ARM STROKE EMG AND KINEMATICS OF SWIMMERS

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The purpose of the study was to investigate the EMG and kinematics of the front crawl stroke of previously injured and non-injured swimmers during swimming and stroke work on the Biokinetic Swim Bench.

Researchers state that dryland exercises used through swimming conditioning programs must have movement patterns identical to those in water with respect to: the overall coordination; and the assumed muscle contraction (Costill and Sharp, 1980; Counsilman, 1969, 1971; Hessburg, 1972, 1973; and Hopper, 1980).

Since many coaches stress the advantage of specific dryland training, Olbrecht and Clarys (1983) performed an EMG analysis on the simulation of the crawl movement with an isokinetic swim bench. Lower EMG activity of the deltoid muscles was recorded on land than in water, despite the greater effort on land. It was noted that an important pattern deviation existed whenever the swimmer acted against a mechanical resistance. Olbrecht and Clarys concluded that specific training cannot be accomplished with dryland devices because of mechanical and environmental differences.

Schleihauf (1983) evaluated specificity of strength from a biomechanical viewpoint. Schleihauf stated that the isokinetic bench exercisers provide the best type of strength training currently available to swimmers. He presented reasons for the "nonspecific" EMG records observed in strength training and the findings of Olbrecht and Clarys. Schleihauf mentions that, in particular, it must be recognized that the basic design of bench exercisers was derived before sculling motions were recognized to be important in the arm stroke. Since single-dimensional training techniques fall far short of simulating the three-dimensional resistance encountered in water, the fundamental differences between straight-back exercise motions and diagonal swimming motions may explain the findings of Olbrecht and Clarys.

Chances of injuries to the shoulders in swimmers may be explained by noticeable changes in the EMG and kinematics of the front crawl stroke pattern during swimming and stroke work on the Swim Bench. Overuse syndromes are more likely to develop through ineffective stroke mechanics. The estimated number of revolutions per week that an average competitive swimmer subjects each of his/her shoulders to is approximately 16,000 and the estimated number of strokes per season is up to 660,000 (Richardson, _et al._, 1981). Because such repetitions occur during many years of swimming, Johnson (1986) stated that overuse injuries to the shoulders seem to be age-related. In other words, those who have been swimming the longest seem to have the longest incidence of injuries, especially to the shoulders.

One of the overuse syndromes of the shoulder joint involves the impingement of the coracoacromial arch (Johnson, 1986; Penny and Welsh, 1981; Hawkins and Kennedy, 1980; Kennedy, Hawkins, and Krissoff, 1978; and Dominguez, 1978). This impingement is related to excessive internal rotation of the humerus and the fingertips crossing the midline of the body during the pull phase. Such an impingement involves the rotator cuff and biceps tendons being brought beneath the coracoacromial ligament. Hawkins and Kennedy describe another impingement sign which involves the internal rotation of the forward flexed shoulder, again with the rotator cuff and biceps tendons being brought beneath the coracoacromial ligament. The reproduction of this "impingement sign" occurs in the "catch position" of the beginning of the pull-through in freestyle.

Johnson mentions that clinically the pain may be very ill-defined, but on examination there may be point tenderness anterolaterally over the rotator cuff and over the biceps tendon anteriorly just below the coracoacromial ligament.

Hypothetically, differences would occur between injured and non-injured swimmers in terms of EMG and kinematics of the front crawl stroke during swimming and stroke work on the Swim Bench. Injured swimmers would execute ineffective front crawl stroke mechanics, generate low power output on the Swim Bench, and produce low electrical activity of the shoulder muscles as compared to the non-injured swimmers. As a result of ineffective front crawl stroke in the injured, injuries to the shoulders might be "brought on" by such movement pattern deviation in the front crawl stroke.

