Original Paper DOI: 10.5604/959287 Biol. Sport 2011;28:207-211

THE INFLUENCE OF LOWER LIMB MOVEMENT ON UPPER LIMB MOVEMENT SYMMETRY WHILE SWIMMING THE BREASTSTROKE

Accepted for publication 28.04.2011

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ABSTRACT: This study 1) examined the influence of lower limb movement on upper limb movement symmetry, 2) determined the part of the propulsion phase displaying the greatest hand movement asymmetry, 3) diagnosed the range of upper limb propulsion phase which is the most prone to the influence of the lower limbs while swimming the breaststroke. Twenty-four participants took part in two tests. Half of them performed an asymmetrical leg movement. The propulsion in the first test was generated by four limbs while in the second one only by the upper limbs. The pressure differentials exerted by the water on the back and on the palm of the right and left hand were measured. Then, the asymmetry coefficient of the hand movement was determined. No changes in the level of the asymmetry index in participants performing correct (symmetrical) lower limb movement were observed. Incorrect (asymmetrical) leg motion resulted in an increase of hand asymmetry. It could be concluded that lower limb faults neutralize upper limb performance when swimming on a rectilinear path. However, most asymmetrical arm performance should be identified with the conversion of propulsion into recovery. Nevertheless, its proneness to influence improper leg performance might be expected at the beginning of arm propulsion.

KEY WORDS: **pressure differential, propulsive phase, arm-leg coordination, motor control**

INTRODUCTION

In contrast to locomotion on land, the upper limbs play the main role in swimming propulsion [1,32], although in the case of the breaststroke opinions differ [13,21,25]. The surface of the hand is the most important propulsion surface [31]. Its trajectory and angle of attack determine the level of propulsion [10,24]. However, it is generated not by pressure on the palm, but by the pressure differential between the palm's surface and the back of the hand [31,32].

It is accepted that symmetrical movements of the upper and lower limbs can be observed in each of the competitive swimming strokes. Mirror symmetry occurs in the breaststroke and butterfly, in which both upper (lower) limbs perform the same movements simultaneously. In contrast, translational symmetry (phase-shift) can be found in the front and back crawl strokes. The movement trajectory of the extremities is the same but it is obtained alternately. The results of research conducted on land reveal a lack of dynamic and kinematic asymmetry of upper limb movements in breaststroke simulation [4,5]. In observations of front crawl stroke simulation [6,20] the asymmetry increases in research conducted in natural conditions [18,26]. Kinematic asymmetry of the legs while swimming the breaststroke is quite frequent. It increases together with swimming velocity [3]. The asymmetrical leg movement leads to veering off from straightforward swimming [8]. Is it due to hand corrections that the swimmer moves on a rectilinear path, when leg movements are asymmetrical? Breaststroke arm-leg coordination is often studied [11,12,13,27] but there is no information about its relationship to movement symmetry. Hence, the purpose of this research was: i) to determine the influence of lower limb movement on upper limb movement symmetry while swimming the breaststroke, ii) to determine the part of the propulsion phase displaying the greatest hand movement asymmetry, iii) to diagnose the range of upper limb propulsion phase which is the most prone to the influence of the lower limbs.

MATERIALS AND METHODS

Participants. Twenty-four males participated in the study. They were university students with no professional background in swimming. It was decided to assess non-experts because they presented an evident asymmetry of leg movement in the breaststroke. They were separated into two groups according to their leg performance.

Half of them performed the correct (symmetrical) lower limb movements (group I). Twelve students (group II) manifested evident asymmetry of leg movements, by displaying different angle positions between the equivalent segments of the right and left limb during recovery and propulsion. As a result the right and left foot moved along different trajectories. The division of participants into groups was made by two experienced coaches. The criteria were FINA (International Swimming Federation) rules for the breaststroke. Each participant was informed about the research and expressed written consent for participation. The research was approved by the Senate Committee for the Ethics of Scientific Research. The characteristics of the participants are presented in Table 1.

Data analysis

The recorded signals were filtered by a 4th Order Butterworth Filter at 12 Hz cut-off frequency. Propulsion phases from the 6[th] to the 10[th] cycle of both tests were analysed. The upper limb propulsion phase starts when the limbs, extended forward, begin to move to the sides and to the back. It ends when the hands stop their backward movement. The arms then straighten in recovery forward [14,25]. It was assumed that the evident increase in pressure differential for the former corresponded to the beginning of the propulsion phase. The decrease of the measured signal for the latter, to the value obtained at the beginning of the phase, indicated the end of propulsion (Figure 1).

