TEMPORAL ANALYSIS OF COMPETITIVE MALE SWIMMERS

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World records in competitive swimming have been undergoing a trend of improvement that has spanned the last two decades. The growth of age-group swimming programs and the commensurate production of researchers in swimming has helped maintain the improvement since the early 1960's. Biomechanical research in competitive swimming is quite evident in the literature; in fact researchers in this area have been meeting on the international level since the first international symposium in Brussels in 1971.

Biomechanical research on competitive swimming strokes has been conducted under two basic conditions. These conditions involve analysis of the swimmer while he/she is connected to a tethered swimming device or while the swimmer swims freely.

Tethered swimming devices restrict the swimmer to a stationary position in the water. Most of the time these devices involve strapping a belt around the swimmer and attaching a cable to the belt. The swimmer then attempts to swim a competitive swimming stroke using the complete stroke or arms alone or legs alone. Numerous researchers have used tethered swimming devices to determine forces developed during each of the competitive strokes (Alley,L.E.,1952; Clarys & Jiskoot, 1975; Magel, 1970). Investigators have also used this technique to analyze propulsive forces of the arms alone or the legs alone (Holmer, 1975; van Manen & Rijken, 1975).

Analysis of swimmers during free swimming has been conducted in both laboratory settings and during actual competition. Although it is advantageous to collect data during actual competition, often times this is not possible.

Coaches of swimming typically use split times and their trained eyes to analyze a swimmer's performance. From this information the coach and the swimmer attempt to make adjustments to improve performance.

The analysis of stroking patterns during competition such as stroke frequency and stroke length are useful to the coach of swimming and competitive swimmers. East(1970) investigated the relationship among stroke frequency (measured in cycles/s), stroke length (measured in distance per stroke cycle), and time. Subjects consisted of competitors at the 1969 New Zealand National Championships. All subjects were filmed during 110-yard race competition in a 55-yard length pool. After adjustments were made for turning distance and diving distance during the start, East calculated stroke lengths and stroke frequencies. An analysis was performed on differences in stroke frequency(SF) and stroke length(SL) with respect to time among all swimmers.

Results of East's study revealed that in the men's freestyle, the faster competitors used higher SFs and slightly lower SLs. For the backstroke and butterfly, faster competitors demonstrated no differences in SF but had significantly higher SLs. No differences were found in the breaststroke for SF and SL. Additionally, significant negative correlations were reported for: SF and time in the men's freestyle; SL and time in the men's butterfly; and SL and time in the men's backstroke.

Craig and Pendergast(1979) analyzed the relationship among stroke rate(SR), SL, and velocity(V). Sixty-three collegiate competitive swimmers served as subjects while data was collected in the first of two experiments. These subjects were analyzed in a laboratory situation using a modified tethered swimming device. Subjects in the second experiment consisted of 223 competitors who were filmed during competition at the 1976 U.S. Olympic Trials. Each swimmer was analyzed by an observer who recorded the time to complete five strokes during each length of the pool. In both experiments, significant correlations were determined between SF and V for all four competitive strokes.

The literature reveals a lack of studies dealing with stroking patterns of elite competitive swimmers during short-course(25-yard length pool) competition. Additionally, all of the studies that have been reported in this area have always analyzed differences in SL and SF among different competitors over the same distance (Craig & Pendergast, 1979). Thus, there is a lack of data on the changes in SL and SF across split times during this type of competition.

The purposes of the investigation were to analyze the relationship among SF, SL, and split time for elite male collegiate swimmers, and to determine the patterns of SF and SL in various parts of selected competitive swimming races.

Thirty-two male collegiate swimmers were randomly selected for analysis. The subjects were competitive swimmers from Southern Methodist University (SMU), University of Texas at Austin(UT), and Texas A&M University (TAM). All competitors were videotaped while competing at SMU's Perkins Natatorium, Dallas, Texas, during November and December, 1983.

Four different swimmers were selected in each competitive stroke and for each distance (100 yards or 200 yards). A Panasonic Video Cassette Recorder(VCR) was used to record each swimmer's performance. The video recording was time-coded using a Telcom model TCG-550 time code generator and a Telcom model T-6010 time code reader character generator (Telcom, 1980). This process enabled the investigators to perform a temporal analysis of each swimmer for each length of the pool that he completed in the race to the nearest .03 seconds. The video recording was viewed on a TV monitor after the time-coding process. For each swimmer, the time to complete each length was recorded along with the number of stroke recoveries. Figure 1 illustrates a sample frame from the TV monitor.