Another hypothesis involved the differences between swimming and stroke work on the Swim Bench in terms of EMG and kinematics for all swimmers. Differences would occur in the electrical activity of the shoulder muscles since straight-back exercise motions would be performed on the Swim Bench and diagonal swimming motions would be performed in the water. Different movement patterns of the upper extremity in both situations would indicate differences in kinematics.

To examine the two hypotheses, EMG and kinematic information were gathered during swimming and stroke work on the Swim Bench.

METHOD

Subjects

Four competitive swimmers from the University of Illinois women's swim team (two non-injured and two previously injured) served as volunteer subjects for the study. Table 1 depicts the demographic data of the swimmers.

Apparatus

The swimming pool facility at the Intramural-Physical Education building (on the University of Illinois campus) was the site of the experiment, and the Biokinetic Swim Bench was used to perform some dryland exercises during the test.

Silver mercury surface electrodes were used to transmit the electrical activity from the muscles to the recorder. Wires from the electrodes were connected to Transkinetics transmitters. The signals from the two transmitters were received by a 2-FM receivers (frequencies of 103 hz and 95 hz, respectively). To display the contractile activity of a muscle as an output, a 2-channel Textronix storage oscilloscope was used. The amplitude was depicted on the screen as volts per division. The sensitivity control on the oscilloscope was used to select certain volts per division for recording, and time rate control was used to select the speed of the signal's appearance on the screen. The signal output from the oscilloscope was videotaped by the VHS video camera.

Procedures

Electrode preparation involved the abrading of the skin, cleaning it with rubbing alcohol, and application of electrolyte gel to the marked sites alongside the belly of anterior and posterior deltoid muscles. A pair of mercury silver electrodes were placed on the marked sites, no more than 2 cm apart.

Maximal isometric contraction tests were administered in order to use the obtained electromyograms as a standard against which subsequent muscle activity levels during swimming and stroke work on the Swim Bench were compared with respect to percent-of-maximum basis. Such tests involved the subject's ability to overcome resistance by flexing (anterior deltoid) or extending (posterior deltoid) the upper extremity at the shoulder against the opposite force that was applied to the upper extremity by an assistant's arms and hands. Each subject had to put an all-out effort into overcoming resistance while lying prone on the Swim Bench with the upper extremity in a plane perpendicular to the seat of the Swim Bench. Flexion or extension of the upper extremity was performed in the sagittal plane with the elbow flexed about 90 degrees to imitate the position of the upper extremity during the midportion of the pull in swimming.

The amplitudes of the electromyograms obtained during maximal isometric contraction were measured by using the setting, volts/division, as a guide from the oscilloscope, and each was set equal to one hundred percent. The amplitudes for two trials (warm up and sprint) of swimming and stroke work on the Swim Bench were measured in a similar fashion, and the resultant total activity level of the muscle during each trial was expressed as a percent of maximum amplitude (Barthels and Adrain, 1970).

The subjects then performed two trials of stroke work on the Swim Bench. During the performance, as well as the maximal contraction tests, EMG was displayed on the oscilloscope. The EMG displayed on the oscilloscope was then videotaped simultaneously with the performance of the Swim Bench in order to identify magnitude and sequencing of EMG with the mechanics of the stroke. The power output on the Swim Bench for 30 seconds was recorded simultaneously.

TABLE 1

DEMOGRAPHIC DATA OF SWIMMERS

Subject 1 (injured swimmer)

Age: 19 yrs.
Height: 5'6"
Weight: 125 lbs.
Yrs. of swimming experience: 11 yrs.
Duration of shoulder injury: 4 yrs.
Location of pain: anterior shoulders
Hurts at which stroke phase: midpull
Arm length: 29.5"
Stroke speciality: freestyle
Events swum: 200- and 500-yd free

Subject 2 (injured swimmer)

Age: 20 yrs.
Height: 5'8"
Weight: 130 lbs.
Yrs. of swimming experience: 13 yrs.
Duration of shoulder injury: 5 yrs.
Location of pain: anterolateral part of both shoulders
Hurts at which stroke phase: catch
Arm length: 28.75"
Stroke specialities: free and fly
Events swum: 50- and 100-yd. fly
50- and 100-yd. free

