Arm coordination in elite backstroke swimmers

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Abstract
In this study, we assessed arm coordination in the backstroke over increasing speeds by adapting the index of coordination originally used in the front crawl. Fourteen elite male backstroke swimmers swam four trials of 25 m at the speeds corresponding to the 400-m, 200-m, 100-m, and 50-m events. The six phases of the arm stroke were identified by video analysis and then used to calculate the index of coordination, which corresponded to the time between the propulsive phases of the two arms. With increases in speed, the elite swimmers increased the stroke rate, the relative duration of their arm pull, and their index of coordination, and decreased the distance per stroke ($P < 0.05$). Arm coordination was always in catch-up (index of coordination of $-12.9\%$) because the alternating body-roll and the small shoulder flexibility did not allow the opposition or superposition coordination seen in the front crawl. This new method also quantified the relative duration of the hand’s lag time at the thigh, which did not change (~2%) with increasing speed for the elite swimmers. The index of coordination enables coaches to assess mistakes in backstroke coordination, particularly in the hand’s lag time at the thigh.

Keywords: Testing, motor control, biomechanics, swimming, backstroke

Introduction
Cyclic activities and, more specifically, swimming performance (Hay, 2002) have traditionally been assessed via the speed, stroke rate, and distance per stroke (Chengalur & Brown, 1992; Chollet, Pelayo, Tourny, & Sidney, 1996; Craig & Pendergast, 1979; Kennedy, Brown, Chengalur, & Nelson, 1990; Pai, Hay, & Wilson, 1984). Stroke rate in the backstroke technique was lower than in the butterfly, front crawl, and breaststroke, and distance per stroke was highest in the backstroke and front crawl techniques, suggesting that it is one of the most discriminative variables of performance. However, because backstroke inter-arm coordination is necessarily in catch-up mode (Lerda & Cardelli, 2003b; Lerda, Cardelli, & Coudereau, 2005), an increase in stroke rate does not explain the change in coordination observed in the front crawl (Seifert, Chollet, & Bardy, 2004). Distance per stroke could thus be the main variable responsible for increased speed in the backstroke technique (Chollet et al., 1996), as it provides a means to compensate for the superposition mode, which is impossible in this specific swimming technique (Lerda & Cardelli, 2003b).

Recent studies have shown that the assessment of coordination adds to the information gathered through the classic analysis of stroke rate and distance per stroke. In the alternating strokes (front crawl and backstroke), inter-arm coordination is assessed from the time between propulsive phases of the right and left arms and can be characterized by a time lag between the propulsion moments, continuity in the propulsions, or their superposition. In the front crawl, Seifert et al. (2004) demonstrated speed-related arm coordination; from the 3000 m to the 200 m, swimmers adopted the catch-up coordination mode, during which they tended to glide with the arm extended forward allowing a greater body-roll, whereas they switched to a relative superposition coordination in the sprints. In the backstroke, the alternating body-roll, which could lead to 90° abduction of the shoulder during the mid-pull (Colwin, 2002; Maglischo, 2003), and the small shoulder flexibility (Richardson, 1986; Richardson, Jobe, & Collins, 1980) require both an additional arm stroke phase to recover into the water surface and a particular arm coordination. Indeed, Maglischo (2003), Lerda and Cardelli (2003b), and Lerda et al. (2005) showed that the second upsweep, also called the “clearing phase” (after the push phase...
and before the above-water recovery), does not allow continuity between the propulsive actions of the two arms. Although Maglischo (2003) reported that some swimmers had a “three-peak stroke pattern” with a propulsive second upsweep, this was not the usual pattern. In most cases, swimmers adopt catch-up as their preferential coordination mode (Lerda & Cardelli, 2003b), which is detrimental to propulsive continuity. Propulsive discontinuities could lead to fluctuations in speed. Craig and Pendergast (1979) and Balonas et al. (2006) showed that fluctuations in speed during the arm stroke are lower in the front crawl and backstroke than in the butterfly and breaststroke. Moreover, high intra-cycle fluctuations in speed lead to high energy cost (Alves, Gomes-Pereira, & Pereira, 1996; Barbosa et al., 2006), suggesting that even if catch-up coordination is the only mode possible in the backstroke, swimmers should minimize the lag time in the stroke. However, recent studies on backstroke coordination (Lerda & Cardelli, 2003b; Lerda et al., 2005) included less skilled swimmers and did not assess one important technical variable specifically related to the backstroke: the hand’s lag time (Colwin, 2002). Indeed, Colwin (2002) stated that too great a lag time is a common technical mistake observed in the backstroke.

