A STUDY OF SCULLING SWIMMING PROPULSIVE PHASES AND THEIR RELATIONSHIP WITH HIP VELOCITY

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The purpose of this study was to identify the effect of sculling propulsive arm actions in displacement on the intra-cycle velocity of the hip. Four phases were defined (based on hand movements) prior to the development of the study: inward, pronation, outward and supination. A group of 9 international synchronized swimmers participated in the study. A displacement of 15 m was recorded using a velocimeter and underwater video cameras (bottom and sagittal views). Mean cycle velocity 0.548m/s, duration 0.828s, sculling frequency 1.220 sculling length 0,455 m and percentage of phase duration: inward (38.6%), pronation (10.3%), outward (33.5%) and supination (17.6%) were obtained. The mean body velocities were similar in the phases, while the durations where significantly different. The sculling propulsive action helps body displacement in the inward, outward and supination phases; while the pronation had a reduced contribution. Reversal stroke actions help to support the hand fixed it the water while the arm muscles are contracted helping the next propulsive phases (inward or outward) to move the hand an body forward.

KEY WORDS: unsteady propulsion, kinematics, velocimetry, vortex recapture

INTRODUCTION: Swimming stroke propulsion is composed of different hand and forearm propulsive actions that were classified as: outsweep, downsweep, insweep and upsweep (Costill, Maglischo, & Richardson, 1992). These propulsive actions can be studied from an steady or quasi-steady approach (Schleihauf, 1979) or considering unsteady propulsive mechanisms (Arellano, Terrés-Nicoli, & Redondo, 2006; Matsuuchi et al., 2009; Ungerechts, 2007). Sculling is a basic propulsive action applied in isolation in synchronized swimming or other aquatic sports, or that can be included in the pulling actions/trajectories of formal strokes. This simple propulsive action, at first sight, reveals an extraordinary complexity when it is carefully studied. Our previous 3D studies of supportive sculling while maintaining a vertical body position revealed a complex 3D path that is changed in length, inclination or peak velocities, under different vertical load conditions (Pochon & Arellano, 2007). Four phases can be defined in the sculling action when the unsteady propulsive mechanics that have been studied in similar biological propellers (Biewener, 2003): inward, pronation [stroke reversal 1], outward and supination [stroke reversal 2]. Supportive sculling (without body displacement) and propulsive sculling (where the body is displaced) were compared observing the pulling path and the wake produced in both conditions. Two pulling paths, “infinite” and “zigzag” shaped, were found (observing in this second case a continuous forward displacement of the hands). The wakes observed were clearly different with a vortex propulsive structure in the second case (Arellano & Pardillo, 2007). Hip velocimetry combined with sculling phase analysis seem a different procedure to analyse this propulsive action and it will be applied in our study. The aim of this study was to measure the effect of propulsive sculling action during horizontal body displacement, measured by the hip velocity and considering the sculling propulsive phases.

METHODS: Nine international synchronized swimmers participated as volunteers in the study. Their basic characteristics are described in Table 1. Each participant performed 3 trials executing propulsive sculling while keeping the body in a horizontal position. The trial with highest mean horizontal hip velocity was selected for the analysis. The swimmer was encouraged to perform as the highest velocity possible.

