Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

Effect of hand paddles and parachute on the index of coordination of competitive crawl-strokers

Thiago Telles[a]; Augusto C. Barbosa[a]; Mário H. Campos[bc]; Orival Andries Júnior[a]
[a] Laboratory of Aquatics Activities, Physical Education Faculty, State University of Campinas, Campinas, Brazil [b] Laboratory of Instrumentation for Biomechanics, Physical Education Faculty, State University of Campinas, Campinas, Brazil [c] Laboratory of Biomechanics and Bioengineering, Physical Education Faculty, Federal University of Goias, Goiania, Brazil

First published on: 06 January 2011

To cite this Article Telles, Thiago , Barbosa, Augusto C. , Campos, Mário H. and Júnior, Orival Andries(2011) 'Effect of hand paddles and parachute on the index of coordination of competitive crawl-strokers', Journal of Sports Sciences, 29: 4, 431 — 438, First published on: 06 January 2011 (iFirst)

To link to this Article: DOI: 10.1080/02640414.2010.523086

URL: http://dx.doi.org/10.1080/02640414.2010.523086

Journal of Sports Sciences, February 15th 2011; 29(4): 431–438

Routledge
Taylor & Francis Group

Effect of hand paddles and parachute on the index of coordination of competitive crawl-strokers

THIAGO TELLES[1], AUGUSTO C. BARBOSA[1], MÁRIO H. CAMPOS[2,3], & ORIVAL ANDRIES JÚNIOR[1]

[1]*Laboratory of Aquatics Activities, Physical Education Faculty, State University of Campinas, Campinas, Brazil,* [2]*Laboratory of Instrumentation for Biomechanics, Physical Education Faculty, State University of Campinas, Campinas, Brazil, and* [3]*Laboratory of Biomechanics and Bioengineering, Physical Education Faculty, Federal University of Goias, Goiania, Brazil*

(Accepted 8 September 2010)

Abstract

We investigated the effects of hand paddles and parachute on the relative duration of stroke phases and index of coordination of competitive crawl-strokers. Eleven male-swimmers (age: 21.9 ± 4.5 years; 50-m best time: 24.23 ± 0.75 s) were evaluated in four maximal-intensity conditions: without equipment, with hand paddles, with parachute, and with both hand paddles and parachute. Relative stroke phase duration of each arm, swimming velocity, and stroke rate were analysed from video (60 Hz). The index of coordination was quantified based on the lag time between propulsive phases of each arm, which defined the coordination mode as catch-up, opposition or superposition. The stroke rate decreased in all conditions ($P < 0.05$) and swimming velocity decreased with parachute and with paddles + parachutes ($P < 0.05$). The coordination mode changed from catch-up in free swimming ($-2.3 \pm 5.0\%$) to opposition with paddles ($-0.2 \pm 3.8\%$), parachute ($0.1 \pm 3.1\%$), and paddles + parachute ($0.0 \pm 3.2\%$). Despite these variations, no significant differences were observed in relative duration of right and left arm-stroke phases, or in index of coordination. We conclude that the external resistances analysed do not significantly influence stroke phase organization, but, as a chronic effect, may lead to greater propulsive continuity.

Keywords: *Hand paddles, parachute, coordination, swimming, crawl*

Introduction

It is well recognized that propulsive force influences swimming velocity and performance in crawl-strokers (Girold, Calmels, Maurin, Milhau, & Chatard, 2006; Mavridis, Kabitsis, Gourgoulis, & Toubekis, 2006; Toussaint & Vervoorn, 1990). Hand paddles and parachutes are widely employed to increase this parameter, even though there are differences between the paths in which each one generates overload.

Hand paddles allow the artificial enlargement of the hand's surface and, as a result, the swimmer can push off against a bigger mass of water, providing a greater resistance to overcome (Gourgoulis, Aggeloussis, Vezos, Antoniou, & Mavromatis, 2008a; Toussaint, Janssen, & Kluft, 1991). Parachutes, differently, cause an increase in drag, which is added to that ordinarily created by the swimmer's body and movements, and to overcome that resistance, he or she should mobilize more force than in conventional swimming.