The aims of this study were thus twofold. The first aim was to assess arm coordination, namely the degree of continuity between the propulsion moments, in relation to speed, stroke rate, and distance per stroke in elite backstrokers over increasing swim speeds. The second aim was to quantify the hand’s lag time at the thigh. It was hypothesized that when swim speed increased, elite swimmers would decrease their catch-up coordination, decrease the hand’s lag time, and increase the distance per stroke to compensate for the lack of continuity between the arm actions.

Methods

Participants

Fourteen elite male backstroke swimmers voluntarily participated in this study. The participants’ mean physical and functional characteristics were as follows: age 19.0 years ($s = 4.6$), height 1.79 m ($s = 0.05$), body mass 70.2 kg ($s = 5.3$), and backstroke 100-m time 59.78 s ($s = 2.08$). The participants included international-standard swimmers who performed to within 89.5% ($s = 3.2$) of the 100-m backstroke world record. The protocol was fully explained to the participants, who provided written consent to participate in the study. The test protocol was approved by Rouen University Ethics Committee.

Swim trials

In a 25-m pool with the water temperature held constant at 28°C, the swimmers performed four successive backstroke trials at increasing speeds separated by 4-min rest periods. Each trial required an individually imposed swim speed corresponding to a specific race distance or training distance, as previously detailed for the front crawl (Chollet, Chalies, & Chatard, 2000): the 400 m, the 200 m, the 100 m, and the 50 m. The trials consisted of swimming at the imposed speed over only 25 m to avoid fatigue effects and maintain the focus on motor control adaptations. The swimmers were instructed to glide no more than 10 m off the wall. After each trial, all swimmers were told their performance time, which was supposed to be within 2.5% of the targeted speed. If this was not the case, the participant repeated the trial. During the trials, speed and stroke rate were monitored with a chronometer and a Seiko Base 3-frequency meter. These measures served only to validate each trial – that is, to ensure minimal discrepancy between the speed expected of each swimmer and the speed at which he actually swam. The experimental data of this study, on the other hand, were obtained by video analysis.

Video analysis

A lateral above-water video camera was superposed on a lateral underwater video camera (50 Hz, Sony compact FCB-EX10L). Both had a rapid shutter speed (1/1000 s) and were fixed on the same trolley. The trolley was pulled along the side of the pool by an operator at the same speed as the swimmer, with each participant’s head being the mark followed by the operator to control parallax. The two cameras were connected to a double-entry audio-visual mixer (Videonics MX-1), a video timer, a video recorder, and a monitoring screen to genlock and mix the lateral underwater and aerial views on the same screen.

A third camera (50 Hz, Sony compact FCB-EX10L) videotaped the swimmers from a frontal underwater view and this was genlocked and mixed with the lateral underwater view on another screen. From this video device, three operators analysed the key points of arm phase with a precision of 0.02 s using a blind technique. The three analyses were compared only when each operator had completed their own analysis. When the difference between the three video analyses did not exceed an error of 0.04 s, the mean of the three analyses was accepted to validate the key point of each phase. When the error exceeded 0.04 s, the three operators together undertook a new assessment of the phase key points.
Finally, a fourth camera (50 Hz, Panasonic NV-MS1 HQ S-VHS), genlocked and mixed with the lateral underwater view for time synchronization, videotaped all the trials of each swimmer with a profile view from above the pool. This camera allowed the measurement of the time it took the swimmers to cover a distance of 12.5 m (from 10 m to 22.5 m), which was then used to obtain the mean speed and stroke rate. Two plots delimited the 10-m and 22.5-m points on the right and left sides of the swimming pool. When the head of the swimmer reached the rope line at 10 m, time was recorded until the head reached the line at 22.5 m. The stroke rate was obtained by counting the requisite number of video frames for the three strokes over the 12.5 m. Using the mean speed and the stroke rate, the distance per stroke could be calculated: distance per stroke = (speed × stroke rate)/60.

Arm coordination

Arm coordination was quantified using an adapted index of coordination (IdC) (Chollet et al., 2000). The mean duration of each phase was determined with a precision of 0.02 s and was expressed as a percentage of the overall duration over three strokes.

Each movement of the arm was broken down into six phases (Chollet, Carter, & Seifert, 2006) (Figure 1):

1. **Entry and catch of the hand in the water**: this phase corresponds to the time between the entry of the hand into the water and the beginning of its backward movement that is followed by a diagonal hand sweep.