Time splits were recorded when each swimmer initially contacted the wall with his hand or hands for all strokes except the freestyle. Split time for freestyle swimming was recorded when the swimmer's feet made contact with the wall.

Each swimmer was assigned an ID number. The ID number, distance of the race, stroke type, number of strokes completed in each length, and the time split at the end of each length, were all entered into a computer file. The file was read by a Fortran program that produced output including: stroke lengths, stroke frequencies, and split time for each 25-yd interval for each 100-yd event. The computer program also produced these variables for each 50-yd interval for the 200-yd events.

STATISTICAL PROCEDURES

Statistical procedures included the calculation of descriptive statistics, intercorrelations between SLs and split times, intercorrelations between SFs and split times, and intercorrelations between SL and SF. Additionally, a 4x4 ANOVA(strokes across split time) with repeated measures across split time was performed on SL and SF, for both the 100-yd and 200-yd races. For all analyses an alpha level of .05 was used in this investigation.

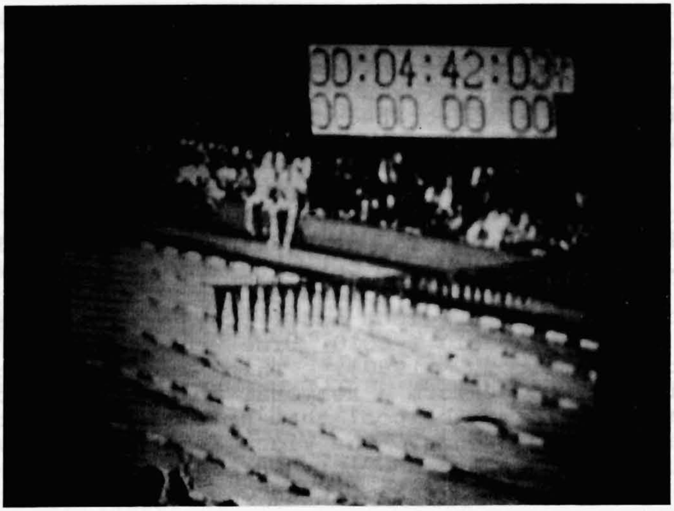

Figure 1- An example of a time-coded frame on a TV monitor. (Time is 4 min. 42 sec. and 3 frames.)

RESULTS

Table one illustrates the descriptive statistics for all swimmers on split times for all 100-yd races. In all cases, split times increase across the 25-yd intervals.

Table 2 illustrates the descriptive statistics for split times on the 200-yd events. These split times demonstrate similar trends to the 100-yd events; times increase across 50-yd intervals.

Means and standard deviations for SF for the 100-yd events and the 200-yd events are reported in tables 3 and 4 respectively. SL means and standard deviations are reported in tables 5 and 6 respectively.

Pearson Product Moment Correlation Coefficents were calculated for SL and SF, SL and split time, and SF and split time for each 25-yd interval on all 100-yd events. The results are presented in table 7.

Table 1
Descriptive Statistics for the Split
Times on the 100-yd. Events

Distance*	0-25	25-50	50-75	75-100	0-100
Butterfly Mean SD	11.59 .54	12.72 .41	13.41 .27	14.09 .35	51.81
Backstroke Mean SD	12.79 .65	13.38 .70	13.86 .54	13.84 .46	53.87
Breaststroke Mean SD	12.80 .55	14.75 .56	15.27 .11	16.22 .77	59.04
Freestyle Mean SD	11.30 .16	11.72 .20	12.33 .30	12.39 .25	47.74

* Distance is reported in yards, all times are in seconds.