As propulsive force depends on both muscle strength and the swimmer's technique (Schleihauf, 1983), it should be expected that high-intensity training sessions, including those with external resistance, would provide the most proximate stroke mechanics normally adopted in free swimming. The effects of these resistance augmentations have primarily been documented through stroke rate and stroke length analysis (Gourgoulis et al., 2008a; Llop, Arellano, González, Navarro, & García, 2002; Llop et al., 2003; Llop, Tella, Colado, Diaz, & Navarro, 2006; Toussaint et al., 1991), with the intent of identifying how different these parameters are from those found in free swimming. Most researchers observed significant changes that varied according to the imposed external load characteristics (Girold et al., 2006; Gourgoulis et al., 2008a; Llop et al., 2002).

In fact, overloaded swimming demands an organization of the neuromuscular system to increase motor unit recruitment (Maglischo, 1993) and, therefore, a greater amount of time is required for such force production. This explains the significant decrease in stroke rate previously reported

Correspondence: A. C. Barbosa, Department of Sports Science, State University of Campinas, Barão Geraldo, Campinas, SP 13083-970, Brazil.
E-mail: augustocarvalhobarbosa@yahoo.com.br

ISSN 0264-0414 print/ISSN 1466-447X online
DOI: 10.1080/02640414.2010.523086

(Girold et al., 2006; Gourgoulis et al., 2008a; Llop et al., 2002), even though, as a predictable chronic effect of systematized resistance training, there should be a greater propulsive force production and a shorter time to reach it without implements as well (Rasulbekov, Fomin, Chulkov, & Chudovsky, 1986). Also, the influence of implements on propulsion and/or drag implies an effect on swimming velocity and, consequently, stroke length.

Many investigations have been conduced in order to establish the behaviour of different biomechanical parameters in overloaded swiming (Gourgoulis, Aggeloussis, Vezos, & Mavromatis, 2006; Gourgoulis et al., 2008a, 2008b, 2009; Sidney, Paillette, Hespel, Chollet, & Pelayo, 2001). One of them is the index of coordination in front-crawl stroke (Chollet, Chalies, & Chatard, 2000; Millet, Chollet, Challis, & Chatard, 2002; Potdevin, Bril, Sidney, & Pelayo, 2006; Seifert, Boulesteix, & Chollet, 2004a; Seifert, Chollet, & Bardy, 2004b; Seifert, Chollet, & Rouard, 2007), which allows a qualitative estimation of phase durations (i.e. entry and catch, pull, push and recovery), lag time between propulsive phases of the two arms and, therefore, propulsive continuity. Propulsive continuity defines the coordination mode, which can be catch-up, opposition or superposition, when the index of coordination is lower, equal, and higher than zero percent, respectively (Chollet et al., 2000).

Previous research showed that expert sprinters, swimming conventionally, tend to increase the index of coordination as long as swimming velocity increases, and adopt opposition (Chollet et al., 2000) or superposition (Millet et al., 2002; Potdevin et al., 2006; Seifert et al., 2004a) as the preferred coordination mode. In these cases, the contribution of the non-propulsive phases (i.e. entry and catch + recovery) is diminished (especially entry and catch), while that of the propulsive phases (i.e. pull and push) is increased significantly (Chollet et al., 2000; Millet et al., 2002; Potdevin et al., 2006; Seifert et al., 2004a).

For national-level swimmers using hand paddles, Sidney et al. (2001) reported a greater contribution of the propulsive phases and, consequently, a significant increase in the index of coordination when paddles were worn, even though the catch-up mode remained predominant. Despite these results, it is unclear how the left and right arms, analysed independently, behave in swimming with paddles. Parachutes, in contrast, were only recently introduced into swimming training and the data available only provides information on stroke rate and length (Llop et al., 2002, 2003), factors strongly affected by resistance augmentation. In addition, a third overloaded situation – when hand paddles and parachutes are used simultaneously – could be examined, which allows the exploration of propulsion increase as well as drag augmentation. However, it is likely that this has not been used because there is a lack of information about its specificity.

Thus, it is unclear whether these overload conditions adversely affect the inter-arm motor organization of male crawl-strokers, particularly when maximal intensity is required. Therefore, the aim of this study was to investigate the effects of hand paddles, parachute, and hand paddles plus parachute on the relative duration of right and left arm-stroke phases and the index of coordination of male crawl-strokers in maximal swimming. It was hypothesized that these implements would lead to a greater propulsive continuity.

Methods

Participants

Eleven well-trained male swimmers (age 21.9 ± 4.5 years) volunteered to participate in the study. To be included, the participants had to have at least 6 years of competitive experience, 5 years experience of training with paddles and/or parachutes, and an index for state competition in 50 or 100 m freestyle. Characteristics of the participants are given in Table I. Written informed consent was obtained and all procedures received approval from the university's ethics committee.

