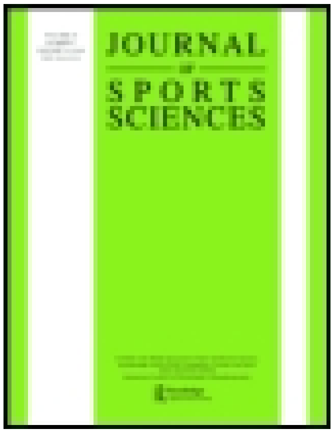

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Abstract
This study investigated the effects of hand paddles, parachute and hand paddles plus parachute on the inter-limb coordination of butterfly swimming. Thirteen male swimmers were evaluated in four random maximal intensity conditions: without equipment, with hand paddles, with parachute and with hand paddles + parachute. Arm and leg stroke phases were identified by 2D video analysis to calculate the total time gap (T1: time between hands' entry in the water and high break-even point of the first undulation; T2: time between the beginning of the hand's backward movement and low break-even point of the first undulation; T3: time between the hand's arrival in a vertical plane to the shoulders and high break-even point of the second undulation; T4: time between the hand's release from the water and low break-even point of the second undulation). The swimming velocity was reduced and T1, T2 and T3 increased in parachute and hand paddles + parachute. No changes were observed in T4. Total time gap decreased in parachute and hand paddles + parachute. It is concluded that hand paddles do not influence the arm-to-leg coordination in butterfly, while parachute and hand paddles + parachute do change it, providing a greater propulsive continuity.

Keywords: *swimming, kinematics, resistance, motor control*

Introduction

Butterfly stroke is characterised by two simultaneous leg movements (with body undulation) for each complete arm cycle (right and left arms together), and the coordination between their actions can be assessed through the total time gap (Chollet, Seifert, Boulesteix, & Carter, 2006). It allows a qualitative estimation of arm (i.e. entry and catch, pull, push and recovery) and leg phases durations (i.e. two upward and two downward undulation), lag time between their propulsive phases and, therefore, propulsive continuity.

The dynamical systems approach to motor control in humans highlights the importance of inter-limb coordination (Kelso, 1995). During the butterfly stroke, this coordination is related to the synchronisation between the starts and ends of arms and legs phases. Better synchronisation between arms and legs phases is supposed to lead to improvement in propulsive continuity and in performance. Additionally, the coordination of arms and legs in butterfly is a consequence of the constraints imposed on action, which may lead to the swimmer's optimal self-organisation (Newell, 1986). Three types of constraints have been identified: organismic, environmental and task. Organismic constraints refer to structural or functional characteristics associated with the individual that may impact coordination. Environmental constraints are associated with factors external to the individual. Task constraints describe the aim of the activity and can be divided into three categories: (i) the goal, (ii) the rules or instructions and (iii) the implements.

Implements such as parachute and/or hand paddles have been successfully used to improve swimming performance by increasing propulsive force (Girold, Maurin, Dugue, Chatard, & Millet, 2007; Toussaint & Vervoorn, 1990). In spite of being used with the same purpose (increase propulsive forces), these implements impose different constraints to the swimmers. Hand paddles artificially enlarge hand surface area (HSA), which augments propulsion, while parachute adds an extra resistance to that

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ordinarily created by swimmers' body and movements and increases drag. It is conceivable that in both conditions swimmers generate greater muscle strength in order to apply more force in each stroke than in conventional swimming (without implements), which may provide an effective strength training stimulus, thus enhancing propulsive force and performance.

Several researchers investigated the effect of these implements on parameters such as swimming velocity, stroke rate, stroke length (Gourgoulis, Aggeloussis, Vezos, Antoniou, & Mavromatis, 2008; Gourgoulis et al., 2008; Llop, Arellano, González, Navarro, & Garcia, 2002; Llop et al., 2003; Llop, Tella, Colado, Diaz, & Navarro, 2006; Telles, Barbosa, Campos, & Junior, 2011) and stroke coordination (Gourgoulis et al., 2009; Llop et al., 2006; Telles et al., 2011). They showed that the use of resistances reduces stroke rate and increases propulsive continuity (Telles et al., 2011), whereas the stroke length and the swimming velocity were increased with paddles and reduced with parachute (Telles et al., 2011). However, these results were obtained for the front crawl they may not be reproduced in other strokes, especially those with propulsive discontinuity and a greater intra-cyclic velocity variation (Barbosa, Fernandes, Morouco, & Vilas-Boas, 2008), as butterfly.

