Original paper

Arm–leg coordination in recreational and competitive breaststroke swimmers

Hugues Leblanc, Ludovic Seifert ∗, Didier Chollet

University of Rouen, France

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Abstract

The aims of this study were to assess the durations of the different arm and leg stroke phases (propulsion, glide, and recovery) and the temporal arm–leg gaps between 12 competitive and 12 recreational breaststroke swimmers. The mean ages and best times for a 50-m breaststroke were, respectively, (recreational: 16.9 ± 1.6 y; 49.55 ± 3.38 s; competitive: 16.2 ± 1.5 y; 33.85 ± 1.96 s). Each swimmer was required to swim 2 × 25-m breaststroke at two different paces (slow and sprint) while being videotaped by two underwater cameras (frontal and lateral views). At the same given speed, recreational swimmers used no glide phase which increased the relative contribution of their recovery and propulsive phases. This was mainly caused by the superposition of their leg extension and the second part of their arm recovery, indicating a technique with no glide time between the arm recovery and the leg extension. In terms of phase duration, the recreational swimmers spent more time in arm recovery and in propulsive phases. Furthermore, it was observed that for a comparable increase of swimming speed (recreational: 23.3%, competitive: 22.6%), competitors switched from a glide to an overlapped coordination while recreational swimmers adopted an overlapped technique whatever the swimming speed. As a result, the relative time spent in propulsive phases did not change in the recreational group, but increased by 27.2% in the competitive one. In a swimming developmental program, particular emphasis should be put on arm–leg coordination drills, when considering the breaststroke.

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1. Introduction

Competitive breaststroke is characterized by the underwater recovery of the limbs. To face this constraint, the swimmers simultaneously recover their arms and legs, and then the sequence leg kick, glide, arm pull and in-sweep follows. According to the glide time, three kinds of coordination are observed1: (1) glide where the body stays fully extended and streamlined before the arm catch, (2) continuous where the arm catch takes over just as the leg kick is completed, (3) overlapped where the arms start their catch and outward motion before the completion of the leg kick. The individual characteristics and the swimming speed are two factors that can influence the arm–leg coordination of a swimmer. For example, Sanders2 found that the glide phase could vary from 0 to 0.55 s per cycle at race pace in male elite swimmers. Concerning the swimming speed, glide coordination has been observed in 200-m events, whereas during shorter races (100 and 50 m), continuous or overlapped coordination is more likely used.3–5 This adaptation eventually allows the swimmer to swim at a higher stroke rate and speed.

The coordination patterns of competitive breaststrokers can give knowledgeable information to the swimming coach, but they give [because the subject is plural: patterns] no hints to understand the coordination of beginners. Up-to-date data are scarce on this topic. In a former electromyographic study,6 the arm pulling phase of unskilled young breaststroke swimmers was associated with noticeable discharges of the rectus femoris muscle, which inserts on the ilium and on the patella and is a hip flexor. It was concluded that the arm pull occurred at the same time as the leg recovery. In other words, the swimmers were simultaneously doing two contradictory actions—from one hand, the leg recovery, which caused a drop of velocity, and from the other hand, the arm propulsion. The authors, however, did not make an analysis of the...
stroke phases or investigate at different swimming speeds. Therefore, this study was twofold: (i) to make an accurate assessment of the temporal aspects of the arm–leg coordination of recreational swimmers; (ii) to analyze the evolution of the arm–leg coordination under different speed conditions. Within this frame, two hypotheses can be made: firstly recreational swimmers are expected to perform their leg kick while recovering their arms and to do their arm pull while recovering their legs. Secondly, their coordination pattern is not expected to evolve from a glide to a continuous or overlapped mode like skilled swimmers do, essentially because they feature no glide phases during their stroke cycle.

2. Methods

Twenty-four male swimmers participated in this study after giving their written consent. Twelve competitors swam at a French regional level, and twelve recreational swimmers were high school students with no particular background in swimming. The main characteristics of the subjects were (for competitors and recreational swimmers, respectively) age: 16.2 ± 1.5 y., mass: 71.2 ± 6.9 kg, height: 176.5 ± 7.8 cm, best time on 50 m: 33.85 ± 1.96 s; which represented 77.3 ± 4.4% of the short course male world record on January 1st/2007; and 16.9 ± 1.6 y., 69.4 ± 10.8 kg, 174.6 ± 11.5 cm, 49.55 ± 3.38 s, 50.9 ± 8.2% (percentage of world record = (swimmer time/world record) × 100). No significant differences were found between the two groups for age, mass, and height. Recreational swimmers had significantly lower best times on the 50-m breaststroke ($F_{1,22} = 193.40$), which represented a smaller percentage of the world record ($F_{1,22} = 226.56$). The $F$ values given here represent the statistical distribution of the ratio of two variates. It was significant if $F > 4.30$.