Subject 3 (non-injured swimmer)

Age: 20 yrs.
Height: 5'8"
Weight: 132 lbs.
Yrs. of swimming experience: 13 yrs.
Arm length: 30.0"
Stroke speciality: free and back
Events swum: 1650-yd. free
200-yd. back

Subject 4 (non-injured swimmer)

Age: 20 yrs.
Height: 5'11"
Weight: 150 lbs.
Yrs. of swimming experience: 11 yrs.
Arm length: 31.25"
Stroke speciality: free
Events swum: 100- and 200-yd. free

TABLE 2

QUANTITATIVE DATA: STROKE WORK ON THE SWIM BENCH

(in volts)

Anterior deltoid muscle:

Subject	Maximum	Trial 1	Trial 2
1	10.0	5.0 (50%)	5.0 (50%)
2	5.0	5.0 (100%)	4.5 (90%)
3	7.5	4.0 (53%)	4.5 (60%)
4	7.0	4.5 (64%)	5.0 (71%)

Averages

Trial 1: 66.75%   Trial 2: 67.75%   Overall: 67.25%

Posterior deltoid muscle:

Subject	Maximum	Trial 1	Trial 2
1	9.5	10.0 (105%)	10.0 (105%)
2	10.0	9.5 (95%)	9.75 (98%)
3	11.0	11.0 (100%)	10.0 (91%)
4	9.75	10.0 (103%)	10.0 (103%)

Averages

Trial 1: 100.75%   Trial 2: 99.25%   Overall: 100%

After the completion of stroke work on the Swim Bench, the electrodes were covered with pieces of moleskin. Since subjects performed the same two trials in the water, the covering of the moleskin sheets was to keep water out of the electrodes as much as possible. The wires that connected the electrodes to the transmitters were hooked to the lifeguard pole. The transmitters were covered with plastic bag, and an assistant who stood next to the pool held the pole while following each swimmer as she swam the length (25 yards) four times with stops at each side of the pool for each trial. The recording of the EMG signals during swimming was similar to that for stroke work on the Swim Bench.

Since the two windows for underwater viewing face the center of the pool, each swimmer's stroke pattern was videotaped from one of the windows while she swam across the center of the pool from the opposite side to the side where the windows are located. Front view of the front crawl was obtained from the videotape.

Videotaping of swimming was separate and after EMG testing. Each swimmer performed the same two trials. Hence, the mechanics of the front crawl stroke could be analyzed from the videotape for comparison with the Swim Bench videotape. The analysis was performed qualitatively by describing the following phases of the stroke in anatomical and spatial terms: entry; downsweep; upsweep; insweep; outsweep; and first and second half of recovery.

RESULTS

The results are presented in the following sections: qualitative and quantitative EMG analyses of the front crawl stroke on the Swim Bench; and descriptive analysis of the front crawl stroke pattern in the water and on the Swim Bench.

Due to excessive artifacts in the EMG recording system while each swimmer was in the water, EMG data of swimmers in the water were not considered valid for either quantitative and qualitative analyses.

Qualitative analysis

Figure 1 depicts the EMG pattern of the two injured subjects and two non-injured subjects during stroke work on the Swim Bench. Pattern analysis of raw EMG signals for each swimmer from the videotape was performed for five phases: entry; entire pull phase; initial lift of the arm; high elbow; and reaching prior to entry. Qualitative comparison was made up of the phases during which muscle activity occurred. The EMG activity of the anterior deltoid occurred in all but one phase (entire pull phase) for the injured swimmers and only in the reaching phase for the non-injured swimmers. Conversely, the posterior deltoid was active during all but one phase (reaching) for the non-injured swimmers. In the injured swimmers, the posterior deltoid was active during the three following phases: last half of the pull; initial lift of the arm; and reaching.

