Quantitative Data Supplements Qualitative Evaluations of Butterfly Swimming

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As mechanical advantage increases with both shoulder extension and elbow flexion during the beginning of the butterfly pull, it was hypothesized that hand force would significantly increase with two events: 1) when the hands first submerge below the level of the shoulders and 2) when elbow flexion begins. Female swimmers (n = 23) from three university teams were tested with Aquanex+Video, swimming butterfly over a 20 m course. As hypothesized, there was a significant ($p<.01$) increase in force for both events, emphasizing the importance of a mechanically advantageous angle at both the shoulder and elbow. Based on the quantitative results, coaches can qualitatively evaluate swimmers to ensure they eliminate the wasted time that their hands are above the shoulders and begin elbow flexion as soon as the arm entry is complete.

Key Words: technique, biomechanics, hand force, quantitative, qualitative, analysis

INTRODUCTION

Previous analyses of thousands of trials of synchronized underwater video and hand force data (e.g. Havriluk, 2006a, 2010) show a dramatic increase in force at the beginning of the butterfly pull immediately following two events: 1) when the hands first submerge below the level of the shoulders and 2) when elbow flexion begins. As both of these events are usually observable by a coach on the pool deck, quantitative data about these events may help coaches to better qualitatively assess technique.

As the mechanical advantage increases with both shoulder extension and elbow flexion at the beginning of the pull, it is hypothesized that hand force will significantly increase with these events. Since hand force is directly related to swimming velocity, it is vital that swimmers capitalize on events that increase hand force. In addition to the potential performance benefits from technique adjustments designed to improve mechanical advantage, it is even more important to avoid mechanically disadvantageous positions that often stress the shoulder. The purpose of this study was to quantitatively determine key events in the initial phase of the butterfly pull that a coach can qualitatively evaluate and modify to improve performance and reduce the onset of injury.

METHOD

Female swimmers (n = 23) from three university teams were tested with Aquanex+Video swimming butterfly (Figure 1). The standard Aquanex testing protocol as described in previous research (e.g. Becker & Havriluk, 2006; Havriluk, 2003, 2004, 2006b) was used. Sensors were positioned at the center of the swimmer's hand between the third and fourth metacarpals to measure the pressure differential between the palmar and dorsal surfaces. The sensor and video output were connected to a computer via an interface on the pool deck. Underwater video and force data were collected over the last 10 m of each trial. Informed consent was obtained. The descriptive statistics were: height in cm (M = 165, SD = 6.7) and mass in kg (M = 62.7, SD = 7.6).

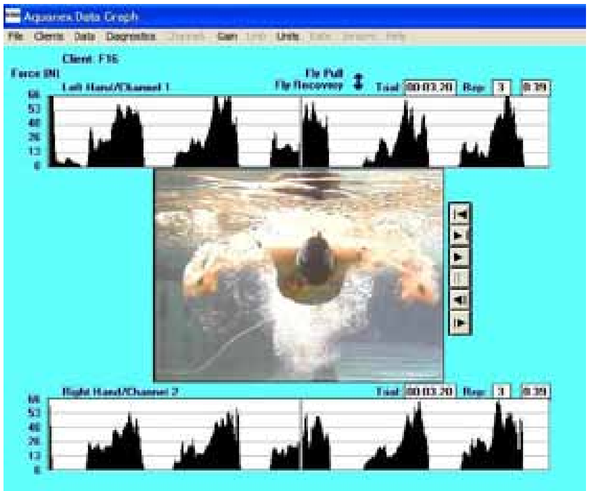

Figure 1. A captured screen from playback of the Aquanex+Video data. The vertical lines on the force graphs are synchronized with the video image and show the rapid increase in force with two simultaneous events - when the hands submerge below shoulder level and when elbow flexion begins.

In addition to the two events specified above, two other events that can also be evaluated by a coach from the pool deck were selected for analysis. The four events selected were (as shown in Figure 2): 1) when the hands first submerge below the level of the shoulders, 2) when elbow flexion begins, 3) when the hands first become medial to the elbows (as determined by when the hands scull inward from a position lateral to the elbows), and 4) when the hands pass perpendicularly below the shoulders (as determined by the video frame with the longest measurement of the upper arm segment). (These events were not selected because they are all recommended technique elements, but because they are typically seen in swimmers of all ability levels.) The average hand force over a .1 sec interval before and after each event was calculated.

RESULTS

There was a significant ($p<.01$) increase in force for two events: when the hands first submerged below the level of the shoulders and when elbow flexion began (Table 1 and Figure 3). There was no significant change in force when the hands first became medial to the elbows or when the hands passed perpendicularly below the shoulders. The swimmers required .35 sec (SD = .11) to submerge the hands below shoulder level out of the .82 sec (SD = .12) of the total time that the hands were underwater generating force.