2. **Pull**: this phase corresponds to the time separating the beginning of the hand’s backward movement (followed by a diagonal hand sweep) and its arrival in a plane vertical to the shoulder and is the first part of propulsion.

3. **Push**: this phase corresponds to the time from the position of the hand below the shoulder to the end of the hand’s backward movement and is the second part of propulsion.

4. **Hand lag time**: this phase corresponds to the time during which the hand stops at the thigh after the push phase and before the clearing (Colwin, 2002; Maglischo, 2003).

5. **Clearing**: this phase corresponds to the time from the beginning of the hand release upward to the beginning of its exit from the water. For swimmers with a “three-peak stroke pattern”, this second upsweep is the third part of the

![Figure 1. Arm stroke phases in backstroke of the left and right arms.](image-url)
propulsion, but few swimmers present this pattern (Maglischo, 2003).

6. **Recovery**: this phase corresponds to the point of water release to water re-entry of the arm—that is, the above-water phase.

In this study, propulsion was not considered as hand-force production (as defined in biomechanics) but was instead conceived as a voluntary act to propel the body forward (as defined in motor control). The duration of the propulsive phase was the sum of the pull and push phases, and the duration of the non-propulsive phase was the sum of the entry and catch, hand lag time, clearing, and recovery phases. The IdC was defined as the time lag between the beginning of propulsion in the first right arm stroke and the end of propulsion in the first left arm stroke, and between the beginning of propulsion in the second left arm stroke and the end of propulsion in the first right arm stroke (Chollet et al., 2000). For each trial, the mean IdC was calculated on three complete strokes and expressed as a percentage of the mean duration of the stroke. Three coordination modes are possible in the front crawl (Chollet et al., 2000), not all of which have been observed in the backstroke (Lerda & Cardelli, 2003b; Lerda et al., 2005): when a lag time occurs between the propulsive phases of the two arms, the stroke coordination is called “catch-up” (IdC < 0); when the propulsive phase of one arm starts when the other arm ends its propulsive phase, the coordination is called “opposition” (IdC = 0); when the propulsive phases of the two arms overlap, the coordination is called “superposition” (IdC > 0).

**Statistical analysis**

For the means of the four speeds, a normal distribution (Ryan Joiner test) and homogeneity of variance (Bartlett test) were verified for each variable, allowing parametric statistics to be used (Minitab 13.20, Minitab Inc., 2000). One-way repeated-measure analyses of variance were used to determine the speed effect (Minitab 13.20, Minitab Inc., 2000) followed by *post-hoc* Tukey tests. Finally, a polynomial regression analysis established the relationships among the distance per stroke, the stroke rate, the IdC, and the speed. For all tests, statistical significance was set at \( P < 0.05 \).

**Results**

**Speed, stroke rate, and distance per stroke**

When the imposed swim speeds increased, speed and stroke rate increased while distance per stroke decreased (Table I). As noted in Figures 2a and 2b, a polynomial regression linked stroke rate to speed and distance per stroke to speed.

**Arm stroke phases and arm coordination**

As shown in Table II, the increase in swim speed led to an accompanying increase in the propulsive phase (\( P < 0.05 \)), which was significant for the pull phase (\( P < 0.05 \)), and consequently a decrease in the non-propulsive phase (\( P < 0.05 \)). These changes in the arm stroke phases increased the IdC with increasing speed (Figure 2c), which indicated less discontinuity between the propulsive actions of the right and left arms. However, IdC remained negative throughout the speeds, which is a characteristic of catch-up coordination.

**Discussion**

**Speed, stroke rate, and distance per stroke**

In agreement with Pai et al. (1984), Klentrou and Montpetit (1992), and Chollet et al. (1996), when speed increased, speed and stroke rate increased and distance per stroke decreased. According to Hay (2002), in his review of cyclic activities, the relationships between stroke rate and speed and between distance per stroke and speed are polynomial functions. However, Table III shows that these changes were not always similar: (i) for the 200-m event, speed ranged from 1.45 m·s\(^{-1}\) in our study to 1.59 m·s\(^{-1}\) (Chengalur & Brown, 1992; Chollet et al., 1996), stroke rate ranged from 34.8 strokes·min\(^{-1}\) in our study to 43.8 strokes·min\(^{-1}\) (Pai et al., 1984), and distance per stroke ranged from 2.15 m·stroke\(^{-1}\) (Pai et al., 1984) to 2.65 m·stroke\(^{-1}\) (Chollet et al., 1996); (ii) for the 100-m event, speed ranged from 1.56 m·s\(^{-1}\) in our...
study to 1.85 m·s⁻¹ (Masset, Rouard, & Taı¨ar, 1999), stroke rate ranged from 39 strokes·min⁻¹ (Masset et al., 1999) to 47.4 strokes·min⁻¹ (Chollet et al., 1996; Kennedy et al., 1990), and distance per stroke ranged from 2.08 m·stroke⁻¹ (Kennedy et al., 1990) to 2.85 m·stroke⁻¹ (Masset et al., 1999).

