RELATIONSHIPS BETWEEN STROKE EFFICIENCY MEASURES AND FREESTYLE SWIMMING PERFORMANCE: AN ANALYSIS OF FREESTYLE SWIMMING EVENTS AT THE SYDNEY 2000 OLYMPICS

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The purpose of this study was to investigate the relationships between measures of stroke efficiency and performance in the freestyle swimming events of the Sydney 2000 Olympics. Measures of variables describing swimming performance were determined from overhead video of the races according to the Australian Institute of Sport protocol. All performances by swimmers in the finals and semifinals were included in the analysis for the 50, 100 and 200 m events and performances for finalists only were analyzed for longer events. A within subjects, repeated measures linear-regression analysis was used to determine relationships. The lack of relationships determined for SI with either swim velocity or performance time in the longer events indicated that the SI was not a good indicator of swimming efficiency for women's freestyle events. In contrast, a predominance of these relationships in the longer events indicated that the SI was possibly an indicator of swimming efficiency for men's freestyle events. SL was not found to be a good predictor of swimming speed or an indicator of swimming efficiency for the freestyle events.

KEY **WORDS:** swimming biomechanics, swimming efficiency, competition analysis

INTRODUCTION: Swimming at speed requires maximising propulsion and minimising resistive drag. Swimming at speed for extended periods of time has an additional requirement of maximising efficiency, that is, minimising the energy cost per second or power output of the swimmer. A common assertion by swimming coaches is that improvements in stroke efficiency are the best way to increase swimming speed. This is because the power required to swim at speed increases approximately as the cube of the swimming speed. Unfortunately there are no simple measures of swimming efficiency. Stroke counts, measures of stroke length (SL), the sum of stroke count and swim time, and stroke length times swim speed – the stroke efficiency index (SI) have all been advocated as efficiency indicators (FINA, 1990; Costill et al., 1992). We have shown previously in trained pool swimmers that SL has a stronger relationship to a physiological measure of swimming efficiency, the oxygen cost per meter swum than does the SI (Wilson et al., 1999). The purpose of this study was to investigate the relationships between measures of stroke efficiency and performance in the freestyle swimming events of the Sydney 2000 Olympics.

METHODS: Subjects. All performances by swimmers in the finals and semifinals were included in the analysis for the 50, 100 and 200 m events. This resulted in two swims by eight swimmers and one swim by a further eight swimmers being included for each of these events. For 400 m and longer events only swims by finalists were included in the analysis.
Measurements. Variables describing swimming performance were determined from overhead video of the races according to the Australian Institute of Sport protocol for competition analysis (Mason, 2000). Of the four phases of competition analysis, starting, turning, finishing and free swimming this study analyzed only the data from the free swimming phase of the race when the swimmer is not preparing or recovering from a turn, slowing down from the start or preparing to finish the race. Variables measured were stroke length (SL); the distance the swimmer's head moves from right hand entry to right hand entry; Velocity each lap (VL) in the free swimming phases of the first and second 25m of each 50 m lap from the distances traveled by the head of

the swimmer divided by the elapsed time; and the efficiency index (SI) determined by multiplying the swimmer's velocity by the swimmer's SL.
Analysis. A within subjects repeated measures linear-regression analysis (STATA, 2000) was used to determine relationships between SL and SI with swimming speed in each lap (VL) and between race average stroke length (AvSL) and performance time (PT).

RESULTS AND DISCUSSION: The means and standard deviations for SL, SI, free-swimming speed (Vf) and performance time (PT), of the finalists in the freestyle events are shown in Table 1.

Table **1** Means and Standard Deviations of Descriptor Variables

		Womens		Mens	
	Variable	Mean	SD	Mean	SD
50 m	SI	3.50	0.20	4.69	0.33
	SL	1.88	0.09	2.17	0.14
	Vf	1.86	0.04	2.13	0.08
	PT	25.42	0.50	22.31	0.21
100 m	SI	3.49	0.14	4.50	0.31
	SL	2.02	0.07	2.32	0.16
	Vf	1.73	0.03	1.94	0.03
	PT	55.42	0.71	49.21	0.52
200 m	SI	3.27	0.20	3.91	0.25
	SL	2.15	0.15	2.37	0.14
	Vf	1.63	0.02	1.77	0.03
	PT	120.25	0.94	108.52	1.61
400 m	SI	3.04	0.24	4.19	0.33
	SL	2.20	0.19	2.81	0.24
	Vf	1.56	0.02	1.69	0.02
	PT	249.46	2.55	207.69	1.61
800 m	SI	2.99	0.19	3.82	0.29
(1500 m for	SL	1.95	0.12	2.37	0.18
men)	Vf	1.53	0.02	1.61	0.02
	PT	507.82	5.74	901.67	10.15