However, as none of the previous studies reported the behaviour of this parameter in overloaded conditions, the effects of hand paddles and parachute on butterfly inter-limb coordination still remain to be studied. It is hypothesised that both parachute and hand paddles can induce larger instantaneous fluctuations in speed, which leads to an increased energy cost (Barbosa et al., 2005), and that highly skilled swimmers can successfully identify these fluctuations in speed and then optimally self-organise their arm-to-leg coordination to enhance propulsive continuity (Chollet, Seifert, Leblanc, Boulesteix, & Carter, 2004; Seifert & Chollet, 2005) and to induce smaller instantaneous fluctuations in speed (Mason, Tong, & Richards, 1992). Therefore, the aim of this study was to investigate the effects of hand paddles, parachute and hand paddles plus parachute on arm-to-leg coordination of competitive butterfly swimmers.

Methods

Participants

Thirteen well-trained national competitive male swimmers (age: 20.1 ± 2.6 years; body mass: 77.1 ± 6.3 kg; height: 182 ± 8 cm; arm span: 193 ± 11 cm; HSA: 153.6 ± 8.6 cm^2) volunteered for this investigation. They were butterfly-stroke specialists (50-m butterfly in short course: 26.48 ± 1.20 s, which corresponds to 82.49 ± 0.03% of the World Record) and were familiar to paddles and parachute, which were regularly used during their training sessions. Written informed consent was obtained, and all procedures received approval from the university's ethics committee (Process 678/2009).

Experimental procedures

All the tests were conducted in one day, in a 25-m pool, with a water temperature of 27°C after a standardised warm-up. Tests consisted of one 25-m maximal swim for each condition analysed: conventional swimming (i.e. without equipment), with paddles (462 cm^2), with parachute (900 cm^2) and with paddles and parachutes together. These implements have the same shapes and sizes as those previously used by Telles et al. (2011). The testing order was randomised within participants. In order to avoid possible metabolic fatigue effects, a 5-min passive rest was observed between trials (Gastin, 2001). Hand paddles were fixed to swimmers' hand by two adjustable elastic tubes positioned close to the wrist and middle finger, while the parachute was fitted through a waist belt. Parachute's surface was kept approximately 1 m away from swimmers' feet, exactly as in their training sessions. HSA was estimated by multiplying the total body surface area, obtained from the equation proposed by Du Bois and Du Bois (1989), by the relative constant for HSA, described by Amirsheybani et al. (2001):

$$\mathrm{HSA} = \left(0.007184^{*}\mathrm{BM}^{0.425*}\mathrm{H}^{0.725}\right)^{*}\mathrm{k} \qquad (1)$$

Where BM is the body mass (kg), H is the height (m) and k represents the relative constant for HSA and is equal to 0.78%.

Of the 25 m covered, the first 7 m and last 3 m were not considered to minimise effects of push-off and finish, as used previously (Barbosa, Castro, Dopsaj, Cunha, & Andries, 2013; Telles et al., 2011). During the 15 m analysed, swimmers were requested to start swimming before the 7-m mark and to hold their breath to avoid any modifications of stroke kinematic (Gourgoulis et al., 2008).

The trials of each swimmer were video recorded using two digital cameras (Sony® DCR-SR68; shutter speed: 1/1000; sampling frequency: 60 Hz) synchronised by a visual signal, which allowed two sagittal views of swimmers' motion: (1) external, 50 cm above water surface and (2) underwater, with the aid of a special designed waterproof box, at a depth of 50 cm. The cameras were fixed on a trolley, which was pulled alongside the pool by an operator at the same velocity as the swimmers'. The swimmer's head was the mark followed by trolley's operator.