Experimental procedures

All testing was conducted in a 25 m pool, with a water temperature of 27°C. As a warm-up, swimmers performed 10 min of active stretching, 10 min of free swimming, and two 15 m sprints 90 s apart. Testing began about 5 min after completing the warm-up.

Tests consisted of two 25 m maximal swims for each condition analysed: free swimming (i.e. without equipment), with paddles (462 cm^2), with parachute (900 cm^2), and with paddles and parachute together, in a randomized order. Hand paddles were fixed to the swimmer's hand by two adjustable elastic tubes, positioned close to the wrist and middle finger, while the parachute was fitted through a waist belt. The parachute's surface was kept approximately 1 m away from the swimmer's feet, exactly as in their

Table I. Main characteristics of the participants (mean ± *s*).

Variables	Data
Height (m)	1.82 ± 0.07
Arm span (m)	1.89 ± 0.14
Body mass (kg)	75.10 ± 3.62
Hand area (cm^2)	201.15 ± 33.70
50 m best time in a 25 m pool (s)	24.23 ± 0.75

Figure 1. Hand paddles and parachute used in the present study.

training sessions. The implements used are shown in Figure 1.

The area of the hand was estimated by multiplying distances between extreme transverse and longitudinal points of the hand. The same procedure was used to estimate the surface area of the hand paddles and parachute. This was done to ensure that the hand paddles were bigger than the swimmer's hand and also to characterize the external resistance.

Leg kicking was allowed and the swimmers were instructed to execute it at maximal intensity. The number of beats per cycle was monitored by video analysis, with one ascending and one descending movement of the legs considered as one leg cycle. Before and during the trials, swimmers were verbally encouraged by the researchers and others athletes.

A 4 min passive rest was given between trials. According to Gastin (2001), maximum efforts close to 10 s, as in the present study, demand a high anaerobic contribution (estimated to be 94%), especially from the alactic system, and phosphocreatine resynthesis can last between 3 and 5 minutes (Glaister, 2005). The 8 min (4 min active + 4 min passive) between conditions was used mainly to attenuate any possible influence of the implements on the swimmers' stroke sensitivity.

Of the 25 m covered, the first 7 m and last 3 m were not considered to minimize the effects of push-off and finish. For this, two vertical underwater bars were positioned perpendicular to the swimmer's displacement at distances of 7 m and 22 m, respectively (Figure 2). Participants were asked to hold their breath during the 15 m analysed.

All procedures were filmed using two Mini DV cameras (Sony® HC38), operating at a 1/1000 s shutter speed and 60 Hz sampling frequency. The

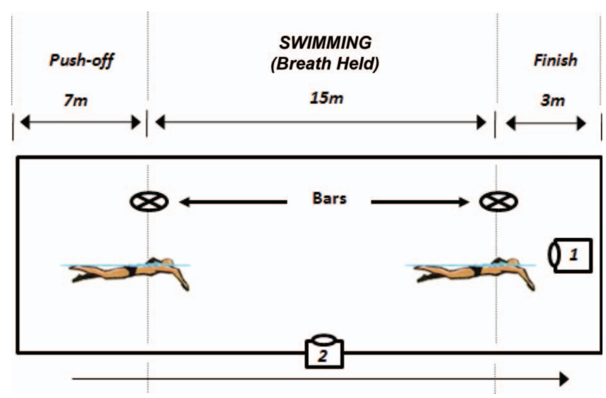

Figure 2. Experimental set-up: 1 = fixed underwater camera, 2 = moving underwater camera.

cameras were placed underwater in waterproof boxes (Sony® SPK-HCC) at a depth of 0.5 m. One camera filmed the swimmer's motion from a fixed frontal view and other from a moving sagittal view, with the aid of a trolley pulled by an operator at the same velocity as that of the swimmer. The cameras were synchronized by a sonorous signal.

Variables sampled

Knowing the distance between bars ($\Delta d = 15$ m), the average swimming velocity (VEL) of each trial was calculated using time spent between them (Δt) according to: $\text{VEL} = \Delta d/\Delta t$. The sagittal view was used to identify the instants when the swimmer's head crossed the 7 m and 22 m bars. Validity of the moving camera velocity measurement was confirmed in a pilot study. One swimmer (age 23 years, training experience 7 years, height 1.85 m, weight 89.9 kg) was asked to undertake a 10×25 m swimming protocol. Results obtained from the moving camera were compared with those acquired simultaneously from two fixed, synchronized cameras, positioned outside the water, 15 m apart, at 7 m and 22 m, with their optical axis perpendicular to the path of the swimmer. All the cameras recorded at a sampling frequency of 60 Hz. Using analysis of variance (ANOVA), we found no differences between methods, an intra-class coefficient correlation of 0.98 (95% confidence interval: 0.94 to 1.00), standard error of measurement of $0.003 \text{ m} \cdot \text{s}^{-1}$, and inter-measure coefficient of variation of 0.17%.

