Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: http://www.tandfonline.com/loi/rjsp20

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To cite this article: Thiago Telles, Renato Barroso, Pedro Figueiredo, Diego Fortes de Souza Salgueiro, João Paulo Vilas-Boas & Orival Andries Junior (2017) Effect of hand paddles and parachute on backstroke coordination and stroke parameters, Journal of Sports Sciences, 35:9, 906-911, DOI: 10.1080/02640414.2016.1201210

To link to this article: https://doi.org/10.1080/02640414.2016.1201210

JOURNAL OF SPORTS SCIENCES, 2017
VOL. 35, NO. 9, 906–911
http://dx.doi.org/10.1080/02640414.2016.1201210

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Effect of hand paddles and parachute on backstroke coordination and stroke parameters

Thiago Telles[a,b], Renato Barroso[a], Pedro Figueiredo[b,c], Diego Fortes de Souza Salgueiro[a], João Paulo Vilas-Boas[b,d] and Orival Andries Junior[a]

[a]Laboratory of Aquatic Activities, Physical Education Faculty, Sports Science Department, State University of Campinas, Campinas, Brazil; [b]Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal; [c]School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil; [d]Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal

ABSTRACT

Hand paddles and parachutes have been used in order to overload swimmers, and consequently increase the propulsive force generation in swimming. However, their use may affect not only kinematical parameters (average speed, stroke length and stroke rate), but also time gaps between propulsive phases, assessed through the index of coordination (IdC). The objective of this study was to assess the effects of hand paddles and parachute use, isolated or combined, on kinematical parameters and coordination. Eleven swimmers (backstroke 50-m time: 29.16 ± 1.43 s) performed four 15-m trials in a randomised order at maximal intensity: (1) without implements (FREE), (2) with hand paddles (HPD), (3) with parachute (PCH) and (4) with hand paddles plus parachute (HPD+PCH). All trials were video-recorded (60 Hz) in order to assess average speed, stroke rate, stroke length, five stroke phases and index of coordination. When average swimming speed was compared to FREE, it was lower in PCH and HPD+PCH, and higher in HPD. Stroke rate decreased in all overloaded trials compared to FREE. The use of hand paddles and parachute increased and decreased stroke length, respectively. In addition, propulsive phase duration was increased when hand paddles were used, and time gaps shifted towards zero (no time gap), especially when hand paddles were combined with parachute. It is conceivable that the combined use of hand paddles and parachute, once allowing overloading both propulsive and resistive forces, provides a specific stimulus to improve muscle strength and propulsive continuity.

ARTICLE HISTORY
Accepted 8 June 2016

KEYWORDS
Swimming; index of coordination; external overload; swimmer

Introduction

Specific resistance training in swimming has been used to improve propulsive forces (Toussaint & Beek, 1992). The overloaded practice in swimming might be important to provide a quicker achievement of maximal peak force and impulse (Barbosa, Castro, Dopsaj, Cunha, & Andries Junior, 2013), and also to increase swimmers' strength (Payton & Lauder, 1995; Telles, Barbosa, Campos, & Junior, 2011; Telles et al., 2015). Hand paddles and parachute are two commonly used implements in training for such purpose. Hand paddles artificially enlarge hand's surface (Monteil & Rouard, 1992, 1994; Payton & Bartlett, 1995; Sidney, Paillette, Hespel, Chollet, & Pelayo, 2001; Telles et al., 2011; Toussaint, 1990), increasing the amount of water moved by the swimmer in each stroke, which requires a greater muscle strength production. On the other hand, parachute creates an additional drag, which is added to the swimmers' body drag (Llop, Arellano, González, Navarro, & Garcia, 2002; Llop et al., 2003; Llop, Tella, Colado, Diaz, & Navarro, 2006; Telles et al., 2011). Similar to hand paddles use, the use of parachute also requires swimmer to produce greater strength per stroke to maintain a given pace.