Variables

Average swimming velocity was calculated using the distance between the bars (Δd = 15 m) and the time spent between them (Δt), according to VEL = $\Delta d/\Delta t$. The sagittal view allowed identifying the instants when the swimmer's head crossed the 7 and 22m bars. This was the same procedure used by Telles et al. (2011), which verified a standard error of measurement of 0.003 $m \cdot s^{-1}$.

Stroke rate, expressed in cycles per minute, was quantified by analysing the time of the first three complete cycles performed right after the initial 7 m. The time between the beginning of the first cycle and the end of the third was also computed through the cameras. The stroke rate was then calculated by dividing the number of cycles (i.e. three cycles) by the time required to accomplish them (Δt) using the equation $(60{\star}3)/\Delta t$. Stroke length was obtained by dividing average swimming velocity by stroke rate, which should be converted to hertz.

Arm and leg stroke phases

Arm-to-leg phases were quantified according to Chollet et al. (2006). Arm stroke movement was divided into four distinct phases: phase A corresponds to the entry and catch of the hand in the water up to the beginning of its backward movement; phase B corresponds to the beginning of the hand's backward movement and its alignment in the vertical plane with the shoulder (pull); phase C initiates with the hand's alignment with the shoulder and ends with its release from the water (push); and phase D refers to the above-water recovery.

The duration of a complete arm movement was the sum of all four phases (A + B + C + D). 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).

The leg stroke was also composed of four phases, according to Chollet et al. (2006): two downward phases (time between the high and low break-even points of the feet); and two upward phases (time between the low and high break-even points of the feet).

The key instants were qualitatively assessed by two independent operators in four complete stroke cycles with an accuracy of 0.016 s. They used a blind technique, which means that their analyses were only compared when each operator had completed his own analysis. When the difference between the analyses did not exceed an error of 0.04 s, the mean of the two analyses was accepted to validate the key point of each phase (Chollet et al., 2006; Seifert, Chollet, & Sanders, 2010). On the contrary, the two operators together proceeded with a new assessment of that key instant, and if any discrepancy remained, a third operator was asked to define the instant in question.

Only swimmers with two leg undulations for one arm stroke were studied. Therefore, one leg stroke corresponded to two leg undulations. The duration of each phase was expressed as a percentage of the total duration of a complete leg stroke.

Arm-to-leg coordination

Arm-to-leg coordination was defined by the time gaps between different stroke phases of each pair of motor limbs, which allowed to analyse propulsive continuity. Four time gaps were identified, as proposed by Chollet et al. (2006):

- T1: time gap between hands' entry in the water and first undulation high break-even point.
- T2: time gap between beginning of hands' backward movement and the first undulation low break-even point.
- T3: time gap between the hand's alignment in the vertical plane with the shoulder and the second undulation high break-even point.
- T4: time gap between hands' release from the water and the second undulation low break-even point.

The total time gap was defined as the sum of the absolute values of T1, T2, T3 and T4 (Seifert, Boulesteix, Chollet, & Vilas-Boas, 2008; Seifert et al., 2010). It assessed the effectiveness of the global arm-to-leg coordination. In all trials, the time gaps and total time gap were expressed as the percentage of one complete arm stroke (Seifert et al., 2008, 2010).

Arm-to-leg coordination values for T1, T2, T3 and T4 were interpreted according to Chollet et al. (2006).

- When T1 = 0: there is continuity between arm recovery and the beginning of the downward undulation (i.e. beginning of leg propulsion).

- When T1 > 0: the arms begin the entry phase while legs are still recovering from the previous-cycle upward undulation (considered as a non-propulsive phase). Therefore, arms glide forward until the moment legs complete their upward undulation. Thus, there is a lag time in glide position.