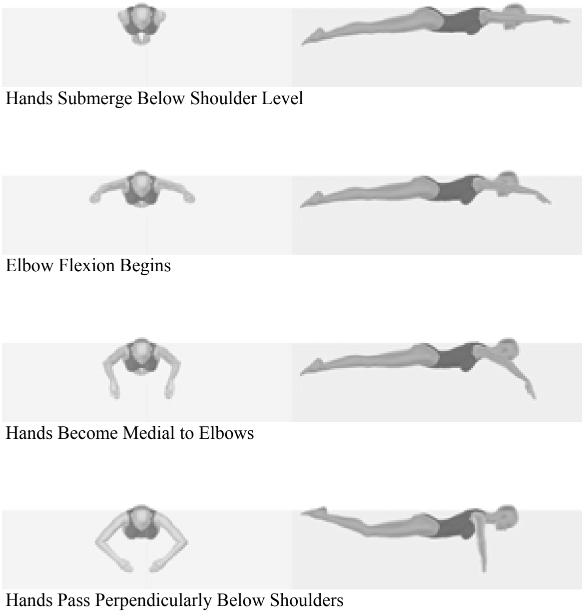

Figure 2. The position of the arms at four key events in the butterfly stroke.

Table 1. Average hand force (N) for .1 sec intervals before and after four key events in the butterfly pull.

Event During Butterfly Pull	Before M±SD	After M±SD	Difference ES	p
Hands Submerge Below Shoulder Level	35.3±13.0	53.3±12.9	1.38	<.01
Elbow Flexion Begins	36.4±15.6	51.0±13.5	1.00	<.01
Hands Become Medial to Elbows	57.1±13.6	57.5±10.3	.03	ns
Hands Pass Perpendicularly Below Shoulders	60.0±13.7	59.8±13.4	-.02	ns

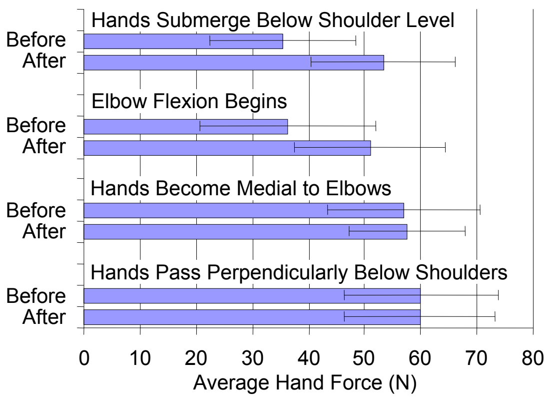

Figure 3. Average hand force (N) for .1 sec intervals before and after four key events in the butterfly pull. The before and after difference was significant (p<.01) for "Hands Submerge Below Shoulder Level" and "Elbow Flexion Begins."

A review of the temporal sequence of two key events prompted a post hoc analysis. About half of the swimmers initiated elbow flexion as the hands submerged below shoulder level and about half after. The swimmers were stratified according to the temporal order of these two events and the average hand force before and after the hands submerged below shoulder level was calculated. The swimmers who initiated elbow flexion after the hands submerged below shoulder level (n = 11) increased force by 12.9 N (.9σ). Swimmers who initiated elbow flexion as the hands submerged below shoulder level (n = 12) increased force by 22.5 N (2.0σ).

DISCUSSION

The analysis has kinetic, kinematic, and anatomical components. The data for all three components support the value of similar technique elements that can be qualitatively evaluated.

As far as kinetics, the large increases in force when the hands first submerged below the level of the shoulders and when elbow flexion began emphasize the importance of a mechanically advantageous angle at both the shoulder and elbow. The importance of mechanical advantage is further supported by the fact that the subgroup of swimmers who initiated elbow flexion before the hands submerged below shoulder level increased force by twice as much as the swimmers who initiated elbow flexion after that event.

The kinematics also provide data for technique evaluation. Over 40% of the time that the swimmers' hands were generating force, the hands were above the level of the shoulders (i.e. posterior to the frontal plane). This is an extremely large proportion of the stroke cycle for the arms to remain in a mechanically disadvantageous position. For example, the swimmer in Figure 4 wasted almost .4 sec before the hands submerged below shoulder level.

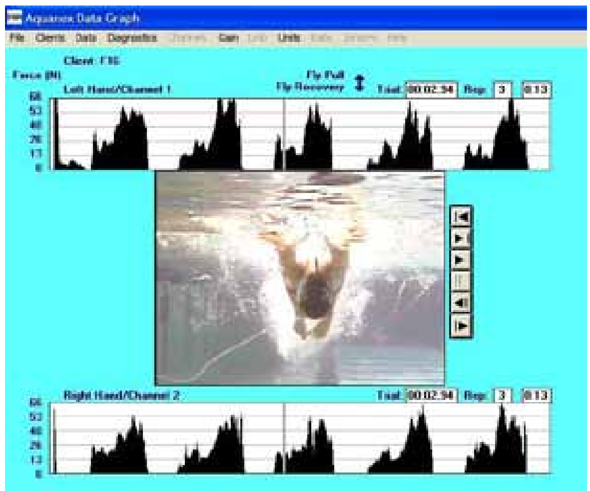

Figure 4. Aquanex+Video example of wasted motion with the arms and head in a mechanically disadvantageous position.

