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Relationships between coordination, active drag and propelling efficiency in crawl

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ABSTRACT

This study examines the relationships between the index of coordination (IdC) and active drag (*D*) assuming that at constant average speed, average drag equals average propulsion. The relationship between IdC and propulsive efficiency (e_p) was also investigated at maximal speed. Twenty national swimmers completed two incremental speed tests swimming front crawl with arms only in free condition and using a measurement of active drag system. Each test was composed of eight 25-m bouts from 60% to 100% of maximal intensity whereby each lap was swum at constant speed. Different regression models were tested to analyse IdC–*D* relationship. Correlation between IdC and e_p was calculated. IdC was linked to *D* by linear regression ($\text{IdC} = 0.246 \cdot D - 27.06$; $R^2 = 0.88$, $P < .05$); swimmers switched from catch-up to superposition coordination mode at a speed of ~1.55 m s^{-1} where average *D* is ~110 N. No correlation between IdC and e_p at maximal speed was found. The intra-individual analysis revealed that coordination plays an important role in scaling propulsive forces with higher speed levels such that these are adapted to aquatic resistance. Inter-individual analysis showed that high IdC did not relate to a

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high e_p suggesting an individual optimization of force and power generation is at play to reach high speeds.

1. Introduction

Swimming speed results from the interaction of propulsive and resistive forces. The arms, legs and trunk actions lead to intra-cyclic speed variations, so that the swimmer does not move at constant speed. As swimming economy has been correlated to low intra-cyclic speed variations (Barbosa et al., 2010), swimming faster would mean to minimize intra-cyclic speed variations toward constant speed. In case of constant speed, average propulsion equals average active drag. Active drag relates approximately to speed squared (Toussaint & Truijens, 2005). Mechanical power out-put is produced to overcome external forces (P_{ext}). Only a portion of this P_{ext} contributes to overcome active drag (P_d), as the swimmer's hand lacks a fixed push off point to propel the body forward, another part of the mechanical power applied by the hand in the water is wasted in kinetic energy imparted to the water (P_k) (Barbosa et al., 2010; Toussaint & Truijens, 2005; Zamparo, Capelli, & Pendergast, 2011; Zamparo, Pendergast, Termin, & Minetti, 2002). Moreover, internal power (P_{int}) is yielded to accelerate and decelerate the limbs with respect to the center of mass. Thus the total mechanical power out-put (P_o) is the sum of the internal power (P_{int}), power delivered to overcome drag force (P_d) and kinetic power (P_k) (Zamparo et al., 2011, 2002):

$$P_o = P_{ext} + P_{int} = P_d + P_k + P_{int} \quad (1)$$

Several methods have been used to assess active drag and/or propulsive efficiency. Assisted towing method (ATM) (Formosa, Toussaint, Mason, & Burkett, 2012), which is a velocity perturbation method, provided measurement of active drag only at maximal speed. Di Prampero, Pendergast, Wilson, and Rennie (1974) proposed a method based on the measurement of sub-maximal oxygen consumption while the swimmers swam partially resisted by a force acting on the opposite direction. But this method only provided satisfactory measurement at sub-maximal speeds – up to maximal lactate steady state – therefore, at swim speeds that were inferior to competitive race paces. The Measuring Active Drag (MAD)-system (Toussaint & Truijens, 2005) provided an interesting alternative to overcome the limits of the other systems of drag measurement. It provided the swimmer with a series of push-off pads installed at fixed distance under the surface. Participants were instructed to use these pads to propel themselves, and the force developed was recorded for each cycle. In that, this system allowed direct measurement of the drag–velocity relationship over the entire range of swim speed a swimmer was capable of adopting (Toussaint & Truijens, 2005). Of course, the MAD-system has its weaknesses. In particular, it required arm-only swimming using fixed push-of pads, which might modify the swim stroke. But a recent study showed that the change of inter-pad distances did not have an effect on active drag determinations, suggesting that it may not be necessary to adapt the inter-pad distance whatever the anthropometric characteristics or speed (Schreven, Toussaint, Smeets, & Beek, 2013).

Using the MAD-system, Toussaint, Carol, Kranenborg, and Truijens (2006) measured the propelling efficiency (e_p) as the ratio between P_d and P_o:

$$e_p = P_d / P_o \quad (2)$$

Therefore, according to Toussaint et al. (2006), swimming fast does not only depend on the ability to produce a high propelling force while minimizing drag, but also requires a high e_p (i.e., to keep P_k low). However, with the MAD-system, no measurements of P_{int} are made so that, according to Zamparo et al. (2011, 2002) e_p corresponds to Froude efficiency of the arm stroke, i.e. the ability of the body to impart useful kinetic energy to the water.