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Antoine Bouvet, Guillaume Nicolas, Nicolas Bideau

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Profiling pacing and underlying kinematics during 400m front-crawl with embedded sensors and functional modeling of large database: highlighting the technical regulations of various performance level

Bouvet, A.1,2,3, Nicolas, G. 1,2, Bideau, N.1,2

1M2S Laboratory (Movement, Sports & Health), University Rennes 2, ENS Rennes, Bruz, France; 2MIMETIC - Analysis-Synthesis Approach for Virtual Human Simulation, INRIA Rennes – Bretagne Atlantique, France; 3CREST, ENSAI, Bruz, France;

INTRODUCTION:

Monitoring of the 400m front-crawl test is of crucial interest to provide valuable feedback on performance and technique, driving construction of training plan and race strategy. Thus, some studies looked at pacing during this event but were limited to split times with narrow performance level [1], reduced sample size [2], and without technical considerations [3]. Then, there is a need for analyzing pacing and kinematics associated with performance at various levels, especially because speed management regarding individual stroke mechanics remains unclear. This study aimed at modeling kinematical features during 400m tests to profile functional patterns of pacing and technical regulations according to specific performance groups and the overall population.

METHODS:

123 trained to elite swimmers performed a 400m all-out in front-crawl with an Inertial Measurement Unit (Xsens DOT, The Netherlands) on the sacrum. Participants were divided into 4 balanced groups from lowest (G1) to best (G4) final time. Speed, stroke rate (SR), stroke length (SL) and jerk cost (JC) were computed by lap and fitted using hierarchical generalized additive models [4] to describe both the relationships between kinematics and performance and evaluate profiles of regulation across the laps. Fisher tests and visualizations of the functional responses were used for interpretations. Significance was set at $p < 0.05$.

RESULTS:

Significant relationships with performance displayed an inverse-sigmoid shape for SL, with inflection points at 1.12 and 1.62 m/stroke, and a rising shape for JC with a deviation for G1. Kinematical profiles displayed significant regulations as reverse J-shape pacing with deviation for G1 that steeper this pattern, reverse J-shape and positive profile for respectively SR and SL functional response with both common opposite deviations for G1 and G4 that correspondingly mitigate and steeper the global regulation, U-shape for JC with deviation for G2 that mitigate the common profile, by opposition of G3 and G4 that steeped it with a higher extent for G4.

CONCLUSION:

Useful technical benchmarks regarding the common and group-specific kinematical regulation across 400m on a large database were provided. Key points of global performance are a SL and a JC respectively higher to 1.25 m/stroke and $15 \text{ g}^2/\text{s}^2 \times 10^{-3}$, even if low intra-cyclic acceleration fluctuations is fundamental for improvement beyond G3. Preserving energy for finish, by the ability to lower the fast start and accentuate the end spurt is a determinant of progress. Such effective pacing involves typical kinematical regulations targeting to maintain stroke smoothness as much as possible, while displaying both opposite and major variations in SR and SL modulations. This framework allows to tailor and drive the development of race strategy by understanding and diagnosing the underlying technical requirements of successful pacing skills.

1. Lipinska et al., 2020, 2. Correia et al., 2023, 3. Morais et al., 2019, 4. Pedersen et al., 2019