Stroke rate, expressed in cycles per minute, was quantified by analysing the time of the first four complete cycles performed after the initial 7 m. The time between the beginning of the first cycle and the end of the fourth one was computed with the cameras. The stroke rate was then calculated by dividing the number of cycles (i.e. 4 cycles) by the time required to accomplish them (Δt), using the equation: $(60 \star 4)/\Delta t$. Stroke length, expressed in meters per cycle, was obtained by dividing average swimming velocity by stroke rate, which should be converted to cycles per second. Only the fatest effort's data were retained for anlaysis.

Arm movement coordination

Arm coordination was quantified using the index of coordination (IdC), as proposed by Chollet et al. (2000). Stroke movement was divided into four phases:

- *Phase A: entry and catch of the hand in the water*. This phase corresponds to the time between the hand's entry into the water and the beginning of its backward movement.
- *Phase B: pull*. This phase corresponds to the time between the beginning of the hand's backward movement and its alignment in the vertical plane with the shoulder.
- *Phase C: push*. This phase corresponds to the time between the hand's alignment in the vertical plane with the shoulder to its release from the water.
- *Phase D: recovery*. This phase corresponds to the time between instant of release of the hand from the water to its re-entry into the water (i.e. the above-water phase).

Two independent operators assessed key instants of the phases qualitatively using data from the fastest effort only. Standard error of measurement of entry, backward movement, hand's alignment in the vertical plane to the shoulder, and release of the hand from the water was 0.003, 0.035, 0.018, and 0.011 s, respectively. These values are in line with the maximum error (0.04 s) proposed by Seifert et al. (2007). In an effort to attenuate these errors, the two operators together proceeded with a new assessment of the different key instants, and if any discrepancies remained, a third operator was asked to define the instant in question.

The duration of each phase was analysed during four strokes (i.e. two right and two left strokes) with a precision of 0.016 s. Duration of a complete arm movement, defined as the sum of all four phases (A + B + C + D), was also calculated. Therefore, each phase was expressed as a percentage of one total arm stroke (i.e. from the initial entry of one hand into the water to the subsequent entry of the same hand into the water). The propulsive phase is the sum of phases B and C (i.e. pull + push) and the non-propulsive phase is the sum of phases A and D (i.e. entry and catch + recovery).

IdC1 was defined as lag time (LT) between the beginning of propulsion in the first right arm stroke and the end of propulsion in the first left arm stroke (LT1). IdC2 was defined as lag time between the beginning of propulsion in the second left arm stroke and the end of propulsion in the first right arm stroke (LT2). The index of coordination was calculated as follow: (LT1 + LT2)/2, and was expressed as a percentage of the duration of a complete stroke.

This analysis allows three possibilities. When IdC $<$ 0%, there is a non-propulsive lag time in arm strokes, giving a "catch-up" coordination. When IdC = 0%, one arm starts the pull phase at exactly the same time the other arm finishes its push phase. In this case, propulsion between the two arms is uninterrupted and the coordination mode is called "opposition". Finally, when IdC $>$ 0%, the propulsive phases of the two arms overlap and the coordination mode is said to be in "superposition".

Statistical analysis

All statistical analyses were conducted using SPSS for Windows (Version 16.0; SPSS, Inc., Chicago, IL). Normality was tested by Shapiro-Wilk test. Homogeneity of variances was tested using Levene's test. Descriptive statistics of the variables are reported as means $\pm$ standard deviations (s).

The purpose of this study was to evaluate the acute effect of each external resistance on swimming technique, thus each was compared with free swimming. For comparisons of average velocity, stroke length, stroke phases (except phases A and B of the left arm), and index of coordination between conditions, one-way ANOVA was used followed by a Bonferroni *post-hoc* test, when necessary. For the

Table II. Average velocity, stroke rate, and stroke length in free swimming (FREE) and when using hand paddles (HPD), parachute (PCH), and hand paddles plus parachute (HPD + PCH) (mean ± *s*).