Using hand paddles, it is expected that some variations on the kinematical parameters: stroke rate (SR) decreases, while average speed (AS) and stroke length (SL) increases (Barbosa et al., 2013; Gourgoulis, Aggeloussis, Vezos, & Mavromatis, 2006; Messinis et al., 2014; Monteil & Rouard, 1992), while using parachute AS, SR and SL decrease (Telles et al., 2011). It was observed that the kinematic effects of hand paddles and parachutes were greater than each of them used separately (Telles et al., 2011). Kinematical parameters may be combined to further extend performance analysis in swimming, by characterising swimming coordination. It has been proposed that swimming coordination can be assessed through the measurement of propulsion gaps between sources of thrust, which in backstroke is mainly due to the arms action (Maglischo, 2003). Although, it is possible to identify three modes of coordination in backstroke (Chollet, Seifert, & Carter, 2008; Lerda & Cardelli, 2003): *catch-up* (IdC < 0), *opposition* (IdC = 0) *and superposition* (IdC > 0), catch-up seems to be most commonly observed. Swimming coordination emerges from the constraints imposed to the task. Organismic constraints refer to structural or functional characteristics associated with the individual. Environmental constraints are associated with factors external to the individual. Task constraints can be divided into three categories, according to the activity purpose: (1) goal, (2) rules or instructions and (3) implements (Newell, 1986). Thus, skill level, specialty, gender, anthropometry and handedness are considered organismic constraints

CONTACT Thiago Telles ✉ tellesfef@gmail.com Sports Science Department, State University of Campinas, Barão Geraldo, Campinas, SP 13083-970, Brazil.

(Seifert, 2010); drag and speed are related to environmental constraints and race pace, stroke rate, breathing pattern and implements are task constraints.

Hand paddles and parachute impose different task constraints by changing the task to be performed. Coaches and swimmers regularly use these implements during training sessions to improve specific strength without understanding how they affect stroke coordination. Recently, researchers investigated the effects of hand paddles and parachutes on the coordination of front crawl (Telles et al., 2011) and butterfly (Telles et al., 2015). Telles et al. (2011) reported that hand paddles, parachutes and the combination of both decreased propulsion time gaps in front crawl swimming, while Telles et al. (2015) observed that hand paddles plus parachutes (in combination) and parachutes, but not only hand paddles, improved butterfly propulsive continuity in all swimmers. However, there is a gap of information on the kinematics and the coordination during overloaded backstroke swimming. Our hypothesis was that at least one of these experimental conditions might change the coordination mode by increasing propulsive continuity. Thus, the purpose of this study was to investigate the effects of the use of hand paddles, parachute and both combined on kinematical parameters (SR, SL and AS) and coordination of backstroke swimming.

Methods

Participants

Eleven male swimmers (age: 20.2 ± 2.2 years, height: 182 ± 10 cm, body mass: 77.8 ± 7.1 kg, hand surface area: 186.7 ± 23.1 cm^2, backstroke 50-m time: 29.2 ± 1.4 s, International Points Swimming score: 623.4 ± 73.1 points) volunteered for this study. To be included, the swimmers had to have at least 3 years of experience in training with hand paddles and parachute, and a time standard for state championship in 50 or 100 m backstroke swimming. All the participants were informed of the risks and benefits of the study and signed a written informed consent before participation. The local ethics committee approved the procedures of this study (process number 678/2009).

Experimental procedures

All the tests were conducted in a short course swimming pool (27ºC). All the swimmers performed a standardised warm up (10 min of free swimming and two 15-m backstroke sprints with 90-s rest interval), and the tests began after 10-min rest.

