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Effect of aerobic training on inter-arm coordination in highly trained swimmers

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ABSTRACT

The effect of three months of aerobic training on spatio-temporal and coordination parameters was examined during a swim trial at maximal aerobic speed. Nine male swimmers swam a 400-m front crawl at maximal speed twice: in trial 1, after summer break, and trial 2, after three months of aerobic training. Video analysis determined the stroke (swimming speed, stroke length, and stroke rate) and coordination (Index of Coordination and propulsive phase duration) parameters for every 50-m segment. All swimmers significantly increased their swimming speed after training. For all swimmers except one, stroke length increased and stroke rate remained constant, whereas the Index of Coordination and the propulsive phase duration decreased ($p < .05$). This study suggests that aerobic training developed a greater force impulse in the swimmers during the propulsive phases, which allowed them to take advantage of longer non-propulsive phases. In this case, catch-up coordination, if associated with greater stroke length, can be an efficient coordination mode that reflects optimal drag/propulsion adaptation. This finding thus provides new insight into swimmers' adaptations to the middle-distance event.

Abbreviations: A (%), relative duration of catch phase; B (%), relative duration of pull phase; C (%), relative duration of push phase; D (%), relative duration of aerial recovery phase; $I^{+}_{/\text{stroke}}$, propulsive impulse per stroke (N s); $I^{-}_{/\text{stroke}}$, resistive impulse per stroke (N s); I^{+}_{r} and I^{+}_{l}, propulsive impulses from right and left hand, respectively; IdC, Index of Coordination; F_{prop}, cycle average propulsive force (N); T_{prop}, duration of the propulsive phase within a cycle; Tpull_r, Tpush_r, Tpull_l, Tpush_l, represent the durations (in s) of the pull and push phases of the right and left arms, respectively; SL, stroke length; SR, stroke rate; v50, average velocity over 50 m in m s^{-1}; v5, swim velocity measured over 5 m in m s^{-1}; VO2max, maximal oxygen uptake.

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1. Introduction

Swimming speed (v, in m s^{-1}) is the result of stroke length (SL, in m $stroke^{-1}$) and stroke rate (SR, in stroke min^{-1}), according to the relationship: $v = SL \times (SR/60)$ (Craig & Pendergast, 1979). Several studies have examined the SL to SR ratio as a function of race distance and expertise level (Craig, Skehan, Pawelczyk, & Boomer, 1985; Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996; Seifert, Boulesteix, & Chollet, 2004). The main results showed that lower SR is observed for longer competitive events (Craig et al., 1985), but that SL discriminates the faster swimmers from the slower ones for a particular race distance (Chatard, Collomp, Maglischo, & Maglischo, 1990). This has led to the conclusion that, for a given speed, SL is an important parameter to discriminate skill level and a potential indicator of swimming efficiency (Costill et al., 1985; Toussaint & Beek, 1992). However, v, SR and SL are indirect indicators of the processes that are in fact responsible for the dynamic balance between propulsive and resistive forces during a stroke cycle, even though this 'balance' is seldom maintained in races, where speed varies with race progression. According to Alberty, Sidney, Pelayo, and Toussaint (2009), performance analysis in swimming should put the emphasis on the factors that explain how this balance is obtained, in particular by examining how propulsive and resistive impulses are generated and coordinated.

A mechanical impulse (N s) corresponds to the integral of a force with respect to time, and it can be modified by varying the force, the duration of the application of this force, or both. Alberty et al. (2009) assumed that the propulsive impulse per stroke ($I^{+}_{/\text{stroke}}$) during a cycle could be calculated according to Eq (1):

$$I^{+}_{/\text{stroke}} = F_{\text{prop}} \cdot T_{\text{prop}} \tag{1}$$

where T_{prop} is the duration of the propulsive phases within the cycle, and F_{prop} the average propulsive force of the cycle.

The resistive impulse per stroke cycle can be estimated using Eq. (2).

$$I^{-}_{/\text{stroke}} = F_{\text{drag}} \cdot T_{\text{stroke}} \tag{2}$$

where I^{-} is the resistive impulse, F_{drag} the averaged drag force of the cycle, and T_{stroke} the cycle duration (in s).

These authors focused mainly on the arm impulses, as the direct contribution of legs to overall propulsion is small (Hollander, De Groot, van Ingen Schenau, Kahman, & Toussaint, 1988; Watkins & Gordon, 1983). As arms propel alternatingly, the propulsive impulse also corresponds to:

$$I^{+}_{/\text{stroke}} = I^{+}_{\text{r}} + I^{+}_{\text{l}} \tag{3}$$

where I^{+}_{r} and I^{+}_{l} are the force impulses generated by the right and left arms, respectively.

Chollet, Chalies, and Chatard (2000) broke the arm cycle into four phases, two non-propulsive (catch and recovery) and two propulsive (pull and push). Consequently, although the resistive impulse per stroke ($I^{-}_{/\text{stroke}}$) has to be calculated throughout the whole cycle, mean $I^{+}_{/\text{stroke}}$ is only generated during the propulsive phases, as can be seen in Eq. (4).

$$I^{+}_{/\text{stroke}} = I^{+}_{\text{r}} + I^{+}_{\text{l}} = F_{\text{r}} \cdot (\text{Tpull}_{\text{r}} + \text{Tpush}_{\text{r}}) + F_{\text{l}} \cdot (\text{Tpull}_{\text{l}} + \text{Tpush}_{\text{l}}) \tag{4}$$

where F (in N) is the average force, and Tpull_{r} and Tpush_{r}, and Tpull_{l} and Tpush_{l}, represent the durations (in seconds) of the pull and push phases of the right and left arms, respectively (Alberty et al., 2009).

Chollet et al. (2000) proposed the Index of Coordination (IdC) to assess the temporal organisation of inter-arm coordination – that is, how $I^{+}_{\text{r}} + I^{+}_{\text{l}}$ are distributed over time with respect to each other within the stroke cycle – by measuring the lag time between the propulsive actions of the upper limbs. The IdC is based on the quantification of the arm stroke phase durations and is expressed as a percentage. Three main models were defined: catch-up (IdC < 0%), characterized by a gliding phase; opposition (IdC $\sim$ 0%), in which propulsion from one arm starts exactly when propulsion from the other arm stops; and superposition (IdC > 0%), in which the propulsive phases of the two arms overlap.