	FREE	HPD	PCH	HPD + PCH
Velocity ($m \cdot s^{-1}$)	1.83 ± 0.10	1.87 ± 0.09	1.25 ± 0.11*	1.29 ± 0.13*
Stroke rate ($cycles \cdot min^{-1}$)	59.21 ± 3.54	54.65 ± 7.74*	54.94 ± 4.02*	48.44 ± 5.73*
Stroke length ($m \cdot cycle^{-1}$)	1.86 ± 0.13	2.08 ± 0.26*	1.37 ± 0.09*	1.61 ± 0.14*

*Significantly different from free swimming ($P < 0.05$).

comparisons of stroke rate, and phases A and B of the left arm, which presented a non-parametric distribution, the Krukal-Wallis and Mann-Whitney were adopted to test and detect significant differences, respectively. Statistical significance was set at $P < 0.05$.

Results

Stroke parameters

We found that the factor "implement" has a significant main effect on swimming velocity ($F_{3,40} = 108.03$, $P < 0.0001$), stroke rate ($P < 0.001$), and stroke length ($F_{3,40} = 36.54$, $P < 0.0001$). Compared with free swimming, the *post-hoc* test indicated a significant lower swimming velocity in the parachute and hand paddles + parachute conditions, whereas with hand paddles only a non-significant increase was detected (Table II).

The Bonferroni *post-hoc* test detected that the stroke rate in free swimming was significantly different from all other conditions analysed (Table II). As detailed in Table II, the same significant differences were detected for stroke length when the Mann-Whitney test was employed.

Stroke phases

No statistically significant differences were observed in any of the stroke phases between conditions. Propulsion (B + C) remained unchanged with the overload. Data for the stroke phases are presented in Table III.

Index of coordination

The mean IdC values were not statistically different between conditions. However, there were differences in the coordination modes adopted among the four conditions. From a practical point of view, the IdC changed from catch-up in free swimming (IdC = −2.3 ± 5.0%) to opposition with "hand paddles" (IdC = −0.2 ± 3.8%), with "parachute" (IdC = 0.1 ± 3.1%), and with "hand paddles + parachute" (IdC = 0.0 ± 3.2%); the last three values were non-significant deviations from zero percent.

Table III. Values of the phases expressed as a percentage of total arm stroke in free swimming (FREE) and when using hand paddles (HPD), parachute (PCH), and hand paddles plus parachute (HPD + PCH) (mean ± *s*).

	FREE	HPD	PCH	HPD + PCH
Right arm				
Phase A (%)	14.0 ± 3.8	12.3 ± 4.6	15.1 ± 6.1	12.5 ± 5.6
Phase B (%)	34.1 ± 4.4	34.4 ± 4.1	33.1 ± 3.9	35.5 ± 4.7
Phase C (%)	24.8 ± 4.2	25.0 ± 3.7	26.6 ± 4.4	26.8 ± 3.3
Phase D (%)	27.2 ± 3.9	28.3 ± 3.6	25.2 ± 4.8	25.2 ± 2.2
Non-prop (%)	41.1 ± 4.6	40.6 ± 5.8	40.3 ± 6.2	37.7 ± 5.9
Prop (%)	58.9 ± 4.6	59.4 ± 5.8	59.7 ± 6.2	62.3 ± 5.9
Left arm				
Phase A (%)	14.0 ± 4.7	11.5 ± 4.3	13.1 ± 4.0	12.3 ± 4.3
Phase B (%)	33.9 ± 5.6	35.6 ± 4.9	32.6 ± 6.9	33.8 ± 2.9
Phase C (%)	21.3 ± 2.7	21.7 ± 3.8	24.8 ± 4.6	24.7 ± 2.9
Phase D (%)	29.3 ± 4.3	32.9 ± 3.1	28.3 ± 3.5	29.0 ± 4.4
Non-prop (%)	43.3 ± 5.2	44.3 ± 4.0	41.4 ± 4.1	41.3 ± 4.5
Prop (%)	55.2 ± 5.5	57.3 ± 4.4	57.4 ± 4.8	58.6 ± 3.8

Note: Non-prop = sum of the non-propulsive phases (i.e. entry and catch + recovery). Prop = sum of the propulsive phases (i.e. pull + push).

Leg kicking

Leg kick pattern did not change with the implements. All of the swimmers adopted a six-beat kick per complete arm movement independently of condition.