The tests consisted of a 25-m maximal backstroke swims for each condition analysed: free swimming (FREE, i.e., without implement), with hand paddles (HPD, 462 cm^2), with parachute (PCH, 900 cm^2) and with paddles and parachute together (HPD +PCH), in a randomised order. Each swimmer performed an initial push-off start from the wall, and the first arm stroke was before the 7-m mark (without glide movements after the push-off). The passive rests between the efforts were of 5 min of duration. During swimming trials, two bars were placed perpendicular to the swimmers' displacement in the 7 and 22 m on the swimming pool, respectively. The initial 7 m and last 3 m of the swimming pool were not considered in the analysis to minimise the effects of the push-off and finish; therefore, a total of 15 m was analysed in each trial. Hand paddles were fixed to the swimmers' 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 swimmers' feet.

The hand surface area was assessed by computerised planimetry in two different days, at least 72 h apart (ICC = 0.99), using ImageJ© software (ImageJ v. 1.43, National Institute of Health, Bethesda, USA).

The trials of each swimmer were video-recorded using three digital cameras (DCR-SR68, Sony©, Tokyo, Japan; shutter speed: 1/1000 s; sampling frequency: 60 Hz) synchronised by a visual signal. Two cameras allowed a sagittal view and the remaining camera a frontal view of swimmers' motion. The sagittal cameras were fixed on a trolley, which was pulled alongside the pool by an operator walking at the same speed as the swimmers, while the frontal camera was fixed on a tripod. One of the sagittal views and the frontal view were both underwater, obtained from inside special designed waterproof boxes, located at a depth of 0.50 m. The swimmers' head was the mark followed by trolley's operator.

Variables

Average swimming speed (AS) was calculated using the distance between the bars (Δd = 15 m) and the time spent to cover the 15 m distance (Δt), according to: AS = Δd/Δt. The sagittal view was used to identify the moment when the swimmers' head crossed the 7 m and 22 m 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 after the initial 7 m. The time between the beginning of the first and the end of the third cycle was also computed through the sagittal video images. The stroke rate was then calculated by dividing the number of cycles (i.e., 3 cycles) by the time required to accomplish them (Δt), and then converted into $cycles \cdot min^{-1}$ using the equation (60×3) /Δt. Stroke length was obtained through the equation SL = (AS × 60) /SR.

Arm coordination

All swimmers studied performed the tests using a backstroke model with five arm stroke phases. Thus, the arm coordination was quantified based on the backstroke index of coordination (Lerda & Cardelli, 2003), where each arm stroke was divided into five phases:

(1) Entry and catch: this phase corresponds to the time between the entry of the hand into the water and the beginning of its backward movement. It can be characterised by a diagonal hand sweep.

(2) Pull: this phase corresponds to the time separating the beginning of the hand's backward movement and its arrival in a vertical transverse plane containing the shoulders grid.
(3) Push: this phase corresponds to the time between the hand placed in the same vertical transverse plane as the shoulder grid and the end of the hand's backward movement.
(4) Clearing: this phase corresponds to the time between the end of the push phase, until the hand's emerges.
(5) Recovery: this phase is the time between the exit and the entry (for the beginning of one other stroke) of the hand in the water.

The pull and push phases are propulsive while entry and catch, clearing and recovery are non-propulsive (Chollet et al., 2008). The index of coordination (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 (IdC1), and between the beginning of propulsion in the second left arm stroke and the end of propulsion in the first right arm stroke (IdC2). For each measurement, the average IdC [IdC = (IdC1 + IdC2 /2)] was calculated by four complete strokes and expressed as a percentage of the average duration of a complete stroke (Lerda & Cardelli, 2003). The absolute duration (s) of each phase was also reported.

For the backstroke swimming, three modes of coordination can be identified: *catch-up* (negative), *opposition* (null) and *superposition* (positive). Respectively, the first shows a lag time during the propulsion, in the second the propulsion is constant (one arm begins when the other ends) and the last mode also shows a constant propulsion mode with both arms doing the propulsion at the same time (overlap).

