THE APPLICATION OF HIGH-SPEED VIDEOGRAPHY TO THE KINEMATIC ANALYSIS OF FREESTYLE SWIMMING

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The purpose of this paper is to present the preliminary results of the use of high-speed videography and subsequent "multi-2D" motion analysis in the study of selected factors associated with Freestyle swimming. Variations in hip velocity in the longitudinal plane of motion were assessed in a series of trials which required swimmers to (1) Perform the underwater pull phase using the traditional "90-degree" elbow bend; and (2) Repeat the effort while holding the elbow in a fully extended position; (3) Allow the elbows to precede the hands while attempting to engage the water during the propulsive phase, i.e. pull with a "dropped elbow." and (4) Consciously guide the hands through an exaggerated lateral path, referred to as the "S pull"; The resulting data produced quantifiable results that address a number of technical assumptions long-held by coaches and swimmers.

KEY WORDS: freestyle swimming, kinematic, high-speed videography.

INTRODUCTION: The Freestyle is the most widely used stroke for both competitive and recreational swimming. During the underwater pull phase of the stroke, efficient Freestyle swimming dictates that the hands be guided through movement patterns, which have been refined over decades (Maglischo, 2003). However, detailed analyses of the stroke have only recently been made possible with the advent of underwater video taping, particularly when combined with slow-motion and freeze-frame technology (Cappaert, Pease & Troup, 1995; Haffner & Cappaert 1999; Kikodelis, Kollia & Hatzitaki, 2005).
The introduction of multi-camera, high-speed videography, coupled with motion analysis software, now allows for more detailed kinematic analyses of swimming stroke mechanics (Prins, Murata, Allen, 2010). As is the case with all four competitive swimming strokes, key elements of the propulsive phase of the pull can be identified and analyzed (Psycharakis & Sanders, 2008; Seifert, Chollet & Bardy, 2004). When examining commonly used Freestyle swimming technique, it is apparent that in addition to the accepted patterns of efficient propulsion, there are often-repeated variations associated with the stroke that may not contribute to efficient propulsion. These variations are not only common, but also predictably result in the loss of stroke efficiency. These movement patterns have been termed "swimming stroke defects".
This paper is a preliminary report of data and analyses designed to examine the affect on linear hip velocity in the Freestyle, when performing four variations in the underwater pull patterns.

METHODS: A total of 18 competitive swimmers, all members of the University of Hawaii Intercollegiate Swimming Team, participated in the study. Subject ages ranged between 17 and 22 years. For data collection, two high-speed digital cameras (Bassler Model 602), were mounted on rigid frames and placed at a depth of 0.3 meters, each at right angles to each other for frontal and lateral viewing. Dual cabling allowed for camera control and frame synchronization. Rotational joint segments were identified using a series of light emitting diodes (LED's), housed in waterproof housings and activated via battery-operated cabling. Two-dimensional (2D) calibration was conducted using a 4-point frame (1m x 1m). Frame rate was set at 100 frames/second.
Each swimmer was filmed for 3 trials each of the four pull patterns as follows: (1) Maintaining a "normal" elbow-bend, traditionally recommended to be close to 90 degree elbow-flexion

during the middle third of the underwater pull; (2) Holding the elbow in a fully an extended position, i.e. a straight-arm pull throughout the underwater pull phase; (3) Consciously allowing the elbow to precede the forearm and hand during the underwater pull phase, a swimming stroke defect termed the "dropped elbow." (4) Consciously tracing the path of the hands to incorporate exaggerated lateral excursions in an attempt to trace a path resembling a two-dimensional figure "S."

Subjects were equipped with a Tempo Trainer (Finis, Livermore, CA), attached to the swimmer's goggles, close to the ear. The device produces an audible signal that was set at one-second intervals. Subjects were required to maintain a stroke cadence of one arm-stroke per second, for all trials.

The resulting video footage was digitized and processed using the Multi 2-D option included in the motion analysis software, (Vicon Motus, Denver, CO). A repeated measures ANOVA with an LSD post hoc test was used to identify differences among the four pull patterns. Significance was determined at the 0.05 level.

RESULTS: Linear hip velocity (LHV) in the longitudinal plane of motion was measured for each trial. Each of the 3 pull patterns, which the subjects were required to consciously simulate, was compared to the traditional bent-arm pull.

Bent arm vs. Straight-arm pull: The maximum elbow-flexion when subjects performed the bent-arm pull averaged 126±20 degrees. Similarly, when pulling with a "straight-arm, maximum elbow flexion averaged 151±18 degrees. No statistical difference between the two arm positions was detected when their effect on LHV was examined (1.54±0.23 versus 1.47±0.17 m/s).

Bent arm vs. "Dropped-elbow": Angular alterations in the degree of elbow-flexion as viewed from a lateral perspective, were measured. LHV values were compared between the traditional bent-arm and "dropped elbow". The mean maximum elbow flexion for the dropped elbow pattern when viewed laterally was 113±21 degrees. LHV was greater with a bent arm (1.54±0.23 m/s) than with a dropped elbow (1.34±0.13 m/s).

Bent arm vs. "S pull": Lateral excursions of the hand during the "S pull" were determined by examining the distance moved by hand in the frontal plane when viewing the subject from head on. These changes were compared to the subject's maximum wingspan and reported as a percentage of maximum wingspans. The average percentage of wingspan was 54.6% ranging from 38.2% to 79.9%. There was no difference in LHV between the bent arm and the S pull (1.54±0.23 versus 1.43±0.26 m/s).

DISCUSSION: In spite of the limitations of 2-D calibration, the Multi 2-D software feature makes it ideally suited for analyzing swimming stroke mechanics in more detail that was previously possible. An additional feature is its ability to generate reports that allow us to combine the synchronized video frames with selected graphs.

