<0.05$.

RESULTS

There was a significant difference between the stronger and the weaker strokes in all the conditions analyzed, as shown in Figure 4.

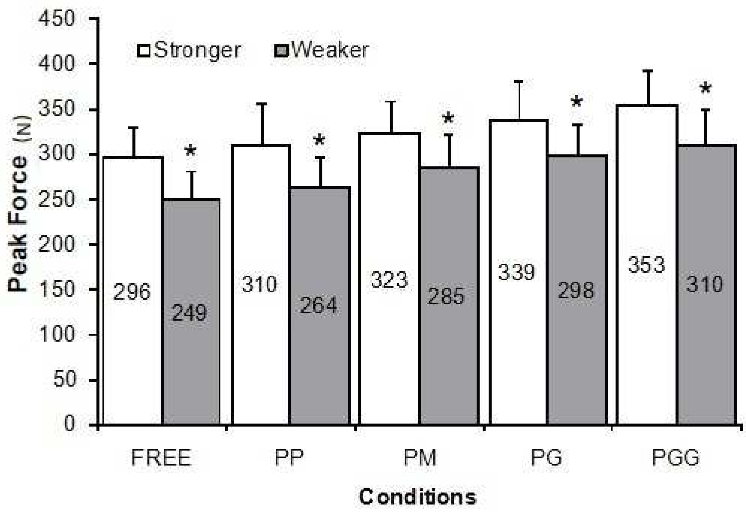

Figure 4. Force peaks (mean ± SD) of the stronger (STR) and weaker strokes (WKR) in free swimming (FREE) and with small (PP), medium (PM), large (PG) and extra-large hand paddles (PGG)

* Intra-condition significant difference ($p<0.05$) in relation to the stronger stroke

In comparison to FREE, no significant changes were detected in the bilateral difference when PP, PM, PG and/or PGG were used (Figure 5).

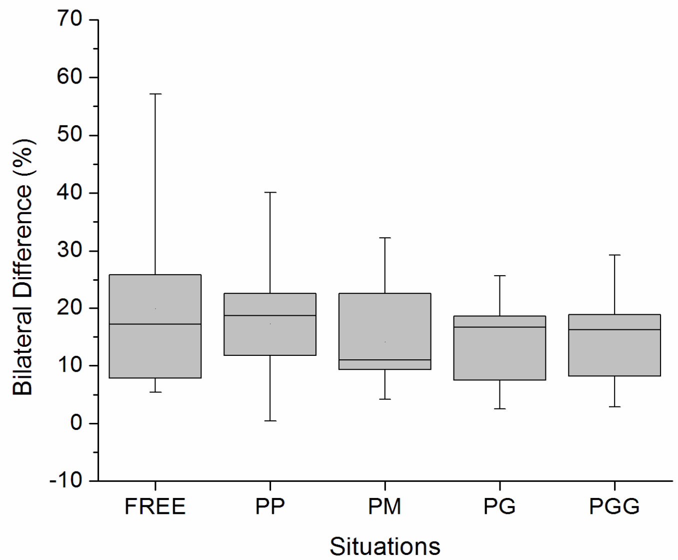

Figure 5. Box-plot of the bilateral differences in free swimming (FREE) and with small (PP), medium (PM), large (PG) and extra-large hand paddles (PGG)

Individual behavior of the bilateral difference throughout the conditions is presented in Table 1.

Table 1. Individual bilateral difference in all the situations analyzed

	FREE	PP	PM	PG	PGG
A.S.	5.4%	0.4%	9.6%	7.5%	8.2%
B.M.	5.8%	13.9%	9.5%	18.6%	18.8%
C.C.	42.2%	20.1%	26.2%	21.3%	29.3%
C.M.	17.2%	24.8%	5.4%	17.6%	22.2%
F.M.	20.6%	14.7%	13.6%	16.7%	18.5%
F.R.	10.2%	11.8%	9.4%	15.1%	16.9%
G.D.	12.5%	11.7%	4.4%	4.7%	3.7%
G.R.	7.0%	22.5%	25.9%	9.6%	12.6%
H.M.	10.8%	18.7%	11.0%	4.3%	8.6%
J.B.	21.9%	3.7%	10.2%	10.4%	5.9%
M.F.	25.9%	40.1%	32.2%	25.4%	28.3%
M.K.	57.1%	23.2%	22.6%	2.5%	2.9%
M.R.	33.9%	21.9%	4.2%	25.7%	9.2%
W.C.	7.8%	14.8%	14.1%	18.0%	16.3%

FREE = free swimming, PP = small paddle, PM = medium paddle, PG = large paddle. PGG = extra-large paddle

A significant reduction ($p<0.01$) was identified when the lower individual values of bilateral difference obtained with hand paddles, independently of the size, were compared to those found in FREE (FREE - median: 14.9%, interquartile range: 20.3%, minimum: 5.4%, maximum: 57.1% vs. Hand paddles - median: 7.4%, interquartile range: 10.0%, minimum: 0.4%, maximum: 25.4%).