Statistical analysis

Data were expressed as average (± SD). Normality was assured through standard visual inspection and Shapiro-Wilk test. A mixed model with repeated measures assuming condition (FREE, HPD, PCH, HPD+PCH) as fixed factor, and participants as a random factor was used for each dependent variable. A Tukey post-hoc adjustment was used in case of significant *F*-values. Significance level was set at $P < 0.05$. The effect size (ES) of the variables was calculated according to Cohen (1988) and interpreted according to previous description (Hopkins, 2004): <0.2: trivial; >0.2–0.6: small; >0.6–1.2: moderate; >1.2–2.0: large; and very large >2.0.

Results

There were significant differences on AS among experimental conditions. Hand paddles (HPD) did not increase significantly as compared to FREE. Opposing, parachute (PCH) and hand paddles plus parachute (HPD+PCH) decreased AS on backstroke swimming ($P < 0.05$, Table 1).

SR was significantly reduced in all overloaded conditions compared to FREE. The combination of hand paddles and parachute (HPD+PCH) decreased SR to a greater extent compared to the other experimental conditions (Table 1).

The use of hand paddles and parachute, respectively, significantly increased and decreased SL compared to FREE. SL in HDP+PCH was significantly higher than PCH only (Table 1).

Table 2 shows that hand paddles (HPD) and hand paddles plus parachute (HPD+PCH) significantly reduced the entry and catch phase, but increased pull phase durations. HPD+PCH also increased push phase relative duration. In addition, recovery phase was decreased during PCH.

The time duration of propulsive and non-propulsive phases was significantly increased at the conditions where the hand paddles are used (HPD and HPD+PCH). In addition, the use of hand paddles seems to shift IdC from catch-up towards opposition. IdC was significantly different between FREE and HPD +PCH, and even though there was no difference between HPD and FREE, there was a strong trend ($P = 0.06$, ES = 0.95) towards shifting IdC closer to 0% (Table 2).

The absolute duration of the stroke phases (Table 3) was significantly different during the hand paddles use (HPD and HPD+PCH conditions) in the phases of pull, push and recovery; and in parachute condition the phases of pull and clearing were different compared to FREE. Absolute duration data show how the hand paddles increased the absolute duration of the propulsive phases and, at the same time, the recovery phase. In the same way, it also happened for PCH.

Figure 1 represents the individual behaviour of the index of coordination in all experimental conditions of the study. When the hand paddles were used (HPD and HPD+PCH conditions), nine swimmers had their coordination changed towards zero (i.e., decreasing the time gaps), while two swimmers had their coordination changed away from zero (i.e., increasing the time gaps). When the parachute was used, seven swimmers shifted the coordination closer to zero or superposition mode.

Table 1. Average speed (AV), stroke rate (SR) and stroke length (SL) in free swimming (FREE), and when using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD+PCH) (average ± SD). Within the brackets the effect size of each variable is presented.

	FREE	HPD	PCH	HPD+PCH
AS (m · s^{-1})	1.75 ± 0.13	1.83 ± 0.12 (0.60)	1.25 ± 0.09^{a,b} (−3.99)	1.30 ± 0.04^{a,b} (−2.42)
SR (cycles · min^{-1})	48.15 ± 6.69	42.11 ± 6.46^{a} (−0.90)	43.54 ± 5.31^{a} (−0.68)	38.44 ± 5.01^{a,b,c} (−1.45)
SL (m · cycles^{-1})	2.21 ± 0.28	2.64 ± 0.31^{a} (1.52)	1.73 ± 0.19^{a,b} (−1.69)	2.04 ± 0.15^{c} (0.22)

[a] Significant difference from FREE ($P < 0.05$); [b] Significant difference from HPD ($P < 0.05$); [c] Significant difference from PCH ($P < 0.05$).

Table 2. Relative duration of each of the five stroke phases individually, propulsive (prop, pull+push) and non-propulsive phases (non-prop, entry and catch +clearing+recovery) and IdC 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) (average ± SD). Within the brackets the effect size of each variable is presented.