TABLE 1. CHARACTERISTICS OF THE PARTICIPANTS (MEANS ± STANDARD DEVIATION)

	Group	
	I (n=12)	II (n=12)
Age [years]	20.7 ± 1.0	20.3 ± 0.9
Body weight [kg]	75.1 ± 9.0	75.0 ± 8.0
Body height [cm]	180.7 ± 6.8	178.8 ± 4.2
t 15 m H+L [s]*	15.9 ± 2.9	21.6 ± 4.2
t 15 m H [s]*	22.9 ± 4.8	30.5 ± 8.0

Note: Group I - correct (symmetrical) leg movements, Group II - incorrect (asymmetrical) leg movements, t 15 m H+L- the time of swimming a distance of 15 m using hands and legs, t 15 m H - the time of swimming a distance of 15 m using only hands, * - significance level p<0.05

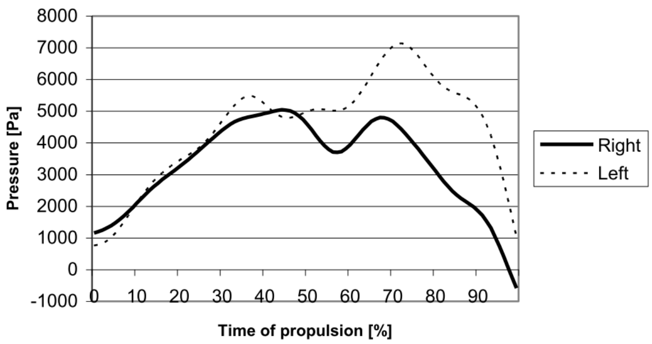

FIG. 1. PRESSURE DIFFERENTIAL FOR RIGHT AND LEFT HAND DURING PROPULSION- INDIVIDUAL DATA

The research stand

The hand generates the major propulsion force during swimming [35]. Thus, sensors were placed between the third and fourth finger of the right and left hand, and connected to a computer by a wire, which ran along the upper limbs to the back, outside the water to a rod, and then to the computer. During measurement the rod followed the participant at the same velocity. This way the drag created by the wire was minimized. Two Honeywell (USA) 26PCB type 5 differential pressure sensors were used. Their pressure range is 345 hPa. They measured the difference of water pressure between the back and the palm of each hand, which resulted from hand movement only. The depth of the sensor immersion did not influence the level of the signal. The sensors were calibrated prior to measurement.

Data collection

The research was conducted in a 25 m long swimming pool. The task of the participant was to swim the breaststroke a distance of 15 m twice at maximal speed: i) using both the hands and legs (H+L), ii) using only the breaststroke movements of the upper limbs (H) – this time, a pull-buoy was placed between the lower limbs and they did not generate propulsion. The subject started without pushing off from the wall or bottom of the swimming pool. The swimming time and the pressure differentials were recorded for the right and left hand separately during both tests. The signal was sampled at a frequency of 100 Hz.

Then, on the basis of the Vagenas and Hoshizaki [33] equation, modified for our needs, the asymmetry coefficient (*A*) for each sample of upper limb movement propulsion phase was calculated as

$$A = \frac{|P_R - P_L|}{2 \cdot max(|P_R|,|P_L|)} \cdot 100\% \qquad (1)$$

where P_R and P_L are the values of the pressure differential for the right and left hand, respectively. The denominator represents the modulus of the highest time sample value between P_R or P_L multiplied by two. When $A=0\%$, hand movement is symmetrical ($P_R=P_L$ and $P_R>0$ and $P_L>0$). Positive asymmetry is for a score of $0\%<A<50\%$ ($P_R>0$ and $P_L>0$ and $P_R \neq P_L$). $A=50\%$ represents borderline asymmetry, while one limb obtaining pressure differential equals 0 ($P_R=0$ and $P_L>0$ or $P_L=0$ and $P_R>0$). For $50\%<A<100\%$ asymmetry is negative ($P_R>0$ and $P_L<0$ or $P_R<0$ and $P_L>0$). $A=100\%$ represents full asymmetry of hand movement ($P_R= -P_L$).

