A PRELIMINARY INVESTIGATION OF THE SUPPORT SCULL IN SYNCHRONIZED SWIMMING USING A VIDEO MOTION ANALYSIS SYSTEM

Peter R. Francis
Kim Welshons Smith
Department of Physical Education
San Diego State University
San Diego, CA 92182

Support sculling is currently regarded as one of the most important skills in the repertoire of the successful synchronized swimmer. Indeed, a recent survey of National Coaching Staff members conducted by Dr. Betty J. Wenz, Chair of the Sports Medicine Committee of United States Synchronized Swimming, Inc. revealed that an increased understanding of the mechanics of support sculling was regarded as being the most crucial factor in the improvement of the coaching of the sport. In view of the fact that synchronized swimming will be included in the 1984 Summer Olympic Games the Sports Medicine Committee requested a research program dealing with selected synchronized swimming skills, with particular emphasis upon the biomechanics of support sculling. Subsequently, a joint research program involving the Biomechanics Laboratories of the University of Arizona and San Diego State University was sponsored by the United States Olympic Committee.

Synchronized swimming involves the simultaneous motions of body segments both above and below water, and since the relatively complex problems of dual media cinematography have been documented (McIntyre and Hay 1975) it was recognized that careful pilot studies would be prerequisites to a major investigation. One such preliminary study was undertaken using a high speed video motion analysis system. The aims of the study were to gather pilot data for an in-depth study of synchronized swimming, and, to evaluate the effectiveness of the video system for projects of this nature.

PROCEDURE

A single subject who was a former world champion was videotaped through an underwater window using a Spin Physics 2000 Motion Analysis System.* The subject repeatedly performed a single leg support scull, and separate front and profile views of the subject were obtained using rates of 500 and 200 pictures per second. The camera was positioned so that its optical axis was horizontal and intersected the subject's body approximately halfway between the water surface and the lowest point of the body. Following repeated trials the tape was rewound to ascertain that acceptable, typical performances had been recorded and that image quality was suitable for analysis.

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Subsequently, the coordinates of the tip of the index finger were obtained for selected frames of typical, stable sculling cycles. Every tenth frame of the 500 pictures per second recordings and every fourth frame of the 200 pictures per second recordings were digitized. The digitization process was carried out with the key board-controlled reticle, and image coordinates were recorded on the peripheral area of each picture.

Two dimensional plots of the locus of the tip of the index finger were constructed, and the videotape was again viewed in order to estimate the relative angle of attack of the hand with respect to its instantaneous velocity vector.

DISCUSSION OF FINDINGS

The built-in time base of the video system was used during an examination of numerous trials and it was determined that the performer was able to maintain a very consistent temporal pattern. Each complete arm cycle was completed in approximately 0.8 seconds.

Elevation of the vertical leg above the surface of the water is produced by hydrodynamic forces acting on the hands and arms of a synchronized swimmer. The video record indicated that the highly skilled subject was able to initiate these hydrodynamic forces by internal and external rotation of the shoulders while the elbows were maintained in relatively constant partial flexion. The posterior surfaces of the hands were inevitably uppermost, but changing angles of attack of the hands with respect to their respective instantaneous velocity vectors appeared to be accomplished through partial pronation and re-supination of the radioulnar joints.

Two-dimensional loci of the index fingers are shown in Figures 1 and 2. An instantaneous body position is superimposed in order to provide a frame of reference for each locus.

The locus of the right index finger was consistently different from the locus of the left index finger. This may be attributed either to idiosyncrasies of the individual performer or to the fact that the performer must initiate an eccentric force in order to maintain a vertical alignment of the bilaterally asymmetrical body shape.

Although Figure 1 and Figure 2 do not represent simultaneous views of the same motion, the two performances are typical examples of the relatively consistent pattern employed by the highly skilled subject. The examples reveal that the hands move in paths which ensure that there are no sudden reversals of direction which produce temporary stationary positions. This characteristic ensures that the net hydrodynamic force on each upper extremity is always non-zero.