	FREE	HPD	PCH	HPD+PCH
Entry and catch (%)	16.33 ± 4.33	13.79 ± 3.30* (0.59)	15.23 ± 4.52 (0.26)	12.49 ± 3.94* (0.89)
Pull (%)	21.36 ± 2.46	23.91 ± 2.60* (2.00)	23.08 ± 1.80 (0.70)	26.36 ± 3.25* (2.03)
Push (%)	17.65 ± 2.99	19.05 ± 2.91 (0.32)	17.78 ± 2.70 (0.04)	19.48 ± 3.08* (0.61)
Clearing (%)	15.07 ± 3.32	13.48 ± 1.80 (0.48)	17.45 ± 3.15 (0.72)	13.20 ± 3.28 (0.56)
Recovery (%)	29.59 ± 2.01	29.76 ± 4.07 (0.09)	26.46 ± 2.34* (1.56)	28.47 ± 4.37 (0.56)
Prop (%)	39.01 ± 1.91	42.96 ± 2.46* (2.07)	40.87 ± 2.23 (0.98)	45.83 ± 3.47* (3.57)
Non-prop (%)	60.99 ± 1.91	57.02 ± 2.49* (2.08)	59.16 ± 2.21 (0.96)	54.17 ± 3.48* (3.58)
IdC (%)	−3.11 ± 1.43	−1.75 ± 1.84 (0.95)	−2.61 ± 1.58 (0.35)	−1.40 ± 1.81* (1.20)

*Significant difference from FREE ($P < 0.05$).

Table 3. Absolute duration (s) of each of the five stroke phases individually, in free swimming (FREE), and when using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD+PCH) (average ± SD). Within the brackets the effect size of each variable is presented.

	FREE	HPD	PCH	HPD+PCH
Entry and catch (s)	0.21 ± 0.06	0.20 ± 0.07 (0.13)	0.21 ± 0.07 (0.11)	0.20 ± 0.07 (0.13)
Pull (s)	0.27 ± 0.04	0.35 ± 0.06* (2.87)	0.39 ± 0.12* (2.87)	0.42 ± 0.05* (3.74)
Push (s)	0.22 ± 0.06	0.28 ± 0.07* (0.33)	0.25 ± 0.05 (0.40)	0.31 ± 0.07* (1.46)
Clearing (s)	0.19 ± 0.04	0.20 ± 0.04 (0.17)	0.24 ± 0.05* (1.24)	0.21 ± 0.07 (0.50)
Recovery (s)	0.39 ± 0.08	0.44 ± 0.09* (0.67)	0.38 ± 0.08 (0.07)	0.46 ± 0.09* (0.92)

*Significant difference from FREE ($P < 0.05$).

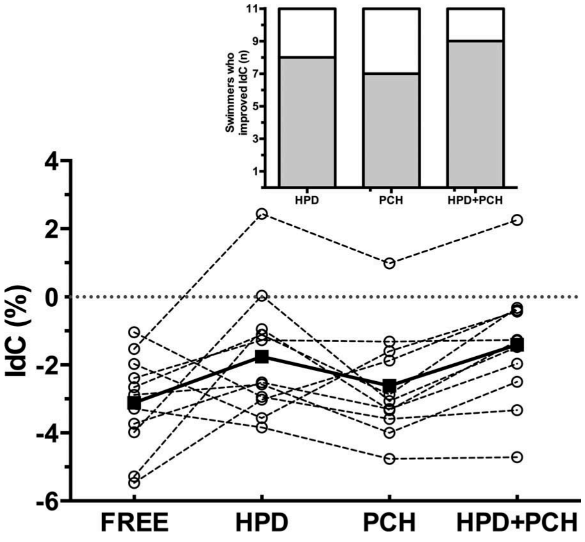

Figure 1. Individual index of coordination (IdC) in conventional swimming (FREE) and using hand paddles (HPD), parachute (PCH) and hand paddles plus parachute (HPD + PCH). Dashed lines represent each individual. Continuous line represents the average. Fulfilled area on inset figure shows the swimmers who improved IdC with the use of implements while the total area shows all the swimmers of the study.