Next, the mean of the asymmetry coefficient for the propulsion phase of each participant was determined. To compare the courses of hand movement asymmetry during propulsion, their normalization against time was introduced. Then, the mean changes in the asymmetry of hand movement were computed for each type of breaststroke and group studied.

Statistical analysis

Normal distribution (Shapiro-Wilk test) and the homogeneity of variance (Bartlett test) were verified. They authorized parametric statistics. The analysis of variance (two groups x two types of breaststroke) with the type of breaststroke as a repeated measure factor was used to identify the differences in the asymmetry index of propulsion. It was followed with a Fisher *post-hoc* test. A *T-test* investigated the differences between courses of asymmetry of hand movements of the two types of breaststroke. Each time unit of the course was tested separately. Statistical analyses were made with Statistica software (StatSoft, Inc., USA). The level of significance was set at $p<0.05$.

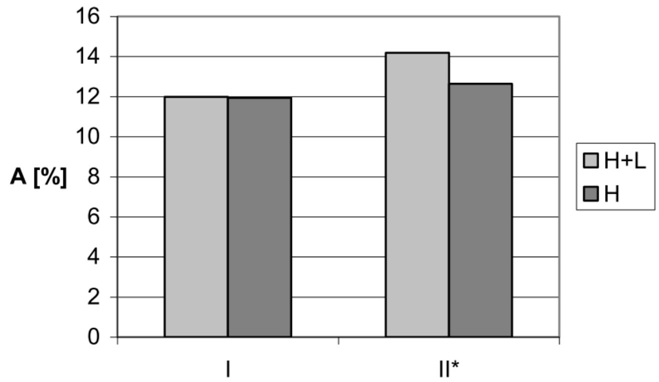

FIG. 2. ASYMMETRY OF HAND MOVEMENTS WHILE SWIMMING TWO TYPES OF BREASTSTROKE: USING HANDS AND LEGS (H+L) AND USING ONLY HANDS (H)

Note: Group I – correct (symmetrical) leg movements, Group II – incorrect (asymmetrical) leg movements, * – significance level p<0.05

RESULTS

The examined groups displayed no differences in anthropometric features. However, the time of swimming a 15 m distance was significantly different ($p<0.05$) for the test performed in two types of swimming (Table 1).

There were no changes in the level of hand movement asymmetry in swimmers performing correct leg movements (group I) regardless of the type of lower limb activity (Figure 2). In the case of group II incorrect (asymmetrical) leg movements resulted in an increase of hand movement asymmetry. The ANOVA revealed that in the sample examined, the change of the type of breaststroke resulted in larger differences in the level of upper limb asymmetry ($F(1,22)=2.32$; $p=0.14$) than did the manner of leg movement performance ($F(1,22)=1.29$; $p=0.27$) but not significantly. Only in the group performing incorrect lower limb movement did the Fisher *post-hoc* test display statistically significant differences ($p<0.05$) in upper limb movement asymmetry between the two types of swimming.

In the groups under study, one tendency was observed regardless of the leg movement or the manner of its performance (Figure 3). At the beginning of the propulsion phase, the value of the hand movement asymmetry decreases and stabilizes in the area of the 2nd