The precise orientation of the plane of the hand at any time could not be determined from the separate two dimensional images. However, the orientation of a cross section of the hand on each two dimensional plane was estimated for arbitrarily selected points on the loci. The relative orientation of the hand and the tangent to the locus at that point were then used to approximate

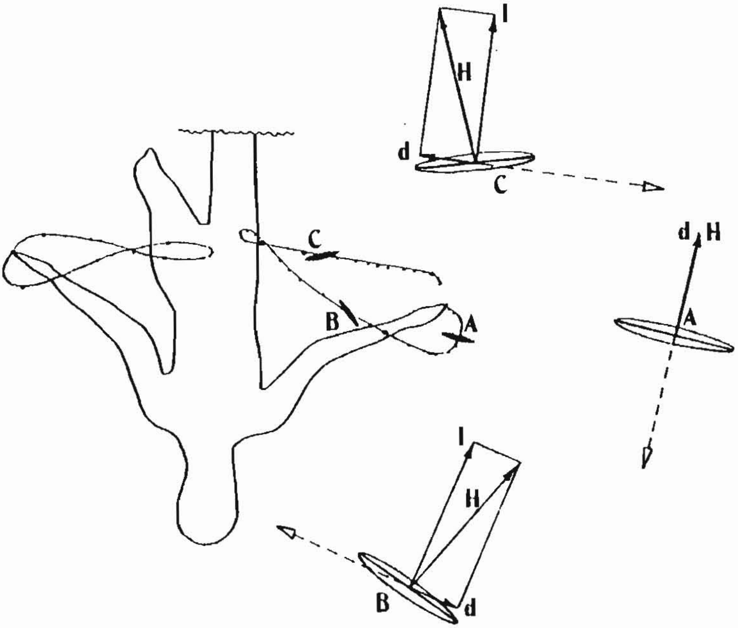

Figure 1. Frontal view of the loci of the index fingers and vector diagrams of hydrodynamic force at selected positions.

the angles of attack of the hydrofoil formed by the hand at each point under scrutiny. This subjective procedure lacks precision but does allow an insight into the nature of hydrodynamic forces involved in the skill. Similar procedures have been discussed for other aquatic activities by Barthels (1979), Schleihauf (1979), Ungerechts (1979), and Wood (1979).

Lift and drag coefficients for different angles of attack of the hand have been estimated by Schleihauf (1979). These values for the hand position adopted by the swimmer used in the present investigation are shown in Figure 3. This information was used in a qualitative sense for subsequent analysis.

In the frontal plane (Figure 1) the hand appears to be moving in a downward direction at point A. Since the plane of the hand is nearly perpendicular to the velocity vector at this point it may be inferred that the major force acting on the hand is the drag component of the hydrodynamic force and that lift is probably insignificant. However, as the hand moves medially to point B the angle of attack becomes positive. As can be seen from the parallelogram of vectors corresponding to point B the instantaneous velocity has a positive vertical component but the hand is probably experiencing a significant positive lift component and a drag component which is appreciably

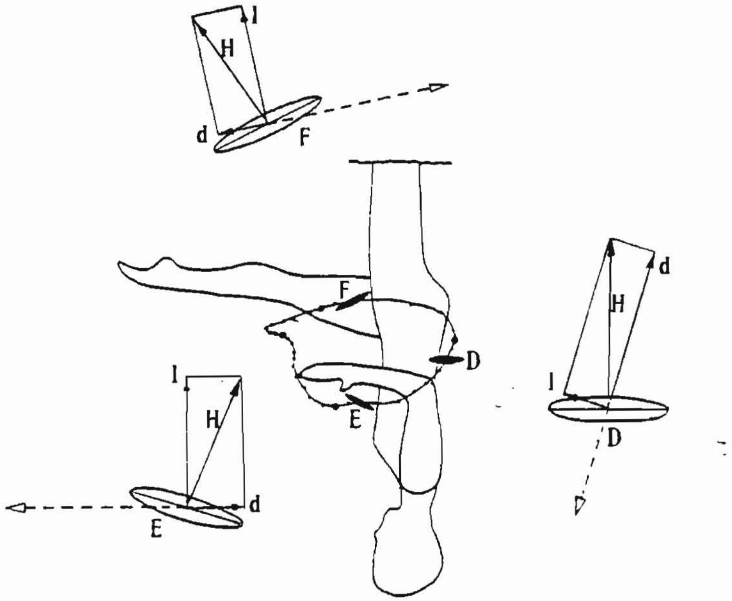

Figure 2. Profile view of the locus of the right index finger and vector diagrams of hydrodynamic force at selected positions.

less than was experienced at point A. The resultant hydrodynamic force will predictably have a significant positive vertical component. Similarly at point C as the hand moves laterally it will probably experience significant lift as indicated by the corresponding vector diagram.