Discussion

In this study, we investigated the effects of hand paddles, parachute and hand paddles plus parachute on kinematical parameters (SR, SL and AS) and index of coordination of backstroke swimmers. Our main findings indicate that the use of hand paddles plus parachute affected backstroke coordination towards greater propulsive continuity. In all the trials, swimmers were asked to swim at maximum intensity for 25 m in randomised order, and with a 5 min rest interval. Consequently, order or fatigue effects are not expected to be considerable (Gastin, 2001). Therefore, we assumed that the results of each experimental condition were a consequence of the implement used during the trial, and we further assumed that, if they were removed, results would be similar to those observed in FREE condition. Thus, it is conceivable that, from the perspective of the constraints, implements changed the task to be performed.

Regarding AS, SR, SL and IdC in FREE, our data are similar to a previous study (Chollet et al., 2008) conducted with backstroke swimmers. Implements such as hand paddles and parachute have been used to improve swimming performance by increasing propulsive force (Girold, Maurin, Dugue, Chatard, & Millet, 2007; Toussaint & Vervoorn, 1990). Even though they are used with the same purpose (increasing strength and, ultimately, propulsive force), they present different constraints to swimming coordination. Hand paddles artificially enlarge hand surface area, which augments the amount of water the swimmer moves in each stroke (Toussaint & Vervoorn, 1990); supposedly they will favour the propulsion to drag ratio if the swimmer may produce an increased force to move propulsive segments at a similar speed. On the other hand, parachute creates an extra hydrodynamic drag; it will compromise the propulsion to drag ratio. Accordingly, these different consequences of the use of implements might cause swimmers to self-organise to achieve an optimal coordination.

The use of hand paddles did not affect swimming speed, which is contrary to what was reported in other swimming strokes, showing tendencies to AS increases (Gourgoulis, Aggeloussis, Vezos, Antoniou, & Mavromatis, 2008). On the other hand, the results of SL and SR were in accordance with previous observations in front crawl (Telles et al., 2011) and butterfly (Telles et al., 2015). We are unaware of any study that investigated the effects of hand paddles on backstroke at maximal intensity, but the lack of improvement in speed with hand paddles might be a consequence of the swimmers' inability to adapt to the size of the hand paddles used in this study and to find an optimal combination of SR and SL to achieve the highest possible speed (Telles et al., 2011). For instance, the use of hand paddles in front crawl increased SL by 12% and decreased SR by 8% (Telles et al., 2011). In the present study, SL increased almost 20% and SR decreased more than 12%. The inability of the swimmers to adapt an optimal technique might be related to the larger hydrodynamic resistance that the swimmers' hand has to overcome during the propulsive phases, but especially during the pull phase. Pull phase is the only propulsive phase that was significantly increased in duration when HPD were used. It is possible that this result might be due to the shoulder flexibility limitation that poses the arms in a position in which swimmers are not able to generate muscle strength to overcome the additional resistance the hands have to face. Alternatively, the swimmers may consciously avoid applying force during this phase as it could cause to the swimmer to move sideways instead of forward, which would increase the relative duration. The relative decrease in entry and catch phase may also be an adaptation of the swimmers to maintain SR. The use of hand paddles slightly shifted IdC towards what is considered optimum for maximal speeds (i.e., opposition mode), increasing propulsive continuity. However, most swimmers kept their coordination in catch-up mode in all trials. Even though there was no significant difference compared to FREE, the effect of hand paddles on coordination was moderate (ES = 0.95). It demonstrated that, similar to front crawl (Telles et al., 2011) and butterfly (Telles et al., 2015), hand paddles seem to reduce the time gap between propulsive phases in backstroke. In addition to relative phase durations, it was also observed in the absolute durations.

Absolute durations of pull, push and recovery phases were higher when hand paddles were used. It is possible that in spite of swimmers attempting to keep a high SR, they had slowed the recovery phase to maintain inter-arm coordination because propulsive phases of the contralateral arm were longer. Thus, body balance would not be negatively affected and would not impair performance. The change in recovery phase demonstrates that swimmers intended to maintain their body balanced.

