Human Movement Science 55 (2017) 240–254

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Perception and action in swimming: Effects of aquatic environment on upper limb inter-segmental coordination

Brice Guignard[a,b,*], Annie Rouard[b], Didier Chollet[a], Omar Ayad[a], Marco Bonifazi[c], Dario Dalla Vedova[d], Ludovic Seifert[a]

[a] *Center for the Study and the Transformation of Physical Activities (CETAPS), Faculty of Sport Sciences, University of Rouen Normandy, UNIROUEN, 76821 Mont Saint Aignan, France*
[b] *Interuniversity Biology and Motricity Laboratory (LIBM), University Savoie Mont Blanc, 73376 Le Bourget du Lac Cedex, France*
[c] *Department of Medicine, Surgery and NeuroScience, University of Siena, Via Banchi di Sotto, 55, Siena SI, Italy*
[d] *Sport Science Department, Medicine and Science Sport Institute, Italian National Olympic Committee (CONI), Foro Italico, Largo Lauro de Bosis 15, 00135 Roma, Italy*

ARTICLE INFO

Keywords:
Human swimming
Fluid flow
Ecological dynamics
Inter-segmental coordination
Coupling angle

ABSTRACT

This study assessed perception–action coupling in expert swimmers by focusing on their upper limb inter-segmental coordination in front crawl. To characterize this coupling, we manipulated the fluid flow and compared trials performed in a swimming pool and a swimming flume, both at a speed of 1.35 m s^{-1}. The temporal structure of the stroke cycle and the spatial coordination and its variability for both hand/lower arm and lower arm/upper arm couplings of the right body side were analyzed as a function of fluid flow using inertial sensors positioned on the corresponding segments. Swimmers' perceptions in both environments were assessed using the Borg rating of perceived exertion scale. Results showed that manipulating the swimming environment impacts low-order (e.g., temporal, position, velocity or acceleration parameters) and high-order (i.e., spatial-temporal coordination) variables. The average stroke cycle duration and the relative duration of the catch and glide phases were reduced in the flume trial, which was perceived as very intense, whereas the pull and push phases were longer. Of the four coordination patterns (in-phase, anti-phase, proximal and distal: when the appropriate segment is leading the coordination of the other), flume swimming demonstrated more in-phase coordination for the catch and glide (between hand and lower arm) and recovery (hand/lower arm and lower arm/upper arm couplings). Conversely, the variability of the spatial coordination was not significantly different between the two environments, implying that expert swimmers maintain consistent and stable coordination despite constraints and whatever the swimming resistances. Investigations over a wider range of velocities are needed to better understand coordination dynamics when the aquatic environment is modified by a swimming flume. Since the design of flumes impacts significantly the hydrodynamics and turbulences of the fluid flow, previous results are mainly related to the characteristics of the flume used in the present study (or a similar one), and generalization is subject to additional investigations.

---

[*] Corresponding author at: Center for the Study and the Transformation of Physical Activities (CETAPS), Faculty of Sport Sciences, University of Rouen Normandy, UNIROUEN, 76821 Mont Saint Aignan, France.

E-mail addresses: brice.guignard@univ-rouen.fr (B. Guignard), annie.rouard@univ-savoie.fr (A. Rouard), didier.chollet@univ-rouen.fr (D. Chollet), omar.ayad@univ-rouen.fr (O. Ayad), marco.bonifazi@unisi.it (M. Bonifazi), dario.dallavedova@coni.it (D. Dalla Vedova), ludovic.seifert@univ-rouen.fr (L. Seifert).

http://dx.doi.org/10.1016/j.humov.2017.08.003
Received 17 February 2017; Received in revised form 23 July 2017; Accepted 8 August 2017