Point D on the locus of the index finger in the sagital plane (Figure 2) approximates the furthermost lateral excursion of the hand represented by point A in the frontal plane. The relative orientations of the velocity vector and the angle of attack at point D indicate that the near vertical hydrodynamic force is predominated by drag. Points E and F are analogous to points B and C, in that significant lift and relatively small magnitudes of drag will produce resultant hydrodynamic forces which can effectively elevate the body in the water.

In summary it would appear that the skilled performer elevates the body using lift for much of the support scull cycle. However, when the hand moves to its most lateral position the restrictive geometry of the shoulder joint necessitates that humeral adduction should occur. During this phase the performer must resort to utilizing drag to maintain elevation of the body. This is followed by a smooth transition as the performer is able to initiate

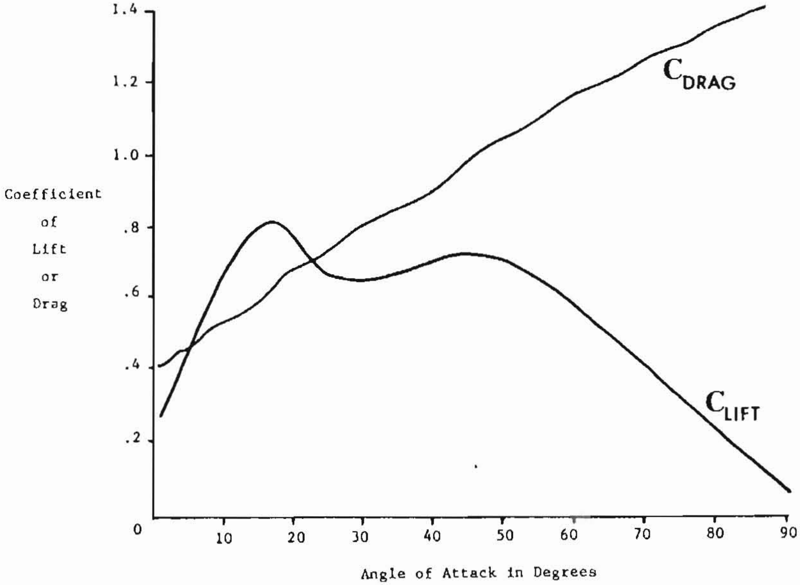

Figure 3. Coefficients of lift and drag for angles of attack of the hand between 0° and 90°, thumb abducted at the leading edge (after Schleihauf, 1979).

significant lift when the shoulder joint permits unimpeded inward rotation.

Throughout the cycle the performer was able to maintain a remarkably constant stationary elevation of the leg above the surface of the water. Thus it must be concluded that the vertical component of the net hydrodynamic force must have remained relatively constant throughout the thirty seconds during which time the performer maintained the single leg support scull position of each performance. Similarly the horizontal component of the net hydrodynamic force must have remained close to zero throughout the performance. It would appear that this is accomplished by having the hands move in opposite directions whenever possible.

The ability of skilled performers to maintain a stationary position of the leg which is elevated above the water surface provides a useful kinetic tool. Figure 4a shows the hypothetical body position when the hands and arms are stationary and Figure 4b shows the elevation of the body during sculling as shown in Figure 2.