Anatomically, the disadvantageous position of the shoulders in the initial phase of the butterfly (Figure 4) is due to internal rotation of the humeral head, placing the greater tuberosity in close contact with the undersurface of the acromion. The resulting position is classically related to joint surface aggravation or "impingement syndrome" (Becker, 1986). Any increased time of compressive joint loading between the humerus and acromion (such as the .35 sec found in the study) presents potentially injurious joint surface irritation. Thus, with ideal stroke mechanics in the butterfly not only does the efficiency of the stroke improve, but there is also a reduction in joint surface compression exposure.

The kinetic, kinematic, and anatomical findings all support an arm entry that positions the arm in a mechanically advantageous position. A downward entry angle will result in a relatively strong arm position at the completion of the entry phase (Figure 5). While these adjustments are primarily designed to avoid shoulder injury and increase average hand force, stroke rate will also increase. Once the entry is complete, elbow flexion can immediately begin.

The lack of significant increase in force for two of the key events can be explained. The angle at the elbow was already 90° when the hands became medial to the elbows, so no force increase due to mechanical advantage could be expected. When the hands passed perpendicularly below the shoulders, any potential increase in mechanical advantage is tempered by a slowdown in hand speed due to the change in musculature from pulling to pushing (Richardson, 1986).

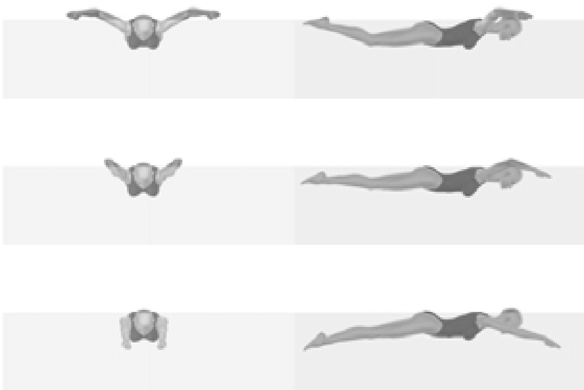

Figure 5. Butterfly arm entry that minimizes shoulder stress and maximizes mechanical advantage.

Logistics often make it difficult for a coach to collect quantitative data on technique during a training session. Qualitative observations to determine when the hands submerge below the level of the shoulders and when elbow flexion begins, however, are entirely possible. Tracking these two events is critical to minimize the time that the arms are in a position likely to stress the shoulders and maximize the time that the arms are in a mechanically advantageous position for force generation.

CONCLUSION

Based on the quantitative results, coaches can qualitatively evaluate swimmers to ensure they eliminate the wasted time that their hands are above the shoulders at the beginning of the butterfly pull by adjusting the entry angle. A downward entry angle will result in a stronger arm position, a faster stroke rate, and less shoulder stress. Coaches can also encourage swimmers to begin elbow flexion as soon as the entry is complete. In addition to improving performance, these technique adjustments will be helpful in reducing the onset of shoulder injury.

REFERENCES

Becker, T.J. (1986). The athletic trainer in swimming. *Clinics in Sports Medicine*. *5*(1), 10.

Becker, T. & Havriluk, R. (2006). Bilateral and anterior-posterior muscular imbalances in swimmers. In J. P. Vilas-Boas, F. Alves, A. Marques (Eds.), Biomechanics and Medicine in Swimming X. *Portuguese Journal of Sport Sciences*, *6*(Suppl. 2), 327-328.

Havriluk, R. (2003). *Performance level differences in swimming drag coefficient*. Paper presented at the VIIth IOC Olympic World Congress on Sport Sciences, Athens.

Havriluk, R. (2004). *Hand force and swimming velocity*. Paper presented at the XVth FINA World Sports Medicine Congress, Indianapolis, IN.

Havriluk, R. (2006a). Analyzing hand force in swimming: Three typical limiting factors. *American Swimming Magazine*, *2006*(3), 14-18.

Havriluk, R. (2006b). Magnitude of the effect of an instructional intervention on swimming technique and performance. In J. P. Vilas-Boas, F. Alves, A. Marques (Eds.), Biomechanics and Medicine in Swimming X. *Portuguese Journal of Sport Sciences*, *6*(Suppl. 2), 218-220.

Havriluk, R. (2010). Performance level differences in swimming: Relative contributions of strength and technique. In Kjendlie, Stallman & Cabri. *Biomechanics and Medicine in Swimming XI*, in press.

Richardson, A.B. (1986). The biomechanics of swimming: The shoulder and knee. In J.V. Ciullo (Ed.), *Clinics in Sports Medicine* (pp. 103-114). Philadelphia: W.B. Saunders.