Before the trials, each swimmer was randomly assigned a passing order. Then, each of them was asked to swim at an imposed velocity over a set of 2 m × 25 m (slow then sprint phases), with 5 min rest in-between. For competitors, the slow pace corresponded to a 400-m breaststroke (their coaches provided the targeted time in reference to training practice). Knowing the performance level of the two groups, the 400-m speed of the competitors was expected to match the sprint speed of the recreational swimmers. After each trial, all swimmers were informed of their performances. Competitors were asked to swim within ±2.5% of their targeted time. Beginners were only asked to swim their slow trial about 20% over their sprint time as recorded during a 25-m pre-test. The trials were monitored by two experienced timers who controlled the stroke rate and the speed with a stopwatch and a Seiko Base 3-frequency-meter to validate each trial. If this was not the case, the subject had to repeat the trial.

Two Samsung SC107 digital camcorders (DV format) were connected via an AV/DV analagical input to two underwater cameras (respectively, from a frontal and an 11-m side view). A third camcorder (Canon Obtura DV) placed on the pool deck videotaped and timed the swimmers over a distance of 12.5 m (between the 10 m and the 22.5 m marks made on the pool edges), enabling calculation of the average swimming speed and stroke rate. The stroke length was computed from this speed and the stroke rate values. A flash light was used to synchronize the pictures, with an accuracy of 1/66 s.

After being downloaded on a PC, the pictures were analyzed with Dartfish Prosuite 4.0® software (Atlanta, GA). Underwater views could be mixed and synchronized to enable the data treatment. The acquisition rate was of 66 frames s$^{-1}$.

These phases have been previously described. Briefly, for each pair of limbs, three phases were defined: propulsion, glide, and recovery. The leg in-sweep was also characterized as the time elapsed between the end of the leg extension and their joined position.

To obtain consistent measurements, the graphic tools of the software were used. For the arm phases, a vertical line which passed through the shoulder profile axis was drawn to have a fixed reference on the swimmer's body. The leg/thigh angle was measured to determine the leg maximal extension and end of recovery. The feet distance was checked on the frontal view to determine the leg in-sweep phase.

Four temporal gaps between the arm and leg actions were defined:

T1: From the end of the leg in-sweep to the beginning of the arm propulsion.

T2: From the beginning of leg recovery to the beginning of the arm recovery.

T3: From the end of leg recovery to the end of the arm recovery.

T4: From the leg extension to the end of the arm recovery.

T1 was calculated in order to quantify the time during which the body is fully extended and glides. T2 and T3 aimed to quantify the arm–leg coordination during the recovery phase. T4 was calculated because it evaluated the synchronization of the extension of the two pairs of limbs.

The propulsive index was computed by doing the sum of the leg and the arm propulsive respective durations. If a propulsive phase of one pair of limbs overlapped the recovery phase of the other pair, then the overlapped duration was subtracted from the propulsive phases.

3. Data analysis

Standard statistical procedures were applied to compute means and standard deviations. The normality of the distributions (Shapiro–Wilk test) and the homogeneity of the variances were controlled, allowing the use of parametric statistics. Two-way ANOVA on repeated measures were computed (among subject factor: skill level, within subject factor: swimming speed). Post hoc comparisons were made by using the Bonferroni test. The level of significance was set at $p < 0.05$. 


As no significant difference was found between the sprint speed of recreational swimmers, and the slow speed of competitive swimmers, it was chosen to compare the two groups at the same given speed, while facing a comparable hydrodynamical constraint.7

4. Results

At the same given swimming speed, competitors covered a significantly longer distance per cycle while maintaining a lower stroke rate (SR) (p < 0.05) (supplementary Table 1).

The arm propulsive (relative values) and recovery (relative and absolute values) phases were significantly longer in the recreational group (p < 0.05). By contrast, the arm glide phase appears significantly shorter in this group, both in absolute and relative values (p < 0.05).

No significant difference was found regarding the leg propulsive phase. As expressed in relative values, the recreational group spent a significantly longer time performing its leg recovery. The leg glide was significantly smaller in the recreational group (relative values) (p < 0.05). The duration of the leg in-sweep was not significantly different between the two skill levels (supplementary Table 2).

In the recreational group, T1 which expressed the glide time, appeared to be significantly shorter (p < 0.05) in the recreational group (relative and absolute values) (supplementary Table 3). No difference was noticed for T2, measuring the time interval between the beginning of the arm and leg respective recoveries. The time interval measured at the end of the arm and leg recovery (T3) showed a significantly greater negative (p < 0.05) value in the recreational group. T4 measuring the time interval between the arm and leg respective extensions was smaller in the recreational group (relative and absolute values). Finally, the propulsion index of the recreational swimmers was significantly smaller in absolute values.