DISCUSSION

The present study aimed to identify the acute effect of different sizes of hand paddles on the bilateral force difference of national competitive swimmers. In all the conditions, an approximately 50 N difference was observed between the peak force of the stronger and weaker strokes. Thus, despite of force augmentation caused by the artificial enlargement of the hands, it happened proportionally in both strokes. These results do not necessarily show that hand paddles cannot be used as a tool for bilateral force difference attenuation.

In fact, the individual data showed that the asymmetry of each swimmer varied according to the different sizes of hand paddles. From the 14 participants evaluated, 11 displayed a reduction of the bilateral difference when the implement was used. The small one was the “best” size for three of them (A.S., C.C. and J.B.), while the medium was for four (C.M., F.M., F.R. and M.R.), the large for two (M.F. and M.K.) and the extra-large for one (G.D.).

The data also show that the effect of a given size is specific and not necessarily will be reproduced by any other size, even in a lower degree. The participant A.S., for example, experimented with an attenuation of the bilateral force asymmetry with PP. However, the differences noticed with the other sizes were higher than that found in FREE.

It is also valid to emphasize the relevant effect of the paddles on the participant M.K. His severe asymmetry of 57% in FREE was dramatically reduced to approximately 3% when PG and/or PGG were used. As normally the stroke is accomplished at a very high velocity, the swimmers might not be able to reproduce a similar movement in the right and left sides. When paddles are worn there is a recognized hand velocity reduction [5], which would allow a swimmer’s better concentration during both actions and, therefore, the reproduction of an more symmetrical alternated movement as well.

These individual behaviors should be expected since the same external resistance may be proportionally different among the swimmers. In fact, when a given size of paddle is worn, hand surface of all the swimmers becomes equal. Hence, at the same hand velocity, swimmers with small hands will have a greater percentage increase in resistance to overcome than those who have a larger hand surface. Besides, it is also expected that morphological and neuromuscular individualities could differentiate the intra-group capacity of propulsive force production for each paddle size.

Then, returning to the group analysis, when lower individual values of bilateral difference obtained with hand paddles, independently of the size, were compared to those found in FREE, it was detected that hand surface enlargement occasioned a significant reduction of bilateral force difference (approximately 49% in the median). Therefore, generally, the employment of hand paddles seems to be valid during technical training sessions.

Nevertheless, it is important to detect the primary cause of this inter-arm force disequilibrium in free swimming, since it is the condition demanded in competition and most used during the training. Breathing has been indicated as the probable cause of this asymmetry. According to Havriluk [7], breathing, executed while the head rotates, could distort body position and modify arm movements. Consequently, some reverberations could occur in attack and/or sweepback angles, which are recognized as determinant factors for propulsive force production [2, 19]. Although there is no consensus [7, 12, 16], it is probable that the ordinary execution of respiratory movements could lead to the incorporation of these deviations to swimming technique and then generate bilateral force asymmetry. Therefore, it is strongly desirable that movement pattern employed in the stronger stroke could be reproduced in the weaker one, especially during breathing.

As reported previously, there is a predominance of the drag force (D) in detriment of the lift in crawl-stroke [15], which, according to the hydrodynamic theory, can be expressed by the following equation:

$$D = 0.5 \cdot \rho \cdot Cx \cdot S \cdot v^2$$

Where "ρ" is water density, "Cx" is the drag coefficient, "v" is hand velocity and "S" is the frontal area of the hand perpendicular to the movement.

Based on this, it can be concluded that hand velocity plays an important role in the propulsive force generation, essentially because of its quadratic relation to drag. Therefore, the increase of the weaker hand velocity could be used as a strategy in those cases in which a very similar spatial pattern would be observed in both strokes (i.e., similar attack and sweepback angles) jointly to a severe bilateral difference.

For those swimmers who did not display any bilateral force difference decrease in relation to FREE (B.M., G.R. and W.C.), it could be possible to increase the external resistance only in the weaker stroke. However, it is not known how this would affect the equilibrium of the others swimming actions, like leg kick, body roll and others. In these cases, other strategies could be found to solve the bilateral differences, such as an association of kinesthetic and visual resources [8].

CONCLUSION

The present results showed that artificial enlargement of hands can acutely reduce bilateral force difference in national competitive swimmers. However, the best size of paddles should be individually chosen, considering the variability of the effects of each one among the swimmers.

PRACTICAL APPLICATION

Hand paddles are widely used for increasing swimmers' propulsive force and the present study showed the important effect of their different sizes on the bilateral force difference. Thus, coaches and sport scientists can test their swimmers to find their individual proper size.

ACKNOWLEDGEMENTS

The authors would like to thank CEFISE for the tethered swimming system. The present research was, in part, supported by the Brazilian Federal Agency for Support and Evaluation of Graduate (CAPES).

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Serbian Journal of Sports Sciences