The occurrence of muscle activity in all phases were similar for both individuals within their respective groups.

Quantitative analysis

The values for the amplitude of both anterior and posterior deltoids during maximum and submaximal contractions are in Table 2 for stroke work on the Swim Bench.

The greatest EMG amplitude occurred approximately midway through the pull phase, and it was measured in voltages from the videotape. The frame-by-frame control button was used to obtain the frame where the midportion of the pull occurred so that the amplitude could be measured for both muscles during maximum contraction and two trials.

Quantitative analysis of the EMG pattern revealed that the average percentage of maximum contractile activity was similar for trial 1 and trial 2 within each muscle during stroke work on the Swim Bench. However, the overall percentage of maximum contractile activity for the anterior deltoid was lower than that for the posterior deltoid (67.25% and 100%, respectively).

There was no clear distinction between injured and non-injured swimmers with respect to the percentage of maximum contractile activity in each muscle during both trials. For example, the injured swimmers, subjects 1 and 2, had the highest and lowest percentages of maximum contractile activity of the posterior deltoid during the first trial (105% and 95%, respectively).

The power output recorded in kilo-pond-meter per second (kpm/sec) for each swimmer is listed in Table 3. The average power output for the second trial on the Swim Bench was approximately 44% greater than that for the first trial. Since intersubject variability was large in the results for the power output, no significant differences can be noted for the injured and non-injured swimmers. For instance, the highest power output for one of the non-injured swimmers was 5.93 kpm/sec, whereas the lowest power output was 3.5 kpm/sec for the other non-injured swimmer during trial 2.

Analysis of front crawl stroke pattern

Tables 4 and 5 depict the stroke pattern in each phase for each swimmer during swimming and stroke work on the Swim Bench, respectively.

*Occurrence of EMG activity in the deltoids

Anterior deltoid muscle

Subject	1	2a	2b	3	4	5
1	*			*	*	*
2	*			*	*	*
3						*
4						*

Phases

Posterior deltoid muscle

Subject	1	2a	2b	3	4	5
1			*	*		*
2			*	*		*
3	*	*	*	*	*	
4	*	*	*	*	*	

Phases

Injured swimmers
1 & 2

Non-injured swimmers
3 & 4

1 -entry
2a-first half of pull
2b-last half of pull
3 -initial lift
4 -high elbow
5 -reaching

Figure 1. Qualitative analysis: EMG pattern of swimmers on the Swim Bench

TABLE 3

POWER OUTPUT
FROM THE BIOKINETIC SWIM BENCH

(in kpm/sec)

(30-second duration)

Subject	Trial 1	Trial 2
1	.97	4.13
2	1.53	3.97
3	1.53	3.50
4	2.93	5.93

There was a distinction in the stroke pattern among swimmers during swimming. In the upsweep, two non-injured swimmers (subjects 3 and 4) moved their hands inward and upward with the adduction and flexion of their upper extremities at the shoulders and elbows, respectively, while the injured swimmers pulled their hands backward with extension and slight extension of their upper extremities at the shoulders and elbows, respectively.

The stroke pattern was similar among the swimmers during the insweep, except that the non-injured swimmers slightly adducted their upper extremities at the shoulders toward the end of the phase while the injured swimmers did not.

During the outsweep, two injured swimmers (subjects 1 and 2) continued to pull their hands backward with extension and slight abduction of their upper extremities at the shoulders. The non-injured moved their hands backward and outward with the extension of their elbows and shoulders.

All swimmers exhibited similar stroke pattern during the following out-of-water phases: entry; and first and second half of recovery. Since one of the non-injured swimmers (subject 4) has a wide front crawl stroke, flexion of the elbow was slight during the first half of recovery. During entry, she entered her hand much further away from the midline of her body than the other three swimmers. Because she exhibited optimum body roll in the water, she was able to pull from the midline of her body.