Table 1. Basic information about the participants

Variable	Mean	SD
Age (y)	20.9	1.4
Height (cm)	171.1	4.3
Mass (kg)	59.1	5.1

Data Collection: The hip velocity was obtained from a velocity–time data recorded using a position transducer, recording at 200 Hz. The apparatus consisted in a resistive sensor (which produced a resistance of 2.45N) with a coiled cable that was fastened to the swimmers' waists at the height of second and third lumbar vertebrae by means of a belt. An external box including a 12 bit analogue to digital converter plus and video processor to allow synchronization the recorded velocity with the video signal (50Hz) to combine both records and to save them in the computer through the USB 2.0 interface. Three views were combined in the video signals using a video mixer and a picture in picture video digital tool that is installed in the Altitude Training Centre of Sierra Nevada swimming pool (up 8 video signal can be combined in different frame positions). The bottom, sagital and lateral-posterior views were combined to observe in detail the initiation of each phase. At least three consecutive cycles were analyzed after the swimmer covered 8 m in the prescribed position.
Variables: The sculling actions were analyzing using the four phases durations (s), sculling frequency (Hz), body displacement by cycle (m), cycle mean velocity (m/s) and sculling phase mean velocity (m/s). To compare or produce coherent data analysis between participants, the durations were later normalized and expressed in percentages (0% was the initiation of the inward phase (I) and 100% was the end of the supination phase (IV).
Data analysis: Descriptive statistics were obtained mean and standard deviation plus ANOVA of repeated measures and post-hoc tests using standard statistical software.

RESULTS: The results are set out in Tables 2 and 3. This propulsive movement produced a limited body velocity; however, this velocity maintains a flat sinusoidal path throughout the cycle duration, with amplitude about ± 0.1 ms^{-1} related with the mean cycle velocity (0.548 ms^{-1}). The sculling frequency seems a little higher related to formal strokes, while the body length displacement is about one third or one quarter.

Table 2. Results (means and SD) obtained after records analysis per scull cycle.

Variables	Mean (SD) Total Cycle
Mean Velocity ms^{-1})	0.548 (0.097)
Duration (s)	0.828 (0.081)
Max. Velocity (ms^{-1})	0.639 (0.120)
Min. Velocity (ms^{-1})	0.475 (0.102)
Sculling Frequency (Hz)	1.220 (0.140)
Sculling Length (m)	0.455 (0.092)

Table 3. Results (means and SD) obtained after records analysis per phase of scull cycle

Variables	Phase I Inward	Phase II Pronation	Phase III Outward	Phase IV Supination
Velocity (m/s)	0.538 (0.106)	0.536 (0.100)	0.543 (0.090)	0.578 (0.106)
Duration (s)	0.322 (0.061)	0.086 (0.013)	0.278 (0.061)	0.143 (0.044)
Percentage (%)	38.58 (4.99)	10.35 (1.34)	33.47 (6.33)	17.6 (6.54)

The phase analysis enabled us to define specific durations related to the hand movements. The inward phase is about a 40% of the total duration, while the pronation is the shortest one. Outward is about a third of total cycle duration and supination is longer than pronation with higher variability. Significant differences have been found between all durantion's phases after apply a post-hoc test of ANOVA of repeated measures ($p<0.01$). However these differences have not been found in the mean velocities between phases. Peak velocities were more frequently obtained in the inward phase (5 cases of 9) and the supination phase (2 cases of 9), while the slowest velocities were more frequently produced at the inward phase (6 cases of 9) and while the swimmers performed the pronation (3 cases of 9).

DISCUSSION: Typical propulsive actions are described during the sculling phases in the inward phase. The path and hand position supported quasi-steady based propulsion with a possible lift and drag propulsive component involved. The velocities values obtained during stroke reversal phases (II & IV) were high enough to keep the body velocity similar or closer than typical propulsive phases (I & III). This stroke reversal is characterized by a complex wake interaction with propulsive hand that should produce enhanced lift [as is explained in several papers on animal biomechanics, see Biewener (2003). These effects added to the inertial influences that could be taken into all phases should explain all the phenomena. A clear forward displacement of the hand during the pulling trajectory, observed mainly through the bottom camera, in a zigzag shape, confirms the previous statements to explain the velocity of the body path.

CONCLUSION: The sculling propulsive action helps body displacement in the inward, outward and supination phases; while the pronation had a reduced contribution. Reversal stroke actions help to support the hand fixed it the water while the arm muscles are contracted helping the next propulsive phases (inward or outward) to move the hand an body forward. A wake analysis combined with the acceleration of the body will enable us to understand the sculling propulsive action in depth in the near future.

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