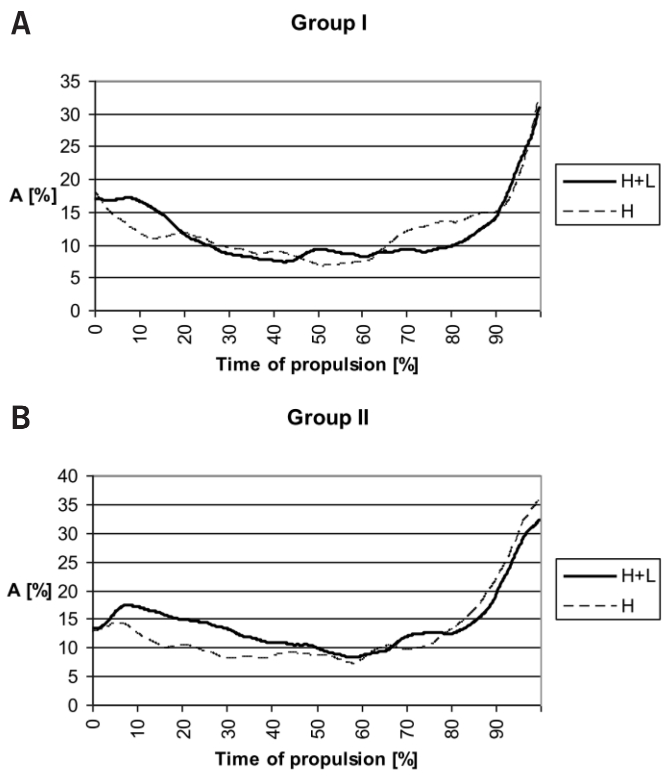

FIG. 3. CHANGES IN THE ASYMMETRY OF HAND MOVEMENT IN THE PROPULSION PHASE OF THE TWO TYPES OF BREASTSTROKE (H+L AND H) DURING CORRECT (A) AND INCORRECT (B) LEG MOVEMENTS

H – HANDS

L – LEGS

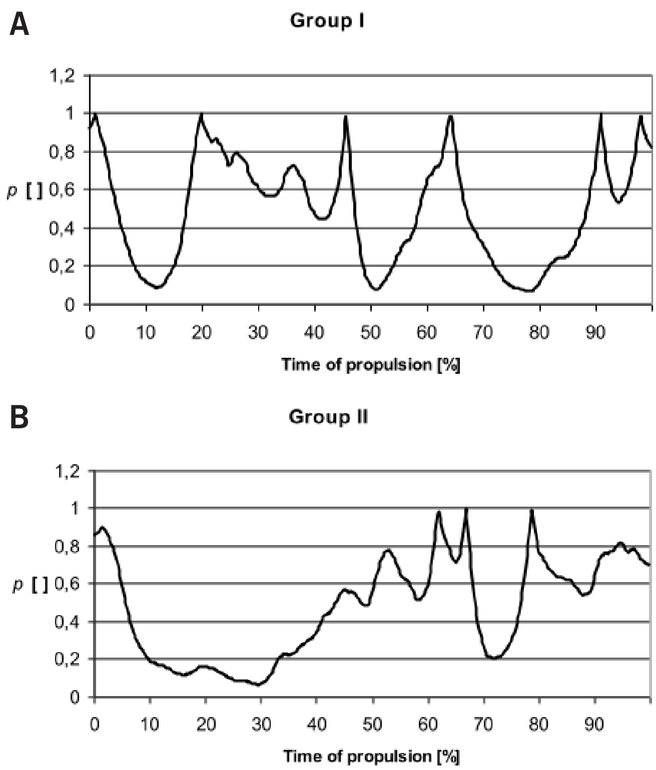

FIG. 4. DIFFERENCES, EXPRESSED AS VALUE OF SIGNIFICANCE LEVEL COEFFICIENT (P), BETWEEN THE COURSES OF ASYMMETRY OF HAND MOVEMENTS OF TWO TYPES OF BREASTSTROKE (H+L AND H) IN THE PROPULSION PHASE DURING CORRECT (A) AND INCORRECT (B) LEG MOVEMENTS

and 3rd quarter of the phase duration. It corresponds to the gradual change from outsweep to insweep. Then, it rapidly increases in order to achieve a maximum value at the end.

In both groups no significant differences ($p>0.05$) were observed between the courses of upper limb movement asymmetry in the two types of swimming examined (Figure 4). However, in the group performing incorrect lower limb movement, a certain type of tendency can be observed. The value of the difference became closer to statistically significant values, remaining at a constant level, from 10 to 30% time of the propulsion phase. This corresponded to the middle of the outsweep.

DISCUSSION

The influence of lower limb movement on upper limb movement symmetry while swimming the breaststroke

Twelve participants performed evident asymmetrical leg movement during breaststroke swimming. These faults and the longer swimming times achieved by them suggest the lower skills of this group [18]. The results obtained would seem to agree with the thesis on the compensation activity of upper limb performance, in the case of lower limb disturbances, while swimming. Symmetrical leg movement did not cause any change of hand movement asymmetry. However, asymmetrical lower limb movement was associated with an increase of upper limb movement asymmetry. It is probably in this way that the human movement system can control the global symmetry necessary in straightforward locomotion. The elimination of the source of disruption, i.e. asymmetrical leg activity [8], caused improvement in the hand motion of the second group.