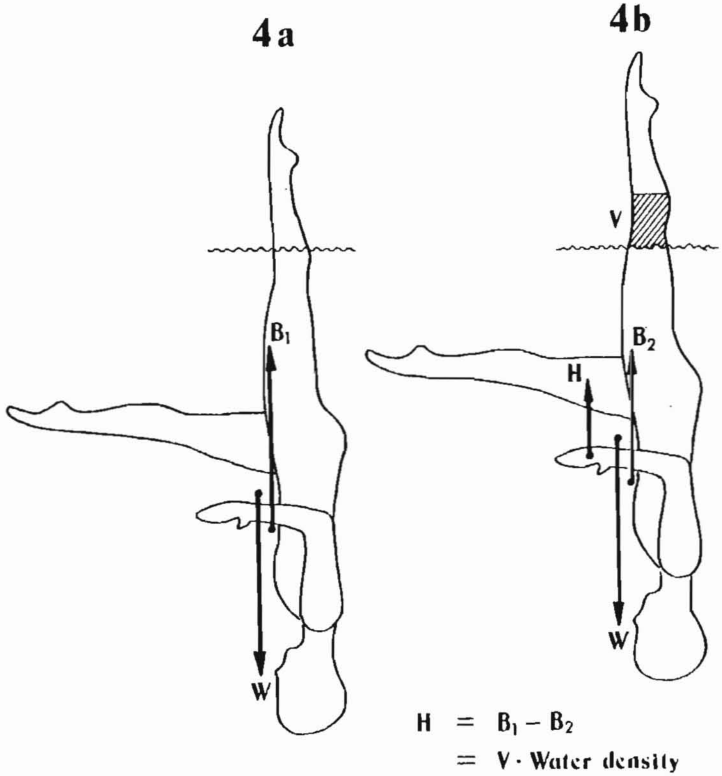

Figure 4a. Free body diagram of the swimmer in static position.
Figure 4b. Free body diagram of the swimmer during sculling.

In the first instance only two equal and opposite forces act on the body. These are W, the weight of the performer acting vertically downwards through the center of gravity, and B1, the buoyance force acting vertically upwards through the center of volume. It is assumed the couple created by the forces would tend to rotate the body unless an eccentric stabilizing horizontal force was applied.

When the athlete creates a net hydrodynamic force, H, on the hands and arms as shown in Figure 4b the body rises and in doing so displaces less water. Thus, according to Archimedes Principle, the buoyancy force drops to some new value B2. At this time the body will assume a new position of static equilibrium in which the sum of the hydrodynamic force and the buoyancy force is precisely equal to the weight of the swimmer. Solution of the two equations reveals that the hydrodynamic force is equal in magnitude to the difference between the initial and final buoyancy forces. The latter quantity is equivalent to the weight of additional water displaced in changing from the latter position to the former. The weight of the additional volume, V, is equal to the product of the volume, V, and density of the water surrounding the swimmer.

Thus in future investigations the water level on the athlete's leg can be marked both while sculling and while resting at the same level of inhalation. Using an appropriate graduated cylinder, the volume, V, can be obtained by submerging the leg from one level to the next. Alternatively the volume of water displaced could be collected and weighed directly. Direct observations of the effects on the hydrodynamic force of such factors as fatigue, training and changes in mechanics can be assessed by observing the water level with respect to fixed markings on the leg during sculling. Objective estimates of the magnitude of the hydrodynamic force can be obtained from water weights.

EVALUATION OF THE VIDEO MOTION ANALYSIS SYSTEM

The video motion analysis system had numerous appealing feature which facilitated data collection. Repeated trials were recorded and viewed until it was determined that acceptable performances and high image quality were included in the record. The system provided the opportunity for synchronous records of the same performance from different views, but due to the limited workspace at the underwater window only a single camera was employed. However, the single camera provided an image which covered all of the available video display. Multiple images necessitate a corresponding reduction in area of the display for each of the images.

The digitization process employs a reticle which is movable in response to keypad controls. The process is initially time consuming, but tends to become more efficient with user-practice. A proposed added feature will automatically move the reticle under softward control to the approximate location of selected points in subsequent frames as described by Francis and Boysen (1978). On-line data storage and analysis were not available at the time of the present investigation. These additional capabilities would greatly enhance the system.

Finally it was apparent that the gap between the quality of video and film images has been reduced dramatically, so that for numerous applications the state of-the-art video system is now preferable to conventional cinematography. If the video system is to be employed as a collection, analysis and teaching tool, the savings in operating costs and rapid availability of information are primary concerns. However, if large and precise images are essential for detailed investigation of a problem, then conventional cinematography may be the researcher's logical choice.