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Assessment of Efficiency of Underwater Undulatory Swimming Strategies Using a Two-Dimensional CFD Method

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Abstract : In competitive swimming, after dives and turns, athletes perform underwater undulatory swimming (UUS), copying marine mammals' method of locomotion. The body, performing this wave-like motion, accelerates the fluid downstream in its vicinity, generating propulsion with minimal resistance. Through this technique, swimmers can maintain greater speeds than surface swimming and take advantage of the overspeed granted by the dive (or push-off). Almost all previous work has considered UUS when performed at maximum effort. Critical parameters to maximize UUS speed are frequently discussed; however, this does not apply to most races. In only 3 out of the 16 individual competitive swimming events are athletes likely to attempt to perform UUS with the greatest speed, without thinking of the cost of locomotion. In the other cases, athletes will want to control the speed of their underwater swimming, attempting to maximise speed whilst considering energy expenditure appropriate to the duration of the event. Hence, there is a need to understand how swimmers adapt their underwater strategies to optimize the speed within the allocated energetic cost. This paper develops a consistent methodology that enables different sets of UUS kinematics to be investigated. These may have different propulsive efficiencies and force generation mechanisms (e.g.: force distribution along with the body and force magnitude). The developed methodology, therefore, needs to: (i) provide an understanding of the UUS propulsive mechanisms at different speeds, (ii) investigate the key performance parameters when UUS is not performed solely for maximizing speed; (iii) consistently determine the propulsive efficiency of a UUS technique. The methodology is separated into two distinct parts: kinematic data acquisition and computational fluid dynamics (CFD) analysis. For the kinematic acquisition, the position of several joints along the body and their sequencing were either obtained by video digitization or by underwater motion capture (Qualisys system). During data acquisition, the swimmers were asked to perform UUS at a constant depth in a prone position (facing the bottom of the pool) at different speeds: maximum effort, 100m pace, 200m pace and 400m pace. The kinematic data were input to a CFD algorithm employing a two-dimensional Large Eddy Simulation (LES). The algorithm adopted was specifically developed in order to perform quick unsteady simulations of deforming bodies and is therefore suitable for swimmers performing UUS. Despite its approximations, the algorithm is applied such that simulations are performed with the inflow velocity updated at every time step. It also enables calculations of the resistive forces (total and applied to each segment) and the power input of the modeled swimmer. Validation of the methodology is achieved by comparing the data obtained from the computations with the original data (e.g.: sustained swimming speed). This method is applied to the different kinematic datasets and provides data on swimmers' natural responses to pacing instructions. The results show how kinematics affect force generation mechanisms and hence how the propulsive efficiency of UUS varies for different race strategies.

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