- When T1 < 0: leg propulsion begins whereas arm recovery is not finished; it corresponds to a negative superposition of two contradictory actions (i.e. arm recovery and leg propulsion). This is not effective since one pair of motor limbs (legs) propels the body forward while the other (arms) do not provide a hydrodynamic position for the body. Indeed, the aerial arm recovery leads to a more vertical trunk position.

- When T2 = 0: there is a mechanical continuity between leg's and arm's actions, i.e. a smaller non-propulsive period.

- When T2 > 0: there is a superposition of arm-to-leg actions. Arm propulsion overlaps the leg's propulsive action.

- When T2 < 0: The arms glide forward while legs perform/complete their upward undulation (considered as a non-propulsive phase). There is a lag time in glide position.

- When T3 = 0: there is synchronisation between two key motor points: the positioning of the hand below the shoulders and the high break-even points of the feet.

- When T3 > 0: the downward undulation begins after hand's alignment in the vertical plane with the shoulder.

When T3 < 0: the lack of synchronisation corresponds to the positioning of hands below the shoulders after the beginning of the downward undulation. In this case, leg propulsion starts before arm-pull phase ends.

- When T4 = 0: the low break-even points of the feet at the second undulation are synchronised to hand's release from the water, confirming that downward leg propulsion facilitates arm recovery.

- When T4 > 0: arms complete their release from the water before the end of leg propulsion; this corresponds to a negative superposition of two contradictory actions since leg propulsion do not provide a maximal advantage for the exiting hands.

- When T4 < 0: there is a lag time because hands' release from the water occurs after the end of downward leg propulsion.

Statistical analysis

All statistical analyses were performed using SPSS for Windows (Version 16.0; SPSS, Inc., Chicago, IL). The assumptions of normally distributed samples and sphericity were verified using Shapiro–Wilk and Mauchly tests, respectively. Repeated measures analysis of variance (ANOVA) computed possible main effect on stroke rate, stroke length, downward phase 1, upward phase 1, downward phase 2, phase A, phase B, T2, T3 and total time gap, which presented parametric distribution. If sphericity was violated, ANOVA's P value was adjusted by the epsilon Greenhouse–Geisser correction factor. Multiple pairwise comparisons were made by Bonferroni test. Due to the non-parametric distribution, average velocity, phase C, phase D, upward phase 2, T1 and T4 were treated using Friedman ANOVA. The Wilcoxon test, with the Bonferroni adjustment, was used to detect any possible significant difference. The significance level was set at $\alpha < 0.05$. All data are expressed as mean ± s (M ± s), 95% confidence intervals are presented in brackets.

Results

Stroke parameters

The statistical analysis showed a main effect on swimming velocity (chi-square$_3$ = 36.47, $P < 0.0001$, Kendall's W = 0.94), stroke rate ($F_{3,36} = 39.91$, $P < 0.0001$, eta^2 = 0.77) and stroke length ($F_{3,36} = 213.66$, $P < 0.0001$, eta^2 = 0.95). The pairwise comparisons with the free condition indicated a lower swimming velocity when parachute and hand paddle + parachutes were used, whereas no changes were observed with hand paddles (Table I). There were also differences in stroke rate and stroke length when the overloaded conditions were compared to conventional swimming, as shown in Table I.

Arm and leg stroke phases

There was a main effect in phases B ($F_{3,36} = 12.95$, $P < 0.0001$, eta^2 = 0.52) and D (chi-square$_3$ = 17.19,

Table I. Average velocity, stroke rate and stroke length in conventional swimming (FREE) and using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD + PCH) (mean ± s, 95% CI are presented in brackets).

	FREE	HPD	PCH	HPD + PCH
Velocity (m·s^{-1})	1.63 ± 0.06 (1.59–1.67)	1.66 ± 0.07 (1.61–1.70)	1.08 ± 0.06* (1.04–1.12)	1.13 ± 0.06* (1.09–1.16)
Stroke rate (cycles·min^{-1})	61.78 ± 4.31 (59.20–64.36)	55.26 ± 5.60* (51.89–58.63)	55.91 ± 3.82* (53.59–58.21)	51.86 ± 3.80* (49.56–54.17)
Stroke length (m)	1.59 ± 0.11 (1.52–1.66)	1.81 ± 0.14* (1.73–1.89)	1.17 ± 0.08* (1.12–1.21)	1.31 ± 0.08* (1.26–1.35)

Note: *Significant difference from FREE (P < 0.05).