There was a similarity in the stroke pattern among swimmers during stroke work on the Swim Bench in all phases. They all showed slight abduction of the shoulders, slight flexion of the elbows, and slight outward movement of the hands during the downsweep.

In the upsweep, all but one extended their shoulders, slightly extended their elbows, and pulled their hands backward. Subject 3, the non-injured swimmer with distinct movement pattern, slightly adducted her shoulder, slightly flexed her elbow, and slightly moved her hand inward during the phase.

All swimmers performed the following movements of their upper extremities during the insweep; shoulder extension; elbow extension; and backward movement of the hands.

During the outsweep, all swimmers extended their shoulders and moved their hands backward with slight abduction of their shoulders toward the end of the phase. One non-injured swimmer (subject 3), however, performed the two following additional movements of her upper extremity: slight extension of the elbow; and slight outward movement of the hand. The same subject showed a lack of shoulder abduction toward the end of the phase.

The stroke pattern was similar among the swimmers during the out-of-water phases. Subject 4 with a wide front crawl stroke performed with slight flexion of the elbow during the first half of recovery and entered her hand much further away from the midline of her body than the other three swimmers during entry.

Comparing the stroke pattern among the swimmers during swimming and stroke work on the Swim Bench, there was a limitation to the sculling movements of the hands in swimmers on the Swim Bench during the entire pull phase. In other words, there was a lack of outward, inward, and upward sweeping movements of the hands during the downsweep and upsweep, respectively. During the insweep, the hand pulled backward from the lateral side of the body. The hand continued to pull backward without any outward sweeping motion toward the end of the outsweep.

There was a distinction between injured and non-injured swimmers in terms of the stroke pattern during the pull phase in the water and on the Swim Bench. Injured

TABLE 4

FRONT CRAWL STROKE ANALYSIS OF SWIMMERS IN THE WATER

Phases	Subjects 1	2	3	4
Entry	SH-E H-1	SH-E H-1	SH-E H-1	SH-E H-1 *H-5
Down-sweep	*SH-AB *EL-F *H-5	*SH-AB *EL-F *H-5	SH-AB EL-F H-5	SH-AB EL-F H-5
Up-sweep	SH-E *EL-E H-4	SH-E *EL-E H-4	SH-AD EL-F H-6,2	SH-AD EL-F H-6,2
In-sweep	SH-E EL-E H-4	SH-E EL-E H-4	SH-E EL-E H-4 SH-AD	SH-E EL-E H-4 SH-AD
Out-sweep	SH-E H-4 *SH-AB	SH-E H-4 *SH-AB	SH-E EL-E H-4,5	SH-E EL-E H-4,5
1st ½ Recovery	SH-AB EL-F H-2,3	SH-AB EL-F H-2,3	SH-AB EL-F H-2,3	SH-AB *EL-F H-2,3
2nd ½ Recovery	EL-E H-3 SH-E	EL-E H-3 SH-E	EL-E H-3 SH-E	EL-E H-3 SH-E

Anatomical Terms:

SH-shoulder E-extension
EL-elbow F-flexion
H-hand AB-abduction
AD-adduction

*-slight +-excessive

Directions of Movement:

1-down
2-up
3-forward
4-backward
5-outward (away from body)
6-inward (toward body)

TABLE 5

FRONT CRAWL STROKE ANALYSIS OF SWIMMERS ON THE SWIM BENCH

Phases	Subjects 1	2	3	4
Entry	SH-E H-1	SH-E H-1	SH-E H-1	SH-E H-1,5
Down-sweep	*SH-AB *EL-F *H-5	*SH-AB *EL-F *H-5	*SH-AB *EL-F *H-5	*SH-AB *EL-F *H-5
Up-sweep	SH-E *EL-E H-4	SH-E *EL-E H-4	*SH-AD *EL-F *H-6	SH-E *EL-E H-4
In-sweep	SH-E EL-E H-4	SH-E EL-E H-4	SH-E EL-E H-4	SH-E EL-E H-4
Out-sweep	SH-E H-4 *SH-AB	SH-E H-4 *SH-AB	SH-E *EL-E H-4 *H-5	SH-E H-4 *SH-AB
1st ½ Recovery	SH-AB EL-F H-2,3	SH-AB EL-F H-2,3	SH-AB EL-F H-2,3	SH-AB *EL-F H-2,3
2nd ½ Recovery	EL-E H-3 SH-E	EL-E H-3 SH-E	EL-E H-3 SH-E	EL-E H-3 SH-E