1. Introduction

The interaction between swimmers and the aquatic environment offers a suitable vehicle to investigate perception–action coupling (Wei, Mark, & Hutchison, 2014). According to Newell, Kugler, van Emmerik, and Mcdonald (1989), the *perceptual-motor workspace* in which an individual (e.g., a swimmer) performs a movement is a dynamic interface between informational flows arising from perception (e.g., in the aquatic environment) and the kinematical and kinetic flows arising from action (e.g., limb movements to propel the swimmer). In this sense, individuals are continuously picking up information from their environment (i.e., interacting with it) to guide action, which in turn provides them with new information. An individual performing a movement produces forces that may alter the state of the environment, thereby changing the layout of the information available about the new state of the individual–environment system (Warren, 2006) and highlighting the circular causality between perception and action (Kugler & Turvey, 1987). Behavioral patterns are available through the perceptual-motor workspace and the individual may or may not adopt a given pattern during the task he/she is performing (Newell, 1991; Newell et al., 1989). For example, in competitive swimming, swimmers might be aware about swimming in the lane as far as possible from a direct opponent in order to reduce the effect of his/her waves, whereas in open-water events, this same distance should be reduced to benefit from drafting (Silva et al., 2008). In the Gibsonian vision of ecological psychology, such possibilities for action are perceived as *affordances*: this perception is direct and thus unmediated by representations. Affordances are considered intrinsic properties of the surrounding environment that are specified in relation to the attributes (i.e., body size, muscle strength, locomotor skill or even fine motor control) of the perceiver–actor (Gibson, 1979). Affordances are predicated on the circular causality between perception and action (Fajen, Riley, & Turvey, 2008) – that is, "*affordances must be perceived, perception must guide action, and actions are implicit in affordances*" (p. 129) (Adolph & Kretch, 2015). Perception–action coupling was illustrated by Turvey (2007) for fish propulsion: "the shedding of vorticity is the hallmark of force production in fluids, reflecting the transfer of momentum to the wake. The bifurcations in vortex patterns are accompaniments of reorganizations of fins that are often subtle and hard to describe in detail" (p. 670). In competitive swimming, swimmers' actions impact the motion of water particles in a circular and tight manner and, in return, the fluid motion will impact their future perceptions and actions. Additionally, in aquatic locomotion, task and environmental constraints are intertwined to play an incommensurable role that will condition swimmers' perceptions and shape their behaviors to appropriately propel themselves forward. Indeed, swimmers' propulsion arises from the simultaneous action of the four limbs, performed in an uncommon horizontal body position, and in environments with specific properties, such as water density (water is 800 times denser than air; Denny, 1993), resistances (i.e., passive and active drag), flow (i.e., laminar vs. turbulent), viscosity or even opacity (e.g., during open-water events) (Toussaint, 2002). Consequently, swimming performance is defined by the (i) minimization of resistances opposed to forward displacement, (ii) generation of propulsive forces and (iii) maximization of propelling efficiency, as only a portion of the mechanical power output contributes to overcoming active drag (Toussaint, Hollander, van den Berg, & Vorontsov, 2000). From an ecological psychology perspective, this *substance* in which swimmers move (i.e., water) is continuously offering possibilities for action, or swimming affordances (Gibson, 1979), such as ways to propel the body forward efficiently and adopt a streamlined position.

The ecological dynamics framework highlights the coupling between the *organism* and the *environment* (Kugler & Turvey, 1987) as the smallest unit in behavioral analysis (Araújo, Davids, & Hristovski, 2006; Davids, Araújo, Hristovski, Passos, & Chow, 2012). This means that the swimmer cannot be dissociated from his/her aquatic environment, since behavior emerges from both the characteristics inherent to the organism itself and the environment in which the movement is performed. More precisely, Newell (1986) identified a set of continually nested and interacting constraints, which channel the qualitative dynamics of movement (Kugler, Kelso, & Turvey, 1980; Kugler, Kelso, & Turvey, 1982). These constraints to action are divided into three main categories: *organismic* constraints are all the inherent properties and characteristics of the individual, *task* constraints are external to the individual and specific to the situation the performer is faced with, and *environmental* constraints are external constraints related to the environment in which the task is performed (Newell, 1986). In this sense, identifying and manipulating key constraints is a way to test the adaptive nature of behavior as a function of perturbation (Davids, Button, & Bennett, 2008; Newell, 1986). The so-called *constraints-led approach* (Davids, Glazier, Araújo, & Bartlett, 2003) is an appropriate perspective for studying (i) the reinforcement of behaviors or the emergence of new movement patterns (Seifert et al., 2014) and (ii) the motor variability that skilled swimmers exhibit to functionally adapt to the situations they encounter (Glazier & Davids, 2009a). In swimming, several categories of constraints (i.e., expertise, stroke rate, swimming speed and gender; see Seifert, Chollet, & Rouard, 2007a) have been used to investigate their possible influence on aquatic locomotion (Seifert, Button, & Brazier, 2010) and the variability of this emerging behavior (Seifert et al., 2014). Among them, the role of environmental constraint – albeit crucial – was classically estimated using an *indirect* approach by manipulating swimming speed (Seifert et al., 2010), which is a major component of drag computation (Pendergast et al., 2005). This study revealed that the resistances increased with the swimming speed and at a critical value of 1.8 $\mathrm{m\,s^{-1}}$, more than 50% of the total drag is related to resistance caused by water motion at the surface, constraining swimmers to adapt their behavior by creating an overlap between their propulsive arm actions (Seifert et al., 2010).

The originality of the present study was the direct manipulation of the swimming environment, since how swimmers coordinate and control their limbs cannot be understood apart from their context of performance. This challenge was met by using a *swimming flume* (Astrand & Englesson, 1972): a basin with fluid flowing in a loop and coming frontally at the participants (i.e., equivalent to a treadmill for running). To maintain their position, swimmers in a flume have no choice but to resist a fluid flow coming at them, otherwise they are pushed to the safety net behind them: this subtly reveals swimmers' adaptability in resisting high and unpredictable environmental constraints. In a classic pool, the strategy is different, as the swimmers create support from the fluid to propel themselves through quasi-inert masses of water. Therefore, the swimming flume might be a valuable device for manipulating