P = 0.001, Kendall's W = 0.44). The relative duration of phase B was increased when parachute was used (Table II). An effect was also detected in the downward phase 1 ($F_{3,36}$ = 6.63, P = 0.001, eta^2 = 0.36), the upward phase 2 (chi-square$_3$ = 15.38, P < 0.0001, Kendall's W = 0.39) and the downward phase 2 ($F_{3,36}$ = 9.34, P < 0.0001, eta^2 = 0.44). Results of *post hoc* comparison are shown in Table II. No changes were observed in the upward phase 1 and phases A and C (Table II).

Results reported in Tables I and II are in accordance to what we would expect. Parachute decreases the speed and the stroke length. On the other side, hand paddles increase the speed and stroke length. In addition, both equipment decreases stroke rate. Phase C is the shortest because of the highest hand's speed, followed by phase B. Phases C and B are the most propulsive phases of the butterfly stroke. Also, we expected the recovery phase to be higher during free swim and with paddles.

The second kick plays a major role in the overall stroke, increasing the propulsion and decreasing speed fluctuation.

Arm-to-leg coordination

ANOVA showed a main effect in T1 (chi-square$_3$ = 23.12, P < 0.0001, Kendall's W = 0.59), T2 ($F_{3,36}$ = 25.51, P < 0.0001, eta^2 = 0.68), T3 ($F_{3,36}$ = 12.27, P < 0.0001, eta^2 = 0.51), T4 (chi-square$_3$ = 15.63, P = 0.009, Kendall's W = 0.40) and total time gap ($F_{3,36}$ = 34.16, P < 0.0001, eta^2 = 0.74). Pairwise comparisons are shown in Table III.

In Figure 1, it is possible to visualise the individual behaviour of total time gap in all trials used in the study. In hand paddles condition, eight swimmers improved (i.e. closer to zero) while the other five worsened (i.e. farther from zero) arm-to-leg coordination. When the parachute was used, all swimmers improved propulsive continuity, by shifting total time gap closer to zero; while in hand paddles plus parachute condition, 12 swimmers demonstrated better and one worse total time gap.

Discussion

The aim of this study was to investigate the effects of hand paddles, parachute and hand paddles plus parachute on arm-to-leg coordination of national butterfly swimmers. Our main findings indicate that the use of parachute (parachute and hand paddles plus parachute conditions) changes arm-to-leg coordination towards a greater propulsive continuity. The present results were discussed under the same

Table II. Mean (± *s*, 95% CI are presented in brackets) values (%) of arm and leg phases in conventional swimming (FREE) and using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD + PCH).

	FREE	HPD	PCH	HPD + PCH
Arms				
Phase A	28.8 ± 4.7 (25.9–31.6)	27.8 ± 4.0 (25.0–30.6)	29.6 ± 3.8 (27.3–31.9)	27.6 ± 3.0 (25.7–29.4)
Phase B	19.4 ± 2.8 (17.7–21.1)	21.2 ± 3.6 (18.7–23.3)	22.8 ± 2.8* (21.1–24.5)	24.2 ± 2.3* (22.8–25.5)
Phase C	19.2 ± 3.5 (17.0–21.3)	19.5 ± 3.4 (17.5–21.5)	19.2 ± 2.5 (17.7–21.7)	19.4 ± 3.4 (17.4–21.5)
Phase D	32.7 ± 5.2 (29.5–35.8)	30.9 ± 3.4 (28.9–32.9)	28.4 ± 3.9* (26.1–30.7)	28.8 ± 2.5* (27.4–30.3)
Legs				
1° upward undulation	20.4 ± 2.5 (18.9–21.9)	20.7 ± 1.5 (19.7–21.6)	20.3 ± 1.5 (19.3–21.1)	20.5 ± 1.4 (19.6–21.4)
1° downward undulation	26.9 ± 2.4 (25.4–28.3)	27.4 ± 2.7 (25.7–29.0)	29.1 ± 2.1* (27.8–30.4)	28.2 ± 1.7 (27.1–29.3)
2° upward undulation	25.9 ± 2.5 (24.5–27.5)	23.8 ± 3.2* (21.9–25.7)	23.3 ± 2.9* (21.5–25.0)	21.6 ± 2.4* (20.1–23.0)
2° downward undulation	26.8 ± 3.6 (24.6–29.8)	28.2 ± 3.1 (26.3–30.0)	27.4 ± 3.0 (25.5–29.2)	29.7 ± 3.4* (27.6–31.7)