Discussion

In the present study, we investigated the effects of hand paddles, parachute, and hand paddles plus parachute on the relative duration of right and left arm-stroke phases and the index of coordination of male crawl-strokers. As maximum intensity was required in all conditions, the modifications found among them were assumed to be a consequence of the use of the implements, otherwise (i.e. if the implements were removed) the variables would present a similar pattern to that found in free swimming.

As the swims were performed over a short distance, the effects of fatigue were not considerable, even though maximum intensity had been required. Thus, a constant swimming speed was assumed during the 15 m accomplished with and without implements, where the mean propulsive force was equal to the mean drag force (Toussaint & Truijens, 2005). Hence, a greater propulsive force was probably obtained in swimming with paddles due to a greater drag force related to a greater velocity of the body. In contrast, the parachute caused an additional resistance, which was added to that ordinarily created by the swimmer's body and movements. In this condition, the hand moves in the opposite direction to displacement of the body and then, hypothetically, tends to displace faster in relation to the water, increasing the drag on it. Thus, it might be that there was an increase of the propulsive forces generated. These effects were summed when both implements were employed together.

Stroke parameters

As might be expected, stroke parameters showed a clear variation associated with the use of overload, in particular stroke length, which reacted negatively to the increase in drag (i.e. when the parachute was employed). In fact, these results are closely related to a decrease in swimming velocity, which occurred even when paddles were worn (i.e. in paddles and parachute) and a higher propulsive force would be developed (Gourgoulis et. al., 2008b), highlighting the powerful effect of the parachute on drag increase.

In contrast, stroke rate did not vary in accordance with the implement(s) used, as it decreased significantly in all overload conditions. This behaviour is in line with previous studies that found significant reductions in stroke rate when hand paddles (Gourgoulis et al., 2008a, 2008b, 2009) or a parachute (Llop et al., 2002, 2003, 2006) were used.

The use of hand paddles and parachute together is undoubtedly the most complex of the three conditions studied. The artificial increase in propulsive area given by hand paddles allows the swimmer to move faster. At the same time, the swimmer is able to push off against a more stationary mass of water and, consequently, produce more propulsion to start this sequence of events again with a lower stroke rate. Hypothetically, this would be repeated until the moment the swimmer's muscular contraction capacities are no longer capable of such force production. All these events possibly caused the most important change in stroke rate. Therefore, given these effects, and considering the specificity principle, it can be suggested that hand paddles plus parachute should be used predominantly at the beginning of the season.

Stroke phases

In the present study, no significant changes were observed in any stroke phase when overload was employed. Thus, from a motor organization point of view, these implements can be used for specific swimming strength and power development.

The results for hand paddles are in agreement with some previous studies (Monteil & Rouard, 1992, 1994) that reported that, despite an increase in absolute values of all phases, the relative phases' durations (i.e. in relation of the total duration of a complete stroke) did not change significantly.

In contrast, Sidney et al. (2001) reported a significant increase in the total amount of the propulsion (pull + push), while the total non-propulsive phase (entry and catch + recovery) was significantly reduced. Sidney and colleagues' results might possibly be due to the size of paddles, which were smaller than those used in the current research (360 vs. 462 cm^2). With a smaller artificial increase of the area of the hand, swimmers are able to develop a higher stroke rate, leading to an increase of the propulsive phases (pull + push) (Potdevin et al., 2006).

Despite the non-significant changes observed with the hand paddles and parachute together, this overload condition caused the most marked effect on swimmers' propulsion, which was 62.3% and 58.6% in right and left arm, respectively, while in free swimming it was 58.9% and 55.2%. Therefore, an increase of the propulsive phase would be expected as a chronic effect of the systematic use of the implements in combination.

Index of coordination

In free swimming, according to Seifert et al. (2007), the index of coordination changes from catch-up to superposition mode at velocities above $1.8\ m \cdot s^{-1}$. However, despite this "threshold velocity" being reached in the current study ($1.83\ m \cdot s^{-1}$), the mean index of coordination remained negative. Analysing performance level, based on the points achieved in the IPS system (http://www.swimnews.com/ipspoints), an evident difference can be noted between the swimmers tested by Seifert et al. (831 points) and those in the present study (768 points). Thus, it can be argued that this crucial velocity for the superposition mode might vary among swimmers of different competitive levels.

Despite the fact that significant differences were not observed, the coordination mode, from a practical point of view, was altered from catch-up in free swimming to an opposition mode with paddles, parachute, and hand paddles plus parachute swimming, highlighting that these external resistances can increase the propulsive continuity of sprint swimmers.