Parachute negatively affected swimming speed, SR and SL, which is in accordance with previous results obtained from other swimming strokes (Telles et al., 2015). The additional drag created by the parachute increased total drag and possibly also elevated intracyclic speed fluctuation (Alves, Gomes-Pereira, & Pereira, 1996; Dominguez-Castells & Arellano, 2012). As a consequence, it is conceivable that swimmers tried to adapt their coordination by decreasing the duration of non-propulsive phases to attenuate these fluctuations, which is an indicator of swimming efficiency (Craig, Skehan, Pawelczyk, & Boomer, 1985). The reduction of the recovery phase duration supports this suggestion. Another expected adaptation to diminish intracyclic speed fluctuation was the reduction in propulsion time gaps. However, no significant difference between FREE and PCH was observed on the IdC, which could indicate that the use of parachute did not affect inter-arm coordination pattern in backstroke. On the other hand, the analysis of absolute durations yields a different perspective, and supports the idea that swimmers tried to keep their body balanced. Propulsive phases' (pull and push) duration was longer, but so was the duration of clearing and recovery. Interestingly, recovery duration during PCH condition was not as long as in HPD, but the clearing phase duration was. We may suggest that as clearing duration was longer in PCH than in HPD, recovery phase did not need to be as long in PCH as it was in HPD to keep the swimmers' body balance. Therefore, we may say that this size of parachutes might be too large to be used keeping the same propulsive force generation.

We also studied a condition in which implements were used simultaneously (hand paddles plus parachute) to enlarge external overload. Swimming speed, SL, and SR changed in the same direction as in PCH. The magnitude of the changes, however, was smaller in AS and SL and higher in SR, indicating that the hand paddles and parachute might play some synergistic role. It is interesting to note that the effects of the use of hand paddles were similar when they were added to FREE (HPD) and to PCH (HPD+PCH): swimming speed was not significantly affected, SR decreased and SL increased. HPD+PCH was the only experimental condition that significantly affected IdC (ES = 1.2). The IdC changes as a consequence of using these implements together were related to the observed changes in the relative duration of the stroke phases (shorter non-propulsive phases and longer propulsive phases). This quest for a more continuous application of propulsive force is in line with the higher strength requirements, and allows us to consider that this is the best condition, among those overload conditions studied, to improve the IdC and to decrease the time gaps between propulsive phases.

Despite the tendency of individual coordination index values, one swimmer presented superposition mode in all overloaded trials, another swimmer presented opposition mode in HPD, three others showed catch-up mode very close to zero in HPD+PCH and the others showed always the same coordinative pattern. These results suggested that, we considered that the swimmers who shifted the coordination towards zero or showed a superposition mode in the trials have improved their coordination (Figure 1 inset), because this behaviour showed a decrease in the propulsion time gaps. These distinct individual respond to the use of implements were expected, as swimmers themselves represent a constraint (i.e., organismic), and by modifying the task, constraints interrelationship was supposed to be affected, thus generating an individualised adjustment.

We suggest to coaches and swimmers using these implements in their training sessions that the hand paddles plus parachute might be the best method to develop and build muscle strength and improve coordination, consequently decreasing propulsion time gaps in a context of maximised specificity.

Conclusion

We conclude that the use of hand paddles plus parachute affects the backstroke swimming coordination towards a condition of larger continuity of propulsive force production. The use of hand paddles only slightly improves coordination, propulsive phases time duration and stroke length; while the use of parachute only seem to degrade coordination and stroke kinematics and the use of the combination of hand paddles and parachute seems to be the best strategy to improve propulsive phases and coordination on backstroke swimming.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior [99999.005005/2014-00, Social Demand Program].

ORCID

João Paulo Vilas-Boas http://orcid.org/0000-0002-4109-2939

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