Note: *Significant difference from FREE (P < 0.05).

Table III. Mean (± *s*, 95% CI are presented in brackets) values (%) of arm-to-leg phases coordination in conventional swimming (FREE) and using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD + PCH).

	FREE	HPD	PCH	HPD + PCH
T1	−9.1 ± 6.7 (−12.5 to −5.6)	−8.6 ± 3.7 (−9.8 to −3.4)	−3.8 ± 4.7* (−6.6 to −0.9)	−3.7 ± 4.2* (−6.3 to −1.2)
T2	−17.4 ± 5.8 (−20.9 to −3.9)	−15.8 ± 5.1 (−18.9 to −12.7)	−13.2 ± 4.6* (−15.9 to −10.4)	−10.7 ± 4.6* (−13.6 to −7.9)
T3	−9.9 ± 3.8 (−12.2 to −7.6)	−9.7 ± 3.4 (−11.7 to −7.6)	−6.8 ± 3.2* (−8.7 to −4.9)	−6.7 ± 2.7* (−8.3 to −5.00)
T4	−3.0 ± 6.1 (−6.8 to 0.7)	−5.6 ± 4.6 (−8.47 to −2.8)	−2.7 ± 3.1 (−4.7 to −0.8)	−4.4 ± 3.6 (−6.6 to −2.3)
TTG	40.3 ± 15.5 (33.1 to 47.5)	39.6 ± 12.4 (32.4 to 46.8)	27.5 ± 11.4* (20.3 to 34.7)	26.2 ± 11.9* (19.0 to 33.4)

Note: *Significant difference from FREE (P < 0.05).

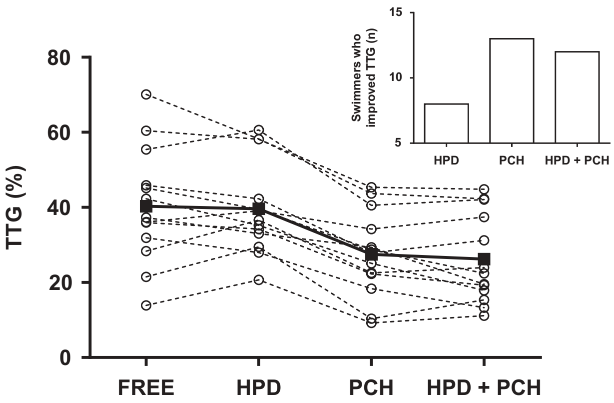

Figure 1. Individual total time gap (TTG) in conventional swimming (FREE) and using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD + PCH). Dashed lines represent each individual. Continuous line represents the mean. Inset represents the number of swimmers who improved TTG with the use of implements.

assumptions adopted by Telles et al. (2011), as following: (1) the modifications observed were a consequence of the use of the implements since maximum intensity was asked in all conditions. Otherwise (i.e. if the implements were removed), the variables would present a similar pattern to that found in conventional swimming, thus the task was only modified by the implements; (2) fatigue effects were not considerable since short-distance trials were adopted with relatively long rest periods; and (3) a greater propulsive force was required when the implements were used.

