Human Movement Science 61 (2018) 219–230

Contents lists available at ScienceDirect

Human Movement Science

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

# Modelling stroking parameters in competitive sprint swimming: Understanding inter- and intra-lap variability to assess pacing management

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ARTICLE INFO

*Keywords:*
Freestyle
Sprint
Race constraints
Variability

ABSTRACT

This study investigated the inter- and intra-lap variability in stroking parameters during sprint competition to gain insight into the race management of speed (S), stroke length (SL), stroke rate (SR) and stroke index (SI) in relation to gender. The stroking parameters of 32 male and 32 female finalists in the 2015 World Championships and French Championships were analysed during 50-m and 100-m freestyle events. Using a video-derived two-dimensional direct linear transformation system, the biological coefficients of variation (BCV) between cycles were computed for the 50-m and the two laps of the 100-m ($L1_{100}$, $L2_{100}$). Speed changes within each lap were modelled by linear, quadratic or cubic models. The 50-m showed higher S and SR but lower SL and SI than $L1_{100}$. The 50-m exhibited greater BCV S than $L1_{100}$, which showed higher S, SR, SL and SI than $L2_{100}$. BCV S and BCV SL were lower in $L1_{100}$ than $L2_{100}$ but BCV SR was higher in $L1_{100}$ than $L2_{100}$. Male swimmers showed greater BCV S than female swimmers in the 50-m and $L1_{100}$. For the whole population, the linear regression model was dominant in the 50-m (53.1%), $L1_{100}$ (53.1%) and $L2_{100}$ (43.8%). High mean speed often related to high intra-lap speed fluctuations and a linear speed decrease in the 50-m suggesting an 'all-out' pacing, while lower fluctuations occurred during the 100-m suggesting an 'economical' pacing.

## 1. Introduction

Competitive swimming is a cyclic locomotors activity that occurs in highly constraining environment (as water density is approximately 800 denser than air), causing higher active drag than other cyclic aquatic activities (such as rowing and kayaking) (Pendergast et al., 2005). It means that swimmers have to manage strategically their stroke length (SL) and stroke rate (SR), in order to guarantee high swimming speed with few fluctuations between and within (Barbosa et al., 2010; Schnitzler, Seifert, Alberty, & Chollet, 2010). Indeed speed fluctuations were found to be positively correlated to energy cost of locomotion (Vilas-Boas, Fernandes, & Barbosa, 2011; Barbosa et al., 2006) and to discontinuity in propulsive actions in front crawl (Schnitzler et al., 2010; Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010). Competition analysis provides crucial information on the management of the stroking parameters (i.e., stroke length, stroke rate and swimming speed) (Mason & Formosa, 2011; Sidney, Alberty, Leblanc, & Chollet, 2011). For instance, stroke rate management during competition exhibited several profiles such as: (i) a linear decrease

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https://doi.org/10.1016/j.humov.2018.08.002
Received 8 January 2018; Received in revised form 14 August 2018; Accepted 15 August 2018
0167-9457/ 

through the 50-m and the 100-m front crawl events for most of the swimmers, (ii) near steadiness or smooth increase through the 200-m, and (iii) a U-shape through the 400-m for most of the swimmers (Sidney et al., 2011; Hellard et al., 2008; Kjendlie, Haljand, Fjortoft, & Stallman, 2006). These various profiles of stroke rate are usually associated to respective variation of stroke length, as swimming speed is the product of stroke rate and stroke length. Thus, swimmers manage their swimming speed to minimize the race time by adapting their stroke rate, their stroke length or both (Chollet, Pelayo, Delaplace, Tourny, & Sidney, 1997). However, one can wonder whether there is only one main strategy to manage the stroking parameters or whether several strategies can lead to short race time. One goal of our study was to investigate the variability of the stroking parameters between and within laps, and then to focus on the speed management modelling to determine the existing strategy in competition for elite swimmers.