When paddles were used, the mean increase in the index of coordination was approximately 8.7%. Sidney et al. (2001) also reported an augmentation of the index of coordination when paddles were used (approximately 20%) that was responsible for the attenuation of the catch-up pattern (IdC $= -1 \pm 4\%$) originally used during free swimming. The artificial enlargement of the hands allows the swimmer to push off against a larger mass of water (Toussaint et al., 1991), causing a decrease in the hand's velocity (Gourgoulis et al., 2008a, 2008b) and a greater duration of the propulsive phases. In the current study, this pattern was observed in particular during phase B of the left arm.

Regarding inter-arm coordination, it can be suggested that the systematic use of these implements would lead to a chronic attenuation of the catch-up pattern. Since the current participants were competitive athletes, this effect would considerably improve their performance by diminishing the effects of intra-cyclic deceleration, especially in sprint events. A reduction in the intra-cyclic velocity variation together with a coincident increase in the index of coordination was originally reported by Sidney et al. (2001), who compared free swimming and swimming with paddles over short distances. However, the same association might not be valid in events strongly affected by fatigue. Alberty and colleagues (Alberty, Sidney, Hout-Marchand, Hespel, & Pelayo, 2005) reported an increase in the relative duration of the propulsive phases without any significant changes in the variation in intra-cyclic velocity.

According to hydrodynamic theory, the drag force (D) can be expressed by the follow equation:

$$D = 0.5 * \rho * Cx * S * \underline{v}^2$$

where ρ is water density, Cx is the the drag coefficient, $\underline{v}$ is velocity, and S is the frontal area of the participant perpendicular to the movement. Thus, when the parachute was used, the frontal area of the implement generated a greater hydrodynamic resistance to be overcome. Because of this, any moment without propulsion would strongly affect the velocity. Therefore, it is possible that the swimmers increased their propulsive continuity (i.e. their index of coordination) to help reduce the variation in intra-cyclic velocity and its effects.

Over time, there might be an approximation of the opposition model for the parachute and hand paddles plus parachute conditions, similar to that expected with hand paddles alone. Nevertheless, the significantly lower velocity recorded in these conditions could not provide the sensitivity of the arms, legs, and body's movements and/or positions, which could be limiting at higher velocities. Thus, it is suggested that these overload conditions characterized by the drag increase should be employed in the early phases of periodization.

Finally, it should be noted that the increase in external resistance can be different among individual athletes. When paddles are used, the surface area used by swimmers is equal; therefore, 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 area. Similarly, considering that each athlete generates a fixed amount of drag, which is related to his or her corporal dimensions and technique, the use of the same size of parachute for all swimmers may cause a larger percentage increment in the resistance to be overcome for those who originally produced less drag, emphasizing the importance of the individualization of training.

Conclusion

We conclude that hand paddles, parachute, and hand paddles plus parachute used when swimming at maximal intensity do not significantly influence the organization of the stroke phases in the right or left arm. It is important to note, however, that the coordination mode was altered from catch-up to opposition when parachutes and hand paddles plus parachutes were used, highlighting a greater propulsive continuity as a chronic effect.

References

Alberty, M., Sidney, M., Hout-Marchand, F., Hespel, J. M., & Pelayo, P. (2005). Intracyclic velocity variations and arm coordination during exhaustive exercise in front crawl stroke. *International Journal of Sports Medicine*, *26*, 471–475.

Chollet, D., Chalies, S., & Chatard, J. C. (2000). A new index of coordination for the crawl: Description and usefulness. *International Journal of Sports Medicine*, *21*, 54–59.

Gastin, P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, *31*, 725–741.

Girold, S., Calmels, P., Maurin, D., Milhau, N., & Chatard, J. C. (2006). Assisted and resisted sprint training in swimming. *Journal of Strength and Conditioning Research*, *20*, 547–554.

Glaister, M. (2005). Multiple sprint work: Physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports Medicine*, *35*, 757–777.

Gourgoulis, V., Aggeloussis, N., Kasimatis, P., Vezos, N., Antoniou, P., & Mavromatis, G. (2009). The influence of hand paddles on the arm coordination in female front crawl swimmers. *Journal of Strength and Conditioning Research*, *23*, 735–740.

Gourgoulis, V., Aggeloussis, N., Vezos, N., Antoniou, P., & Mavromatis, G. (2008a). Hand orientation in hand paddle swimming. *International Journal of Sports Medicine*, *29*, 429–434.