Table 2
Descriptive Statistics for the Split
Times on the 200-yd. Events

Distance*	0-50	50-100	100-150	150-200	0-200**
Butterfly Mean SD	25.05 .28	28.46 .33	29.19 .19	29.57 .43	1:52.27
Backstroke Mean SD	26.87 .71	29.04 .54	30.36 .15	30.70 .16	1:56.97
Breaststroke Mean SD	30.25 .33	33.48 .38	33.97 .82	33.57 .15	2:11.27
Freestyle Mean SD	24.59 .46	26.10 .19	26.36 .57	25.94 .19	1:42.99

* Distance is in yards
** total time is in minutes and seconds

Table 3
Descriptive Statistics of Stroke Frequency
for 100-yd Events

Distance		0-25	25-50	50-75	75-100
Butterfly	$\bar{X}$=	.54	.71	.69	.69
	SD=	.39	.62	.48	.65
Backstroke	$\bar{X}$=	1.07	1.17	1.15	1.19
	SD=	.16	.12	.09	.09
Breaststroke	$\bar{X}$=	.63	.75	.74	.73
	SD=	.18	.15	.11	.13
Freestyle	$\bar{X}$=	1.24	1.37	1.34	1.33
	SD=	.08	.05	.12	.10

Table 4
Descriptive Statistics of Stroke Frequency
for 200-yd Events

Distance		0-50	50-100	100-150	150-200
Butterfly	$\bar{X}$=	.61	.65	.66	.68
	SD=	.41	.47	.45	.33
Backstroke	$\bar{X}$=	1.00	.99	.95	.98
	SD=	.12	.63	.36	.41
Breaststroke	$\bar{X}$=	.54	.54	.55	.62
	SD=	.96	.78	.92	.13
Freestyle	$\bar{X}$=	1.06	1.16	1.20	1.29
	SD=	.11	.11	.73	.92

Table 5
Descriptive Statistics of Stroke Length
for 100-yd Events

Distance		0-25	25-50	50-75	75-100
Butterfly	$\bar{X}$= SD=	4.02 .30	2.80 .26	2.71 .14	2.58 .25
Backstroke	$\bar{X}$= SD=	1.87 .36	1.61 .21	1.58 .18	1.52 .12
Breaststroke	$\bar{X}$= SD=	3.29 .80	2.32 .39	2.28 .43	2.18 .41
Freestyle	$\bar{X}$= SD=	1.79 .10	1.57 .08	1.52 .12	1.52 .12

Table 6
Descriptive Statistics of Stroke Length
for 200-yd Events

Distance		0-50	50-100	100-150	150-200
Butterfly	$\bar{X}$= SD=	3.24 .22	2.71 .14	2.60 .13	2.48 .21
Backstroke	$\bar{X}$= SD=	1.88 .16	1.74 .90	1.72 .85	1.65 .53
Breaststroke	$\bar{X}$= SD=	3.09 .54	2.80 .51	2.74 .57	2.47 .60
Freestyle	$\bar{X}$= SD=	1.91 .17	1.66 .11	1.58 .13	1.50 .12

Table 7
Intercorrelations Among Stroke Length (SL),
Stroke Frequency (SF), and Split Time (TIME),
for the 100-yd Events

Specific Quarter of the Race	Variables	Pearson R	Level
1st	SL & SF SL & TIME SF & TIME	-.961 -.039 -.137	<.001 .443 .307
2nd	SL & SF SL & TIME SF & TIME	-.934 .287 -.540	<.001 .141 .011
3rd	SL & SF SL & TIME SF & TIME	-.931 .231 -.538	<.001 .195 .066
4th	SL & SF SL & TIME SF & TIME	-.925 .458 -.727	<.001 .037 <.001

Table 8
Intercorrelations Among Stroke Length (SL),
Stroke Frequency (SF), and Split Time (TIME),
for the 200-yd Events

Specific Quarter of the Race	Variables	Pearson R	Level
1st	SL & SF SL & TIME SF & TIME	-.949 .364 -.564	<.001 .083 .011
2nd	SL & SF SL & TIME SF & TIME	-.942 .593 -.769	<.001 .008 <.001
3rd	SL & SF SL & TIME SF & TIME	-.924 .524 -.745	<.001 .018 <.001
4th	SL & SF SL & TIME SF & TIME	-.895 .440 -.738	<.001 .044 <.001

Table 8 presents the results of intercorrelations among SL and SF, SL and split time, and SF and split time for the 200-yd events.

In order to investigate possible differences in SL and SF across intervals, a 4x4 ANOVA with repeated measures across intervals was calculated for SL and SF for each distance(100 yds and 200 yds). If a significant difference was found on the intervals' main effect, then a Tukey Honestly Significant Difference(HSD) test was used to determine where the differences occured.