Anatomical Terms:

SH-shoulder E-extension
EL-elbow F-flexion
H-hand AB-abduction
AD-adduction

*-slight +-excessive

Directions of Movement:

1-down
2-up
3-forward
4-backward
5-outward (away from body)
6-inward (toward body)

swimmers (subjects 1 and 2) had the tendency to pull their hands backward in the sagittal plane without any apparent movements in the frontal plane during swimming and stroke work on the Swim Bench. In contrast, the non-injured swimmers (subjects 3 and 4) performed more outward, inward, upward, backward, and outward sculling movements in the frontal and sagittal planes in the water than on the Swim Bench.

DISCUSSION

From the viewpoint of kinematics, all swimmers' general inability to duplicate the underwater sculling movements of the hands on the Swim Bench seems to agree with Schleihauf (1983) regarding the fundamental differences between straight-back exercise motions on an isokinetic training device and underwater diagonal swimming motions.

The lack of sweeping motion of the front crawl by the injured swimmers in the water and on the Swim Bench may be related to the location of pain being in the anterior or anterolateral portion of the shoulder. In other words, injuries to their shoulders could be brought on by movement deviation in the front crawl stroke which involved constant backward movement of the hands during the pull phase.

Since both injured swimmers have been competitive swimmers for a long period of time and have had shoulder troubles for several years, their status seem to correspond with Johnson's (1986) statement that overuse injuries seem to be age related. One injured swimmer has swum for 11 years and had shoulder troubles for four years, while another has had injuries for five years and swum for 13 years.

One of the injured swimmers mentions that the location of pain occurs in the antero-lateral part of both of her shoulders during the catch, and this seems to match with the description by Hawkins and Kennedy (1980) regarding the internal rotation of the forward flexed shoulder as one of the impingement signs. The location of pain described by the swimmer seems to agree with Johnson's description about the usual location of the pain in the shoulder region (i.e., point tenderness anterolaterally over the rotator cuff and over the biceps tendon anteriorly just below the coracoacromial ligament).

Since there is a diversity in the physical characteristics of the swimmers, injury to the shoulder is not a significant factor to the comparison of all swimmers in terms of power output and electrical activity of the shoulder muscles on the Swim Bench.

In an attempt to duplicate the underwater stroke on an isokinetic training device, one may want to ask the following question: will one be able to duplicate the under-water stroke on an isokinetic training device by conscious effort? In other words, will one be able to try to concentrate on performing the sweeping motions on an isokinetic training device by mental effort? If one is able to train with the pull buoy and hand paddles executing the sculling motions in the water, he/she may try to duplicate the underwater sweeping motions on an isokinetic training device. Most training devices have paddle-like handles for a swimmer to hold onto while performing the stroke exercises. The next question one may want to ask is whether EMG signals would be comparable for the front crawl stroke movement both in the water and on an isokinetic training device. If the EMG signals are comparable and stroke pattern appears similar in both situations, duplication of the underwater stroke on an isokinetic training device becomes evident.

With regard to the design and development of multidimensional exercise resistance, will the quality of the front crawl stroke pattern improve with close duplication of the underwater stroke on an isokinetic training device? Such a question requires the knowledge of engineering, biomechanics, and the anatomy and functioning of shoulder muscles for one to understand the relationship between underwater stroke pattern and movement pattern on a particular isokinetic training device.

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