Recreational and competitive swimmers performed the sprint trials at a significantly (p < 0.05) greater speed, with a higher SR and a shorter stroke length (SL) (supplementary Table 1). The percentage of increase of speed between the slow and the sprint trials were not significantly different between the two groups (respectively, 23.34% ± 0.09 for recreational swimmers and 22.56% ± 0.06 for competitive swimmers).

The arm propulsion phases significantly decreased in recreational as in competitors (relative values, p < 0.05). However, in the recreational group, this was also verified in absolute values. The gliding phase of the arm significantly decrease in the competitive group (p < 0.05), but remained unchanged in the recreational group, whatever the pace. The arm recovery phase significantly decreased in real terms in the recreational swimmers. The leg propulsion phase showed a similar evolution than that of the arm. Competitive and recreational swimmers significantly diminished their leg glide with the increase of speed (p < 0.05). For both groups, the leg recovery phase significantly decreased but only in absolute value (p < 0.05) (supplementary Table 2).

In both groups, the gliding parameter T1 duration was significantly smaller at sprint speed. T2, T3 and T4 parameters did not evolve with the speed increase in any of the groups (p < 0.05). Only T4 as expressed in percentage significantly increased in the competitive group.

In the recreational group, the propulsive index remained constant in relative value, but statistically significantly decreased in absolute terms (p < 0.05). Inverse conclusions are noted in the competitive group (supplementary Table 3).

5. Discussion

5.1. Skill level comparison at a given speed (sprint pace for recreational swimmers vs. slow pace for competitors)

The first research hypothesis was partially confirmed: recreational swimmers perform their arm recovery while doing their leg kick, showing a simultaneous extension of their two pairs of limbs. However and contrary to what was expected, they did not pull with their arms while recovering their legs. This seems more a characteristic of novice children8 than more mature swimmers.

In a former study, Saito9 measured the stroking characteristics of 163 beginners aged 15–16 y in breaststroke swimming. After a 6-week period of training, the swimmers performed at a higher speed and this was related to an improvement of their SL, as their SR did not change. This evolution was attributed to an improvement of the arm and leg movements in combination. This coordination aspect will be discussed hereafter.

5.1.1. Glide vs. motor continuity

The T1 parameter, which characterized the motor and propulsive continuity after the leg kick, was always positive in the recreational group. This indicates that the arm propulsive phase started before the end of the leg in-sweep. By contrast, the competitive group used a gliding coordination at slow speed. It has also been observed that elite breaststrokers use glide coordination at sub-maximal speed4,10 Meanwhile, they are able to maintain a higher intra-stroke velocity than less-competitive swimmers during this non-propulsive phase, just before the arm could take over.11,12

5.1.2. Recreational swimmers have longer arm recovery

The two groups of swimmers spent the same amount of time recovering their legs, starting at the same moment. However, the recreational swimmers’ arms took far longer to recover. This may be linked to a longer breathing time. Swimming educators routinely observed that beginners can have an incomplete expiration during the propulsive phase of the arm, which forces them to finish expiring when their mouth emerges, just before taking their breath. In total, the recreational group spent nearly 50% of one stroke cycle in
the arm recovery, i.e. in a decelerating phase, as opposed to 29.4% in the competitive group. As a direct consequence, an overlapping was noticed between the arm recovery and the leg extension as the negative value of T3 parameter shows. Further analysis showed that the mean angle formed by the swimmers’ arms and forearms at the end of the leg recovery was of 95.1° in the recreational swimmers as compared to 156.4° for the competitive swimmers (supplementary Figs. 1 and 2 for typical examples).

In recreational swimmers, the end of the extension of the lower and upper limbs was simultaneous. Some authors have suggested that the central nervous system imposes two kinds of constraints in the organization of inter-limb coordination. In the first kind (so-called egocentric), the limbs are naturally drawn to perform a synchronized motion toward or away from the longitudinal axis of the body. This seemed to govern the simultaneous arm and leg extension that was observed in seven out of twelve of the recreational swimmers showing a symmetrical pattern between the arms and the legs with respect to the longitudinal axis of their body (supplementary Fig. 3). In this mirror-like pattern, these swimmers extended their arms forward and outward, diagonally, along with the leg outward and backward extension. The six other swimmers extended their arms in a joined position, featuring more a transversal arm–leg symmetry.