The existence of hand movement asymmetry when the legs do not propel is interesting. It could be expected that the upper limbs – as a precise tool – ought to have displayed full symmetry during this test. However, that was not observed. Possibly, the asymmetry observed reflects the existence of asymmetry characteristic to all humans [7,16,19]. During gait the legs may have different tasks [22,23]. One limb supports the body while the other one propels. Similar differences in the functioning of upper limbs during front crawl swimming have been observed [26]. Due to this relationship, these types of locomotion would be naturally asymmetrical. Nevertheless, in the breaststroke, the limbs perform mirror movements. Although they are easier to control [9,28] they rarely occur in pure form. It is possible that the asymmetries observed in the examined groups also result from the different functions of the upper limbs. Moreover, it may be a manifestation of the search, by the movement system, for an optimal solution accompanied by external or internal interferences.

The fragment of the propulsion phase displaying the greatest upper limb movement asymmetry

Peaks in hand asymmetry appeared at the beginning and especially at the end of the propulsion phase (Figure 3). The curves of upper limb movement asymmetry resemble the inverse curves of the forces generated [14]. It seems that the development of minimal movement asymmetry responds to the development of maximal force, and vice versa. This may indicate that the level of limb movement asymmetry is inversely proportional to the force developed by those limbs. On the other hand, when comparing movement trajectory [15] with the courses of upper limb asymmetry, the greatest asymmetry value is manifested during the dynamic change of hand movement direction. This takes place when the propulsion changes into recovery. The hands are moved backward to the chest and then forward. Then the swimmer's speed is the highest [30]. In some cases the upper limbs might perform different phases at this time (Figure 1). One limb may finish the propulsion while the other one may start the recovery. Although such hand performance may be disadvantageous for muscle symmetrization in the shoulder girdle [29] and straight swimming direction, it may facilitate more economical activity. The change from mirror movement to alternate movement results in smaller oscillations of the swimmer's velocity in the cycle and average velocity increase [17]. A reduction of velocity fluctuation may also be attained by undulation in breaststroke [2,34].

The range of propulsion phase which is the most prone to the influence of the lower limbs

Only group II revealed relative upper limb susceptibility to lower limb influence (Figure 4b). This is understandable as its members performed incorrect leg movements. This susceptibility was observed in the first part of propulsion. This probably describes the time when the hands compensated leg movements. But why was its appearance slightly delayed? Is it related to different types of coordination? There are three types of breaststroke coordination: 1) hands start propulsion after gliding, 2) leg propulsion is followed directly by hand propulsion, 3) the end of leg propulsion overlaps the beginning of hand propulsion [15,25,27]. The existence of the mentioned delay suggests the second or third type of coordination [12]. Some delay in compensation is needed to find the effect of leg propulsion. Then hand correction can be made.

The method used is objective and repeatable. It gives rapid feedback to the experienced coach, with the results being easy to archive for future comparisons. This method, however, has its limitations. The area of application is constrained by the length of the wire and rod. Radiotelemetry seems to solve this problem. Moreover, this system does not provide a complete description of swimming performance. For this purpose, it should be combined with video recording. The main value of this method, for coaches and scientists, is the opportunity to find relationships between leg and arm performance in straightforward breaststroke swimming. The monitoring of limb symmetry will yield the weak points of performance. In the case of excessive asymmetry, targeted training should be started. Asymmetric leg activity should be practised without arm participation to avoid harmful leg influence on arm performance. Other drills are recommended to decrease hand asymmetry at the end of propulsion; for instance, the insweep could be finished by a clapping of the appropriate fingertips of right and left hands. Finally, at this stage of study, further questions arise: “what is the level of hand asymmetry in elite swimmers?” and “do females present a lower level of asymmetry than males?”

CONCLUSIONS

This study indicates that, during breaststroke swimming, there is a mutual interaction between the upper and lower limbs. Hand propulsion is characterized by a relatively steady level of movement asymmetry. Its increase means compensation of local asymmetry affected by incorrect leg movement. This compensation probably appears at the beginning of hand propulsion. Nevertheless, the highest level of hand movement asymmetry occurs at the end of upper limb propulsion. It seems to be the result of an asynchronous ending of propulsion.

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