Stroke parameters

Hand paddles caused a slight increase in swimming velocity which is possibly related to a greater propelling efficiency (Gourgoulis et al., 2008) occasioned by the artificial enlargement of swimmers' hands surface. Propelling efficiency is the ratio between the useful mechanical power spent to overcome drag (*Pd*) and the external mechanical power output (*Po*), which can be expressed by the following equation:

$$ep = Pd/Po = Pd/(Pd + Pk) \quad (2)$$

Po is the sum of the power used beneficially to overcome drag (*Pd*) and power lost in giving water a kinetic energy change (*Pk*) (Zamparo, Pendergast, Mollendorf, Termin, & Minetti, 2005). With the increase of HSA, a greater part of the total mechanical work is devoted to generate useful power and to overcome drag (*Pd*) while less power is lost moving water backward (*Pk*) (Gourgoulis et al., 2008; Toussaint, Janssen, & Kluft, 1991). This also explains the increase of the stroke length.

Differently, in parachute swimming there is an additional resistance to overcome, which is added to that ordinarily created by swimmers' body. Assuming no change in swimmers' mechanical power output, this increase in total drag to be overcome explains the decrease of swimming velocity and stroke length as well.

The decrease of the stroke rate is a consequence of the increased external resistance caused by the use of implements. This greater external resistance demands higher force production during the stroke with hand paddles (Gourgoulis et al., 2008), but its effects are controversial with the use of parachute (Gourgoulis et al., 2013; Schnitzler, Brazier, Button, Seifert, & Chollet, 2011). With hand paddles, the neuromuscular system needs greater amount of time to increase the number of motor units recruited and their firing rate. These mechanisms are responsible for modulating muscle strength (Enoka, 1997), and the use of hand paddles may affect them. Thus, hand paddles seem to be an excellent strategy to improve specific muscle strength. Alternatively, when parachute is used the greater amount of time during each stroke might be due to the need for a higher mechanical impulse (Barbosa, Santos Silva, Sousa, & Vilas-Boas, 2002) to overcome additional drag.

Arm and leg stroke phases

In the present study, changes in arm stroke phases B and D were observed when parachute (parachute and hand paddles plus parachute conditions) was used. During most part of phase B, the leg is doing the first upward kick phase, which is considered as non-propulsive. Because of this, arms alone should generate propulsion to overcome a greater drag compared to conventional swimming, that is, the resistance generated by swimmers' body and movements summed to that created by the paddles and parachute. The greater amount of time to perform phase B is probably a requirement of a greater mechanical impulse to overcome increased drag (Barbosa et al., 2002) caused by the use of parachute. Differently, in phase C, arms and legs do the propulsive actions simultaneously, which may explain the lack of changes of its relative duration whatever the overload tested.

Contrary to the increase in relative duration of phase B, phase D was reduced whenever the parachute was used (i.e. parachute and hand paddles plus parachute conditions). During this moment of the stroke, arms and legs are being recovered concomitantly and because no propulsion is being generated, the intra-cyclic velocity reaches its lowest point (Craig, Termin, & Pendergast, 2006). When using parachutes, a greater stroke deceleration is expected and then it is likely that swimmers tend to perform their arm recovery phase (which is aerial and, therefore, there is less drag to be overcome) faster in an effort to minimise propulsive discontinuity and maintain horizontal speed.

Concerning the leg phases, major changes were observed in the second downward undulation. Relative duration of this leg phase was decreased in all overloaded conditions. It is possible the greater resistance to overcome caused the reductions in the relative duration of the second kick, especially in the downward phase, possibly in an attempt to synchronise with the arms and therefore the synchronisation between the second downward kick and the push phase of the arms. This suggestion is based on the observation that the arms' phase B increased in overloaded conditions.

Arm-to-leg coordination

In all conditions, the time gap between hands' entry in the water and first undulation high break-even point (T1) presented a negative value, which means that the leg propulsion began whereas arm recovery was not finished yet. It is less effective than if T1 was zero since legs start to propel the body forward while the trunk is still more vertical because of arms recovery.