Figure 2. Polynomial regression between stroke rate and speed (a), distance per stroke and speed (b), and index of coordination and speed (c).

Table II. Arm phases and IdC, according to the imposed swim speeds (mean ± s).

<table>
<thead>
<tr>
<th>Imposed swim speeds</th>
<th>Catch phase (%)</th>
<th>Pull phase (%)</th>
<th>Push phase (%)</th>
<th>Hand time lag (%)</th>
<th>Clearing phase (%)</th>
<th>Recovery phase (%)</th>
<th>Propulsive phase (%)</th>
<th>Non-propulsive phase (%)</th>
<th>IdC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-m</td>
<td>17.5 ± 4.5</td>
<td>18.1 ± 1.9</td>
<td>15.8 ± 3.2</td>
<td>2.4 ± 0.9</td>
<td>14.1 ± 3.1</td>
<td>31.9 ± 3.4</td>
<td>33.9 ± 2.9</td>
<td>66.1 ± 2.9</td>
<td>16.3 ± 2.8</td>
</tr>
<tr>
<td>200-m</td>
<td>16.9 ± 4.1</td>
<td>18.5 ± 1.9</td>
<td>17.4 ± 3.1</td>
<td>2.1 ± 0.7</td>
<td>13.6 ± 3.0</td>
<td>31.4 ± 3.2</td>
<td>35.9 ± 3.6</td>
<td>64.1 ± 3.6</td>
<td>14.2 ± 3.6</td>
</tr>
<tr>
<td>100-m</td>
<td>15.2 ± 3.7</td>
<td>20.7 ± 1.8c</td>
<td>17.8 ± 3.2</td>
<td>1.8 ± 0.5</td>
<td>14.0 ± 3.1</td>
<td>30.4 ± 3.2</td>
<td>38.5 ± 3.5c</td>
<td>61.5 ± 3.5c</td>
<td>11.4 ± 3.7</td>
</tr>
<tr>
<td>50-m</td>
<td>14.6 ± 3.8</td>
<td>21.4 ± 2.2bc</td>
<td>18.6 ± 2.7</td>
<td>1.8 ± 0.4</td>
<td>13.8 ± 2.9</td>
<td>29.8 ± 3.2</td>
<td>40.0 ± 3.9bc</td>
<td>60 ± 3.9bc</td>
<td>9.9 ± 4.2</td>
</tr>
<tr>
<td>Mean</td>
<td>16.0 ± 4.1</td>
<td>19.7 ± 2.4</td>
<td>17.4 ± 3.2</td>
<td>2.0 ± 0.7</td>
<td>13.9 ± 2.9</td>
<td>30.4 ± 3.2</td>
<td>37.1 ± 4.1</td>
<td>62.9 ± 4.1</td>
<td>12.9 ± 4.2</td>
</tr>
<tr>
<td>F-value (n = 56)</td>
<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
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<td>$F_{5,52} = 9.4$</td>
<td>$F_{5,52} = 9.4$</td>
</tr>
<tr>
<td>Effect size ($R^2$)</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
</tr>
</tbody>
</table>

Note: All arm phases and IdC are expressed as a percentage of a complete arm stroke.

*aGreater or less than preceding speed, bGreater or less than 200-m, cGreater or less than 400-m, P < 0.05. IdC = index of coordination; n = number of strokes swum; $F_{5,52}$ is the degree of freedom where 3 refers to the imposed swim speeds (4 speeds – 1 = 3), while 52 is the residual error (total – imposed swim speeds = 56 – 4 = 52).*
The differences between our results and those of previous research could be due to the absence of fatigue in our study, since the swimmers had to reproduce the pattern of each speed over only 25 m. Moreover, the technique we used might explain why we obtained the slowest speeds and different values of stroke rate and distance per stroke. In our study, only the swim time in the central 12.5 m of the pool was taken into account to calculate the clean speed, whereas most of the studies in the literature included the dive, the turn-in, and the turn-out, which overestimates the mean speed (Chollet & Pelayo, 1999). Thus, to attenuate the differences in the spatial-temporal values noted between the studies, four speeds were imposed, which enabled us to scan all the speeds, stroke rates, and distances per stroke observed in the different studies.