The mean SI decreased with event distance for women's and men's events with the exception of the 400 m event for men. That is, swimmers in the longer distance events swim with lower SI values than swimmers in shorter distance events. By contrast the mean SL increased with event distance up to 400 m. However, for the 800 and 1500 m events, SL was less than for the corresponding women's or men's 400 m event. These mean data indicate that the SI is very dependent on the event distance and if SI is to be used as an indicator of efficiency interpretation should be limited to changes in SI within an event. This is assuming the stature of the swimmers is similar over the event distances.
In Table 2 are shown the regression coefficients of the predictor variables expressed as a percentage of the dependent variable and the R^2 and p value for the relationships tested. The size of the coefficient indicates the size of the effect produced by a unit change in the predictor variable. For example, a unit change in SI in the women's 50 m event would be associated with an increase in swimming speed of 6.8%. It should be noted that the within-subject variation during an event was generally less than the between-subject variation, reported as the standard deviation in Table 1.

Table 2 Regression Coefficients, R^2 and p Values for the Relationships Tested

		Womens				Mens			
		Coefficient (percent)	R^2	P		Coefficient (percent)	R^2	P	
50 m	VL by SI	6.8	0.705	0.001	*	5.2	0.232	0.003	*
	VL by SL	5.1	0.021	0.102		-0.3	<0.000	0.896	
	PT by AvSI	-5.1	0.274	0.013	*	-0.9	0.073	0.157	
	PT by AvSL	-4.4	0.045	0.277		-0.7	0.009	0.539	
100 m	VL by SI	15.2	0.575	<0.000	*	8.3	0.465	<0.000	*
	VL by SL	5.4	0.010	0.331		6.2	0.038	0.007†	*
	PT by AvSI	-5.0	0.213	0.010	*	-1.6	0.220	<0.021	*
	PT by AvSL	-2.8	0.018	0.477		-2.1	0.099	0.013	*
200 m	VL by SI	4.5	0.152	0.013	*	6.4	0.313	0.001	*
	VL by SL	0.1	-	-		3.1	0.015	0.140	
	PT by AvSI	1.6	0.143	0.007		-2.7	0.190	0.013	*
	PT by AvSL	2.6	0.209	0.012	* *	-2.0	0.039	0.534	
400 m	VL by SI	1.0	0.014	0.510		4.0	0.265	0.007	*
	VL by SL	-2.0	0.022	0.491		3.4	0.049	0.026†	*
	PT by AvSI	2.2	0.259	0.198		-2.0	0.026	0.552	
	PT by AvSL	3.4	0.392	0.097		-3.4	0.035	0.019	*
800 m	VL by SI	2.9	0.096	0.278		3.4	0.174	0.006	*
(1500	VL by SL	0.5	0.009	0.903		1.7	0.014	0.503	
m for	PT by AvSI	-0.4	0.005	0.864		-0.1	0.169	0.003	*
men)	PT by AvSL	-0.8	0.009	0.827		-0..1	0.174	0.369	

* Significant at $p<0.05$, † Not significant if "lap" was included in the regression

For women's 50,100 and 200 m freestyle events the VL and PT were significantly related to the SI and AvSI respectively. Only one significant relationship with SL was observed between PT and AvSL for the 200 m event. No significant relationships between VL and SI or SL or PT and AvSL or AvSI were observed for 400 and 800 m events. The observed significant relationships for the shorter distance events is contrary to what was expected in that swimming efficiency was hypothesised to be more of a factor in swimming at speed in longer distance events. Thus SI is possibly not an indicator of swimming efficiency in women's freestyle swimming. However, (a) there was possibly too little data in the longer distance events to produce a significant result, (b) performances were too similar in the subject group for regression analysis to be effective, or (c) technical factors such as SL and SI, since SI = SL x V, were outweighed by other unaccounted for variables such as a measure of physiological conditioning.

For men's events, there were significant relationships between VL and SL for 100 and 400 m events. However, if SL and lap were entered into the regression the contribution of SL was no longer a significant predictor of VL. That is, the speed swum in each lap was more determined by the lap number than by the SL. SI was a significant predictor of VL as was AvSI for PT for the 100, 200, 400 and 1500 m events. SL was not a significant predictor of VL (when controlled for lap swum) and was significant only as a predictor of PT for the 400 m event. The predominance of significant relationships in which SI and AvSI are predictor variables of VL and PT respectively in the longer distance events, supports the hypothesis that SI may be an indicator of swimming efficiency in the male freestyle events.

CONCLUSION: The lack of relationships determined for SI with either swim velocity or performance time in the longer events indicated that the SI was not a good indicator of swimming efficiency for women's freestyle events. In contrast, a predominance of these relationships in the longer events indicated that the SI was a possible indicator of swimming efficiency for men's freestyle events. SL was not found to be a good predictor of swimming speed or an indicator of swimming efficiency for the freestyle events.

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