Moreover, these various profiles of speed, stroke rate and stroke length could also relate to the management of the race components (dive, turn, free swim, finish) (Mason & Formosa, 2011). Therefore, a second goal of our study was to understand how the race components should be chained and optimized lap to lap during competition. For instance, in 400-m international swimming competition, Mytton, Archer, Rumbold, and Gibson (2015) emphasized that the variance of speed profiles tended to increase as the race progressed. Similar results were also observed by Robertson, Pyne, Hopkins, and Anson (2009) when analysing between-swimmers average and standard deviation times for the 200-m freestyle for males and the 400-m freestyle for both gender. (Mytton et al., 2015; Mytton, Archer, Gibson, & Thompson, 2014) related this higher variance of swimming speed in the final lap to an indication of fatigue and deterioration in mechanical efficiency as the race progresses. In addition, Mytton et al. (2014) showed that performance in the final lap in 400-m (collected in international competitions between 2005 and 2011), and especially the differences in absolute, normalized, and relative speed can differentiate between medallists and non-medallists. These authors suggested that the success associated with a more pronounced end spurt could mean that medallists were able to call on reserves of energy not available to non-medallists three-quarters of the way through the race. These studies as well as other recent research on speed management in cyclic activities (e.g., running, swimming, cycling, skating, kayaking, etc) showed that the management of the stroking parameters is a key aspect of performance and more importantly of winning the race (Foster et al., 1993, 2003, 2004, 2009; Thompson, Haljand, & MacLaren, 2000; Thompson, MacLaren, Lees, & Atkinson, 2004; Tucker & Lambert, 2006). However, these researches only consider lap times (i.e. average value of speed for 50-m lap) and even 100-m times for the 400-m freestyle event analysed by Mytton et al. (2014, 2015) and Thompson (2015), neglecting the possible effect of turning in the pacing. Following this race components analysis, Shimadzu, Shibata, and Ohgi (2008) exemplified how race analysis can be modelled according to speed fluctuations during each part of the race. Based on the initial part just after the dive or turn (when swimming speed is higher than mean lap speed), the clean swimming part (when speed is close to mean speed) and just before the turn or finish (when speed decreases) (Shimadzu et al., 2008).

Although this effort to model race analysis, the main limitations of these studies might be the impossibility to accurately determine the inter-individual variability of race management, notably due to the effects of skill (finalist *vs.* semi-finalist; national *vs.* international), specialty (sprint *vs.* distance swimming; swimmers *vs.* open water, triathletes; front crawl *vs.* back stroke, butterfly and breaststroke) and gender, which is an important issue to detect any individual profiles (Sidney et al., 2011). Indeed, as mentioned previously different profiles of stroking parameters management between laps could be observed, with sometimes, high performance outcome relationships (Mason & Formosa, 2011; Mytton et al., 2014, 2015; Sidney et al., 2011; Thompson et al., 2000, 2004). These findings suggest that the stroking parameters variability is not automatically detrimental to achieve high performance in swimming (Seifert, Komar, Barbosa, et al., 2014). Indeed, to achieve high performance in competitive swimming there is a need to strike a delicate balance between behavioural stability and variability because, although swimmers need to achieve consistent outcomes, they also need to be able to successfully adapt their stroking parameters to changes in the performance environment (Seifert, Komar, Barbosa, et al., 2014; Newell, 1986). Notably, the observation of several profiles to manage the stroking parameters within lap (Mason & Formosa, 2011; Simbaña Escobar, Hellard, Pyne, and Seifert, 2018) suggests that swimmers functionally adapt to task and environmental constraints (such as glide, swimming speed, effect of start, turn, finish, fatigue) (Hellard et al., 2008; Seifert, Komar, Crettenand, & Millet, 2014; Seifert, Komar, Barbosa, et al., 2014; Seifert, Komar, Araújo, & Davids, 2016). Studies about behavioural variability pointed out the interest of going deeper in competition analysis through the examination of stroking parameters management within laps, in order to better understand inter-individual variability and to refine the detection of individual profile. In this regard, using a video camera system to automatically track swimmer's motion coupled with a 2D direct linear transform method (Benarab, Napoléon, Alfalou, Verney & Hellard, 2015), Simbaña Escobar et al. (2018) recently modelled the speed changes between and within 50-m laps in 200-m freestyle events and compared those modelling between 32 top-level male and female swimmers. First, the authors highlighted that speed changes within lap were best represented by a cubic, then linear and quadratic regression models, and second that the cubic model was more frequent for males than for females, suggesting greater capacity of males to generate higher acceleration after the turn. The various models exhibited for the 200-m front crawl event emphasize that each swimmer adapts his/her pacing to the race constraints and suggest to focus on the race components to understand the speed management. In comparison to the 200-m front crawl, the 50-m and 100-m events are characterised by different task and organismic constraints. Notably, the higher speeds reached in sprint as well as the higher contribution of the alactic and glycolytic metabolism (Rodriguez & Mader, 2011) might prevent the possible generation of speed in the middle of the 50-m lap.

Therefore, the aim of our study was to use the 2D direct linear transform method from video system (Benarab et al., 2015) to investigate the stroking parameters management between and within laps during sprint events, and according to gender. In particular our study examined the relationships between the average swimming speed of the lap, the amount of speed variations between cycles and the nature of these speed variations through a regression modelling. We hypothesise that various profiles of swimming speed management can both lead to top elite performance. Globally, we expect that higher average swimming speeds are associated to higher amount of speed variations and lower speed decrease within laps (which could be reflected by linear modelling between speed and lap distance).