Arm stroke phases and arm coordination

In elite front crawl swimmers, some studies (Chollet et al., 2000; Millet, Chollet, Chalies, & Chatard, 2002; Seifert et al., 2004) have shown that an increase in speed leads to a change in arm coordination mode. In contrast, in our elite backstroke swimmers, the IdC was substantially negative whatever the speed, indicating that the swimmers maintained the catch-up coordination. In the front crawl, the catch-up mode is adopted for slow speeds (Chollet et al., 2000; Millet et al., 2002; Seifert et al., 2004) and by less skilled swimmers (Chollet et al., 2000; Lerda & Cardelli, 2003b). For the backstroke, the present results for elite swimmers and the results of Lerda and Cardelli (2003b) for less skilled swimmers suggest that all swimmers irrespective of standard use this coordination mode for all speeds. Indeed, Lerda and Cardelli (2003b) reported an IdC of −9.67% for the more expert backstrokers (speed = 1.44 m·s⁻¹ for 100 m) and an IdC of −11.33% for the less expert swimmers (speed = 1 m·s⁻¹ for 100 m). As seen in the front crawl (Chollet et al., 2000; Keskinen & Komi, 1993; Millet et al., 2002; Seifert et al., 2004) and for less skilled backstrokers (Lerda & Cardelli, 2003b), this change in motor organization (i.e. a rise in IdC) is explained by the increase in the relative duration of the propulsive phase (pull and push) and the corresponding decrease in the relative duration of the non-propulsive phase (entry and recovery).

Catch-up appears to be the exclusive coordination mode in backstroke, due to limited shoulder flexibility (Richardson, 1986; Richardson et al., 1980) and the alternating body-roll (Colwin, 2002; Maglischo, 2003; Richardson et al., 1980). These two characteristics of the backstroke impose a particular coordination between the two arms and an additional phase in the arm stroke, the clearing phase (Lerda & Cardelli, 2003b). Indeed, Richardson et al. (1980) noted that body-roll was maximal at the transition between the pull and push phases, with the shoulder in 90° abduction. Colwin (2002) and Maglischo (2003) observed that the push phase of one hand entailed a body-roll to the opposite side, which enabled the entry and catch phase of the other hand. Thus, unlike in the front crawl where the push phase is followed by the exit and recovery phase, in the backstroke the hand is 0.48 m underwater at 75% of the stroke duration (Masset et al., 1999) and this is followed by a clearing phase before the exit of the hand. This clearing phase, however, prevents continuity between the propulsive phases of the two arms, except when a “three-peak stroke pattern” is

<table>
<thead>
<tr>
<th>Authors</th>
<th>Events</th>
<th>Speed (m·s⁻¹)</th>
<th>Stroke rate (strokes·min⁻¹)</th>
<th>Distance per stroke (m·stroke⁻¹)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present study</td>
<td>2003</td>
<td>1.34 ± 0.13</td>
<td>30.0 ± 5.0</td>
<td>2.71 ± 0.29</td>
<td>400 m</td>
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<tr>
<td></td>
<td></td>
<td>1.45 ± 0.11</td>
<td>34.8 ± 5.3</td>
<td>2.53 ± 0.25</td>
<td>200 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.56 ± 0.09</td>
<td>40.5 ± 5.2</td>
<td>2.33 ± 0.22</td>
<td>100 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.62 ± 0.09</td>
<td>44.3 ± 5.1</td>
<td>2.21 ± 0.21</td>
<td>50 m</td>
</tr>
<tr>
<td>Masset et al.</td>
<td>National Championship 1994</td>
<td>1.85 ± 0.10</td>
<td>39.0 ± 3.6</td>
<td>2.85 ± 0.29</td>
<td>100 m</td>
</tr>
<tr>
<td>Chollet et al.</td>
<td>French Championship 1992, 1993, 1994</td>
<td>1.59 ± 0.03</td>
<td>41.1 ± 2.7</td>
<td>2.65 ± 0.17</td>
<td>200 m</td>
</tr>
<tr>
<td>Chengalur and</td>
<td>Olympic Games 1988</td>
<td>1.59 ± 0.06</td>
<td>42.0 ± 3.0</td>
<td>2.24 ± 0.16</td>
<td>200 m</td>
</tr>
<tr>
<td>Brown (1992)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kennedy et al.</td>
<td>Olympic Games 1988</td>
<td>1.69 ± 0.10</td>
<td>47.4 ± 3.0</td>
<td>2.08 ± 0.13</td>
<td>100 m</td>
</tr>
<tr>
<td>Pai et al.</td>
<td>British Commonwealth Games 1982</td>
<td>1.57 ± 0.03</td>
<td>43.8 ± 2.4</td>
<td>2.15 ± 0.12</td>
<td>200 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.64 ± 0.04</td>
<td>46.8 ± 3.0</td>
<td>2.11 ± 0.11</td>
<td>100 m</td>
</tr>
<tr>
<td>Craig and</td>
<td>US Olympic Trials 1975</td>
<td>1.57 ± 0.10</td>
<td>39.0 ± 6.0</td>
<td>2.40 ± 0.30</td>
<td>200 m</td>
</tr>
<tr>
<td>Pendergast (1979)</td>
<td></td>
<td>1.70 ± 0.10</td>
<td>46.0 ± 7.0</td>
<td>2.24 ± 0.30</td>
<td>100 m</td>
</tr>
</tbody>
</table>
used – that is, a clearing phase that can be partly propulsive in the beginning of the upsweep (Maglischo, 2003).