Gourgoulis, V., Aggeloussis, N., Vezos, N., Kasimatis, P., Antoniou, P., & Mavromatis, G. (2008b). Estimation of hand forces and propelling efficiency during front crawl swimming with hand paddles. *Journal of Biomechanics*, *41*, 208–215.

Gourgoulis, V., Aggeloussis, N., Vezos, N., & Mavromatis, G. (2006). Effect of two different sized hand paddles on the front crawl stroke kinematics. *Journal of Sports Medicine and Physical Fitness*, *46*, 232–237.

Llop, F., Arellano, R., González, C., Navarro, F., & García, J. M. (2002). Variaciones em La técnica de crol durante el nado resistido com paracaídas. *Revista Motricidad*, *8*, 7–20.

Llop, F., González, C., Hernando, E., Diaz-Rincon, J., Navarro, F., & Arellano, R. (2003). Analysis of modifications on technique and lactate concentration during added resistance freestyle swimming. In J. C. Chatard (Ed.), *Biomechanics and medicine in swimming IX* (pp. 343–348). Saint-Étienne: Publications de l' Univesité de Saint-Étienne.

Llop, F., Tella, V., Colado, J., Diaz, G., & Navarro, F. (2006). Evolution of butterfly technique when resisted swimming with parachute using different resistances. *Portuguese Journal of Sports Science*, *6*, 96.

Maglischo, E. W. (1993). *Swimming ever faster.* Montain View, CA: Mayfield Publishing.

Mavridis, G., Kabitsis, C., Gourgoulis, V., & Toubekis, A. (2006). Swimming velocity improved by specific resistance training in age-group swimmers. *Portuguese Journal of Sports Science*, *6*, 304–306.

Millet, G. P., Chollet, D., Chalies, S., & Chatard, J. C. (2002). Coordination in front-crawl in elite triathletes and elite swimmers. *International Journal of Sports Medicine*, *23*, 99–104.

Monteil, K. M., & Rouard, A. H. (1992). Influence of the size of the paddles in front crawl stroke. In D. McLaren, T. Reilly, & A. Lees (Eds.), *Biomechanics and medicine in swimming: Swimming science VI* (pp. 99–104). London: E & FN Spon.

Monteil, K. M., & Rouard, A. H. (1994). Free swimming versus paddles swimming in front crawl. *Journal of Human Movement Studies*, *27*, 89–99.

Potdevin, F., Brill, B., Sidney, M., & Pelayo, P. (2006). Stroke frequency and arm coordination in front crawl swimming. *International Journal of Sports and Medicine*, *27*, 193–198.

Rasulbekov, R. A., Fomin, R. A., Chulkov, V. U., & Chudovsky, V. I. (1986). Does a swimmer need explosive strength? *National Strength and Coaches Association Journal*, *8* (2), 56–57.

Schleihauf, R. E. (1983). Specificity of strength training in swimming: A biomechanical view point. In A. P. Hollander, P. A. Huijing, & G. Degroot (Eds.), *Biomechanics and medicine in swimming* (pp. 184–191). Champaign, IL: Human Kinetics.

Seifert, L., Boulesteix, L., & Chollet, D. (2004a). Effect of gender on the adaptations of arm coordination in front crawl. *International Journal of Sports Medicine*, *25*, 217–223.

Seifert, L., Chollet, D., & Bardy, B. G. (2004b). Effect of swimming velocity on arm coordination in the front crawl: A dynamic analysis. *Journal of Sports Sciences*, *22*, 651–660.

Seifert, L., Chollet, D., & Rouard, A. (2007). Swimming constraints and arm coordination. *Human Movement Science*, *26*, 68–86.

Sidney, M., Paillette, S., Hespel, J. M., Chollet, D., & Pelayo, P. (2001). Effect of swim paddles on the intra-cyclic velocity variations and on the arm coordination of front crawl stroke. In J. R. Blackwell & R. H. Sanders (Eds.), *Proceedings of Swim Sessions of XIX Symposium International on Biomechanics in Sports* (pp. 39–42). San Francisco, CA: Human Kinetics.

Toussaint, H. M., Janssen, T., & Kluft, M. (1991). Effect of propelling surface size on the mechanics and energetics of front crawl swimming. *Journal of Biomechanics*, *24*, 205–211.

Toussaint, H. M., & Truijens, M. (2005). Biomechanical aspects of peak performance in human swimming. *Animal Biology*, *55* (1), 17–40.

Toussaint, H. M., & Vervoorn, K. (1990). Effects of specific high resistance training in the water on competitive swimmers. *International Journal of Sports Medicine*, *11*, 228–233.