In the second kind of constraints (so-called allocentric), non-homologous limbs (arms vs. legs) tend to have a synchronized motion in the same direction. That could explain why all the swimmers synchronized their leg and arm respective recoveries: the flexion of the legs was associated with the extension of the arms, with both movements directed forward with respect to the swimmers’ body. In the case of recreational swimmers, however, this constraint seemed to be overcome by the egocentric constraint in the second half of the movement.

5.1.3. At a given speed, recreational as competitors used the same timing to perform their leg and arm propulsive actions

The direct consequence of the absence of glide phase in recreational swimmers was that the proportion they devoted to the propulsive and recovery parts of their arm and leg was greater in comparison with those of competitors.

The same timing was used by all swimmers to perform their leg propulsive phase, but competitors could take advantage of the thrust produced by their leg kick because their arms were already recovered and well aligned. In contrast, recreational swimmers could barely perform any glide because they had already done their leg kick when this glide should have appeared. Recreational as competitive swimmers spent the same amount of time to complete their arm propulsive phase. But this does not necessarily mean that recreational swimmers did effectively apply propulsive forces in the water. It has been already observed that for a given arm-stroke duration, elite swimmers are able to produce more acceleration of their body and to cover a longer distance during this phase. This may contribute to the larger SL of elite swimmers who covered 0.50 m more distance per stroke.

Finally, no differences were found in the relative duration of the propulsive index, but in real terms, this index was smaller in the recreational swimmers, as a direct consequence of their overlapped coordination. By doing so, the swimmers performed two opposite actions altogether: the arm recovery which occurred underwater and opposes the forward progression of the swimmer; and the leg extension which causes a velocity increase. Given that, the recreational swimmers could barely perform an efficient leg propulsive action. This may account for the higher SR they used to maintain the same speed as competitive swimmers.

5.2. Effect of speed increase on coordination

The second hypothesis was confirmed: having no glide time, recreational swimmers can hardly modulate their coordination according to the swimming speeds.

5.2.1. Recreational swimmers overlapped their propulsive phases

At sprint speed, T1 decreased both in percentage and in real time. From an overlapped coordination, recreational swimmers moved even more deeply in this type of coordination. An exaggerated overlap time led the swimmers to start their arm propulsion while their leg kick was still accelerating their body. As a result, they might have increased their form drag because their arms were no longer streamlined. Form or pressure drag constitutes a resistive force and forms when water has to be moved away from the swimmer’s body as it progresses forward. This overlapped time of the recreational swimmers is linked to the shortening of their arm recovery and causes an earlier catch up. The video replay often shows a partial extension of the arm during the end of the recovery at sprint pace. The resistance they faced could even have worsened as they tried to recover their arm as fast as possible at sprint pace. In swimming, it is well established that a body must overcome a resistive force (drag) that increases with its squared velocity. Water is some 820 times more dense than air, and the specificity of this medium may have a strong impact on the coordination. At higher speeds, breaststroke swimmers must increase their propulsive force while minimizing the drag they oppose to motion. This is quite a difficult task because an increasing propulsive force will result in an increase of resistive force. This is particularly acute in the breaststroke where all the recovery phases are performed underwater. This could constrain swimmers of different skill levels to adopt an overlapped coordination.

5.2.2. Recreational swimmers face difficulties to adapt their coordination

With the speed increase, competitors switched from a glide to an overlapped coordination while the other swimmers seemed “locked” in the overlapped mode. This is consistent
with the results obtained by Soares et al.\(^3\) who did not note any change in relative arm and leg phase durations of swimmers under different speed conditions. To reinforce this, the relative value of the propulsive index did not evolve in the competitive group as a result of the decrease of the T1 (glide) parameter. In this study, beginners somehow were not able to adjust their coordination according to the pace. Paradoxically, by adopting an overlapped coordination, beginners seem to conform to a mechanical principle: eliminating the dead space in propulsion in order to limit the decrease in intra-stroke velocity. Nevertheless, this was not associated with a longer SL or a higher speed as was the case in the competitive group.

The observation of the coordination pattern of recreational swimmers reflects a common view of teaching methods where the arm recovery is represented as occurring during the leg extension. If the teaching process does start on the basis of the motor repertoire of the subject, it should not confine him to a coordination that could impede further progress.

**Practical implications**

- Swimming educators should include coordination and glide drills in their programs to improve the arm–leg coordination of recreational swimmers.
- Swimmers should practice coordination drills, (e.g. two kicks to one arm pull breaststroke), gliding drills (e.g. kick only breaststroke), and arm pull and recovery drills (e.g. vertical arm pull or breaststroke pull with flutter kick).

**Appendix A. Supplementary data**

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2008.01.001.

**References**