The consequences of this motor organization are such that three recommendations can be made to improve backstroke performance:

1. Swimmers should minimize the clearing phase (when it is not propulsive) and the hand’s lag time at the thigh, notably by increasing the hand speed in this specific phase that could be achieved by a greater or a faster roll of the shoulder.

2. They should modify their hand sweep from a “two-peak” to a “three-peak stroke pattern”, with a partly propulsive clearing phase (Maglischo, 2003), although this is possible only for swimmers with elbow hyperextension.

3. They should compensate the loss of speed in the clearing phase – which prevents propulsive continuity – by increasing the distance per stroke.

Regarding the first recommendation, IdC analysis should be completed by measurement of the hand’s lag time at the thigh to assess the effectiveness of the coordination, because a common mistake observed in non-expert swimmers is a large lag time at the thigh between the end of the push phase and the beginning of the clearing phase (Maglischo, 2003).

In the present study, we noted that elite swimmers had a short hand lag time (near 2%) relative to the duration of a complete stroke. An indication of their high skill was the observation that this lag time remained short whatever the speed. As regards the spatial-temporal variables, Pai et al. (1984), Kennedy et al. (1990), and Chengalur and Brown (1992) showed that compared with the butterfly, front crawl, and breaststroke, backstroke showed the lowest stroke rate and distance per stroke was greatest in the backstroke and front crawl. These findings suggest that the propulsive discontinuity can be minimized and the time lag due to the clearing phase can be compensated for by using greater distances per stroke. Indeed, for both submaximal speed and maximal speed, the fastest swimmers showed the greatest distances per stroke (Klentrou & Montpetit, 1992). Moreover, Alves et al. (1996) reported that the amplitude of intra-cycle speed variation in the backstroke was positively correlated with energy cost at submaximal speeds. Recently, through an incremental set of 200-m swims until exhaustion, Barbosa et al. (2006) confirmed that the intra-cycle speed variation is correlated with the energy cost in the backstroke ($r = 0.55$), freestyle ($r = 0.62$), breaststroke ($r = 0.60$), and butterfly stroke ($r = 0.55$). These results confirm the importance of increasing propulsive continuity by increasing IdC, minimizing hand lag time, and maximizing distance per stroke, because these modifications reduce intra-cycle speed fluctuations (Alves et al., 1996; Craig & Pendergast, 1979) as well as energy cost (Alves et al., 1996; Klentrou & Montpetit, 1992), ensuring effective propulsion in the backstroke.

**Conclusion**

With increases in speed, elite swimmers increased stroke rate, relative duration of the arm pull and IdC, and decreased distance per stroke. Our results further revealed that arm coordination in the backstroke was always in catch-up mode because the alternating body-roll and limited shoulder flexibility did not allow the opposition or superposition modes typical of the front crawl. This method also quantified the relative duration of the hand’s lag time at the thigh, which did not change (~2%) with increases in speed for the elite swimmers. The IdC can be used by coaches to assess mistakes in backstroke coordination, particularly regarding the hand’s lag time at the thigh.

**References**