The figures included below present single-frame examples of reports of the pertinent video clips combined with corresponding graphs. Linear hip velocities plotted over time allow analysis of the associated pull patterns. The vertical line in the graphs is a feature of the software, which tracks the synchronization of each video frame with the respective time intervals on the selected graphs.

Bent arm vs. Straight-arm pull: A long-held belief has been that swimmers need to flex their elbows to an angle of approximately 90 degrees during the middle-third of the underwater pull. Consequently, it was surprising that all the subjects instinctively flexed their elbows to obtuse angles (104 to 150 degrees) when required to swim with a "normal bent arm" pull. When required to swim with a "straight-arm," the values ranged between 122 and 174 degrees, indicating the difficulty in consciously maintaining an extended arm when pulling. This condition is most likely due to the additional loads imposed on the shoulders when pulling with a "straight arm." There were no statistical differences in LHV seen between the two arm positions.

The second area of interest that emerged from the data was that no matter whether the subjects were swimming with "bent" arms or "straight" arms, the peak LHV for all swimmers, occurred approximately midway through the stroke, i.e. when the hands were passing underneath the vertical line of the shoulder. Figure 1 is a single frame extract of a Motus report highlighting frontal and lateral views of a "straight-arm" pull, with the accompanying graph plotting LHV as a function of time. As indicated by the vertical line on the graph, peak hip velocity occurs during approximately the middle-third of the underwater pull.

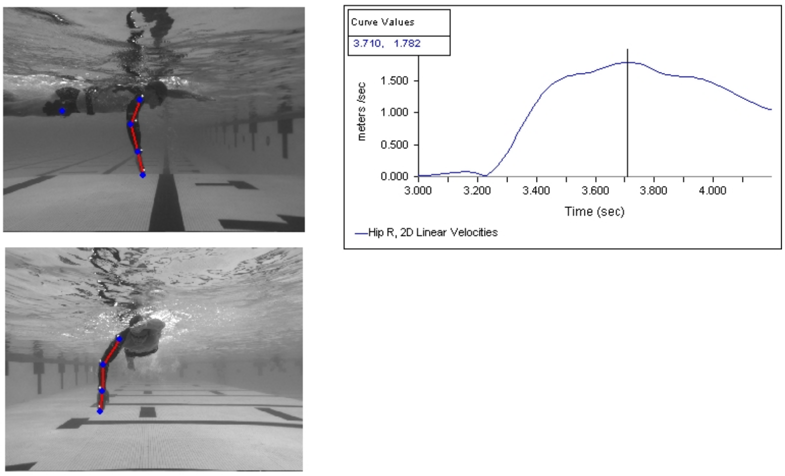

Figure 1: Lateral and frontal views of the mid-stroke Freestyle pull, with synchronized graph plotting linear hip velocity.

Bent arm vs. "Dropped-elbow": Efficient Freestyle swimming requires minimal elbow-flexion during the mid-third of the underwater pull. Therefore, it is not surprising that observed values in the study of 139 to 80.3 degrees of elbow, flexion when viewed laterally, significantly affected LHV. This data provides evidence that we can expect reductions in propulsive force when swimming with a dropped elbow.

Bent arm vs. "S pull": Although statistical analysis of the current data did not conclusively show a significant influence of lateral hand excursions on LHV, the Motus reports confirm the inherent inefficiency of the so-called "S Pull." In Figure 2, the synchronized video frame accompanying the graph shows the hand approaching the widest lateral point of the pull. The top graph shows the LHV starting to decrease as the hand moves out sideways, indicating that lateral excursions of the hand do not provide for optimum applications of propulsive drag forces, resulting in a predictable drop in LHV. The bottom graph is included to indicate how lateral hand motion was calculated; the horizontal line marks the center of the chest on the X-axis and the curved line shows the location of the fingertip to that center line.

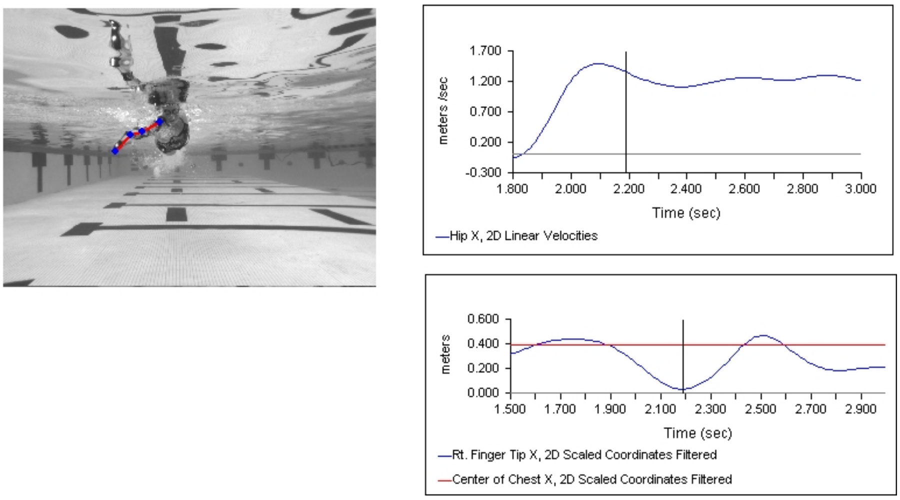

Figure 2: Frontal view of lateral hand excursion in Freestyle with synchronized graphs of linear hip velocity and lateral hand displacement.

CONCLUSION: The study demonstrates the advantages of combining multiple, synchronized cameras and motion analysis software, for investigating swimming stroke technique. Although detailed discussion of the implications of these findings, as they apply to coaching, is beyond the scope of this paper, it underscores the need for ongoing evaluation of swimming stroke mechanics, particularly as observed in elite competitive swimmers.

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