The results of the ANOVA on the SL in the 100-yd events was significant, $\underline{F}(3,36)= 65.74, p<.001$. This significant difference indicated that SL decreased over the 25-yd intervals for all strokes combined. The post hoc test revealed that for each stroke except freestyle, SL on the first length was greater than all other lengths. Also, no differences were apparent among the SLs on lengths 2,3,and 4. No significant differences were found on SL for the 100-yd freestyle.

The results of the ANOVA on the SF variable in the 100 yd events indicated a significant difference across intervals, $\underline{F}(3,36)=17.93, p<.001$. The post hoc analysis revealed that for all strokes, SF increased after the first length, but did not significantly change among lengths 2,3, and 4.

The results of the ANOVA for SL in the 200-yd events was significant, $\underline{F}(3,36)=72.41, p<.001$. Post hoc analysis demonstrated that for each stroke SL decreased from the first 50-yd interval to the second and third interval, and from the second and third interval to the last interval($p<.05$).

The ANOVA for the SF in the 200-yd events was significant across intervals, $\underline{F}(3,36)=11.95, p<.001$. Post hoc analysis for each stroke revealed that SF did not significantly change in the butterfly, backstroke, and breaststroke. In the freestyle, SF increased from the first to the second 50-yd interval, and from the third to the last 50-yd interval($p<.05$).

DISCUSSION

Previous researchers in the area of stroke analysis have concerned themselves with the relationships among SF or stroke rate, SL, and time to complete a race or calculated velocity during free swimming (Craig & Pendergast,1979; East,1970; Hay & Guimaraes, 1983). This present study was an attempt to analyze the changes in SF, SL, and split time over the course of a 100-yd or 200-yd competitive swimming races. The results of this study tend to support the fact that the swimmer generally increase his SF and decrease his SL across split times in 100-yd races. This trend was present in all 100-yd swimming events for all strokes except the freestyle. In the freestyle, the SL did not significantly change as the SF increased. In the 200-yd events, the freestyle swimmers demonstrated similar trends in SF and SL to the other 100-yd competitors. Although SF did not significantly change for the 200-yd butterflyers, backstrokers, and breaststrokers, a significant decrease in SL was present for all these swimmers. Hay and Guimares (1983) reported similar results on collegiate swimmers who competed in 200-yd races.

Councilman (1980) reported differences in strokes taken on the third length of the 100-yd freestyle in swimmers that decreased their times from one set of ten 100-yd repeats to another set of ten 100-yd repeats. These results seem to support this present study; as the swimmers slowed down, they generally increased the number of strokes taken in the 100-yd events.

There are several reasons why SL decreses across split times. As the swimmer gets tired, his legs may decrease their kicking forces and thus tend to drop the body position. A drop in body position would cause an increase in drag force of the swimmer's body and make it more difficult to pull the body through the water. Along with the possible drop in body position, the swimmer may tend to drop the elbows during the propulsive phase of each stroke. The drop in the elbow position would tend to reduce the force of the arm pull through the water, thus the stroke length would decrease. In some cases , the combination of reduced kicking force and the dropped elbow may work together to bring about the decrease in SL.

In summary, the analysis of SF and SL can be helpful to the competitive swimmer or coach of competitive swimming. Too often, time splits are solely used to gain information about the performance of the competitive swimmer. Stroke counting, by using videotaped recordings during competition, can further the analysis of swimming performance. Analysis of stroke patterns in short-course competition is important to determine an optimal stroke pattern for each swimmer, in order that turns may be negotiated properly. The latter is particularly true for double-arm recoveries in the breaststroke and butterfly races, where one stroke too many, or one stroke short, may mean the difference between first place and fifth place.

Future studies should be performed to determine the optimal SF and SL for a given swimmer. Past investigations have focused on differences in these variables among fast and slow swimmers, but have not analyzed these differences in actual race competition of a specific swimmer. For example, a 12-year-old female who is five feet tall, and who can swim the 200-yd freestyle in 1 minute, 52 seconds, will have a drastically different SF and SL compared to an 18-year-old male swimmer, who is six-feet tall, and swims at the same pace. The influence of age, sex, height, weight, and race pace, all may effect the optimal SF and SL. Investigation of these variables can aid the coach of swimming or the competitive swimmer in making decisions about stroke mechanics.

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