In both conditions with parachute (i.e. parachute and hand paddles plus parachute conditions), T1 was increased compared to FREE and hand paddles and got closer to zero. Because of the reduction in the duration of arms recovery phase, the legs start their descending phase closer to the moment that the arms' enter in the water. This arms and legs position is said to be more appropriate to reduce drag by keeping the body in a more streamlined position (Chollet et al., 2006).

Similarly, in all conditions, the values of T2 were negative, indicating that the arms glided forward while the legs were still completing the first upward undulation. In the conditions in which parachute was used, T2 was meaningfully increased. These are very reasonable results if considering the important and disadvantageous effect of the parachute on swimming velocity. Then, swimmers anticipate the beginning of the first downward undulation, which reduces the glide and allows greater propulsive continuity.

T3 was negative in all conditions, pointing out that leg propulsion started before the end of the arm-pull phase. The use of parachute increased T3 values. As mentioned previously, the anticipation and depreciation in the amplitude of the second kick, caused by the added resistance, occasioned a reduction in the time spent in undulation, especially in the downward phase of the second kick. This hypothesis was initially proposed by Seifert et al. (2008) to explain the differences in T3 among swimmers with different skill levels. However, it also seems reasonable to explain changes in coordination in overloaded conditions. This result, associated to the increase of phase B, modified the synchronisation between the second downward kick and the push phase of the arms.

The negative values found in T4 indicate that hands' exit occurred after the end of the downward leg propulsion. Differently from the other time gaps, the lack of changes in T4 revealed that none of the implements caused relevant changes in arm-to-leg coordination during this moment of the stroke. Then, swimmers are able to keep their arm-to-leg coordination unaltered despite the external imposed resistance.

Concerning the total time gap values, hand paddles do not change arm-to-leg coordination in butterfly, whereas the use of parachute (parachute and hand paddles plus parachute conditions) induces greater propulsive continuity. Propulsive continuity depends on the appropriate synchronisation of the arm and leg key points, which is known as the "in-phase" mode in the dynamical systems approach (Chollet et al., 2006). This synchronisation is important to minimise intra-cyclic speed fluctuations and seems to be accomplished by increasing stroke rate (Potdevin, Bril, Sidney, & Pelayo, 2006). Conversely, even though stroke rate decreased with the use of parachute, swimmers in the present study switched from an out-of-phase to an in-phase arm-to-leg coordination. Considering that intra-cyclic speed fluctuations are greater when a parachute is used (Gourgoulis et al., 2013), we suggest that not stroke rate but swimmers' ability to successfully identify intra-cyclic speed fluctuations is the main control parameter determining inter-limb coordination. By doing so, swimmers can optimally self-organise arm-to-leg coordination and enhance propulsive continuity (Chollet et al., 2004; Seifert & Chollet, 2005), reducing intra-cyclic speed fluctuations and improving performance (Mason et al., 1992). These findings along with the individual analyses (Figure 1) of total time gap suggest that a parachute should be used to improve coordination in butterfly as it seems to minimise intra-cyclic speed fluctuations.

Conclusion

In summary, our results taken together suggest that the use of parachute induces swimmers to enhance propulsive continuity, by decreasing recovery phase duration, and to increase horizontal impulse during propulsive phases, by amplifying phase B duration. Further, hand paddles do not seem to affect stroke phase duration neither propulsive continuity, but it could be used for fitness building up programme. Therefore, the main contribution of this study for the coaches and practitioners is that both implements (i.e. parachute and hand paddles) should be used with different purposes. Hand paddles could be used to improve muscle strength and stroke length, while parachutes should be used to improve arm-to-leg coordination.

Although these results might seem beneficial from a motor organisation point of view, it is still unknown whether metabolic and some other important biomechanical parameters (e.g. trajectory of propulsive segments and/or electromyographic similarities) are preserved in these overloaded conditions. Additionally, it is also unclear whether performing training sets with parachute affects arm-to-leg coordination after the implement is removed. Thus, future studies should investigate how the long-term use of implements improves coordination along a training period and affects metabolic and biomechanical parameters.

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