ASSESSMENT OF NORMALIZED DISTANCE PER STROKE AND SWIMMING EFFICIENCY IN THE 2000 OLYMPIC GAMES

Scott Riewald
USA Swimming Biomechanics, Colorado Springs, CO, USA

Stroke length has been viewed as an important determinant in swimming speed and performance. However, recent studies of elite level athletes have shown that stroke length (SL) typically does not correlate with swimming speed in elite athletes. These studies have focused on absolute stroke length and have not taken into consideration the size of the athletes. The noted lack of correlation may be due to the variability introduced by differences in athlete size. This study looks at athlete SL normalized to body height and introduces the concept of using normalized SL (NSL) as a measure of efficiency. Pearson correlation coefficients were computed to relate NSL to swimming speed and analyses of variance were conducted to examine differences between finalists and semifinalists at the 2000 Olympic Games. Significant findings and their relationship to performance are discussed.

KEY **WORDS:** stroke length, normalized stroke length, efficiency

INTRODUCTION: Stroke length has been a variable thought to be a significant determinant of swimming performance. Studies of major swimming competitions over the past 20 years have shown that stroke length (SL) has consistently increased in elite swimmers (Craig, 1979; 1985; Mason. 1999; 2000). Since performance times have also improved over this period, it was thought that SL had a significant impact on swimming speed. While changes in SL may result in changes in speed, absolute SL may not directly correlate with swimming velocity. In fact, Mason (1999) and Mason and Cossor (2000) have shown that SL only rarely correlates with performance in elite level swimmers. Significant relationships between SL and performance were found in only one race out of 26 contested in the 1998 World Championships and in 5 races in the 1999 Pan Pacific Games.

These studies examined absolute SL, and did not take into consideration the size of the athletes. The inherent variability found in any group of athletes can make it difficult to distinguish differences when only looking at absolute values. Intuitively, it makes sense to study absolute variables since they ultimately determine swimming speed. At the same time, if one is looking to identify distinguishing characteristics among athletes, it may be beneficial to look at normalized variables; assessing how well an athlete "uses what he or she has."

While a number of studies have looked at anthropometric variables and their impact on swimming performance (Grimston. 1985; Soares dos Santos, 1999), none have specifically used these measures to normalize performance variables (i.e. SL or SR). Additionally, only Mason (1999, 2000) has attempted to quantify biomechanical efficiency. The purpose of this study was to study normalized SL and efficiency and their relation to swimming speed.

METHODS: At the 2000 Olympic Games, a 7-camera system was used by the AIS Biomechanics Team to capture video from each of the semifinal and final heats for analysis. Four of the cameras were oriented to each film a four lane by 25 m segment of the pool. In this way the full 50 m course was filmed for each of the eight competition lanes. The remaining three cameras were positioned to capture all eight competition lanes at the 25 m mark and at the 7.5 m mark at the start and turns. The composite video signal from each camera was amplified and stored on videotape for subsequent analysis. The video was also synchronized with the official starting system. This synchronization allowed a time code, used for computation of intermediate split times and stroke rates, to be imbedded on the videotapes. Prior to video collection and analysis, each lane was calibrated by digitizing reference points at known positions. This calibration was necessary for computing average velocities and stroke lengths over each 25 m segment of the races 200 m in length or shorter, and for every 50 m segment in races 400 m in length or longer.

Analysis consisted of digitizing the swimmer's head position, and noting the corresponding

(¡ʍɐs, at the start of ənd completion of three full stroke cycles within the calibrated swimming areas. This allowed for average stroke rate (SR), stroke length (SL), ənd swimming velocity (using measured intermediate split times) to bɐ computed for each swimmer over each 25 m segment. An efficiency measure (Eff), computed by multiplying swimming velocity by distance pep stroke, was also computed for each athlete.

Average SR, SL and swimming velocity values were computed over the entire race for ɐəob athlete. To compute normalized stroke length (NSL) ənd efficiency (Neff) values, the absolute variables were divided by body height (obtained from the official athlete entries). NSL tells how many bodʎ lengths a swimmer travels pep stroke cycle. Single factor (finalist or semifinalist) analysis of variance (ANOVA) was usɐd to compare SL, Eff, NSL ənd Neff between the finalist (1-8) ənd semifinalist (9-16) groups and əssɐss their impact on performance. Additionally, Pearson Product Moment Coefficients were computed to əssɐss the correlation between these variables ənd the final swimming time.

| ʌ ɐ 1 Male ~ɐ i ⓪ , S l and S l Values

	~ ə l ɐ Finalists			Male Semifinalists		
	Height (m)	SL ($m\cdot cyc^{-1}$)	NSL ($BL\cdot cyc^{-1}$)	Height (m)	SL ($m\cdot cyc^{-1}$)	NSL ($BL\cdot cyc^{-1}$)
FR, S0 m	1.94±0.06	2.18±0.12	1.13±0.06	1.90±0.04	2.12±0.11	1.12±0.06
FR, 100 m	1.94±0.04	2.29±0.13	1.18±0.05	1.93±0.06	2.22±0.15	1.15±0.08
FR, ZOO	1.92±0.06	2.34±0.17	1.22±0.09	1.91±0.05	2.38±0.08	1.24±0.04
FR, dOO	1.92±0.05	2.77±0.26	1.44±0.12	-	-	-
FR, 1500 m	1.88±0.08	2.37±0.18	1.26±0.12	-	-	-
BA, ꓕ00 m	1.90±0.05	2.14±0.16	1.12±0.07	1.87±0.06	2.13±0.11	1.14±0.06
BA, Z00 m	1.89±0.04	2.30±0.11	1.21±0.07	1.89±0.05	2.38±0.08	1.25±0.04
BR, ꓕ00 m	1.84±0.06	1.84±0.15	ꓕ.00ㄥ0.09	1.91±0.09	1.73±0.11	0.91±0.05
BR, 200 m	1.83±0.05	2.32±0.18	1.26±0.10	1.83±0.06	2.15±0.15	1.17±0.07
FL, 100 m	ꓕ86⊥OOS	1.92±0.08	1.04±0.05	1.86±0.05	1.93±0.05	1.04±0.01
FL, ZOO m	1.88±0.06	2.01±0.08	1.07±0.04	1.83±0.06	1.95±0.07	106⊥OOS

Table 2 Male Swimming Velocity, Eff and Neff Values

	~ ə l ɐ Finalists			~ ə l ɐ Semifinalists		
	Swim Vel. ($m\cdot s^{-1}$)	Eff ($m^2\cdot s^{-1}\cdot cyc^{-1}$)	Neff ($m\cdot s^{-1}\cdot cyc^{-1}$)	Swim Vel. ($m\cdot s^{-1}$)	Eff ($m^2\cdot s^{-1}\cdot cyc^{-1}$)	Neff ($m\cdot s^{-1}\cdot cyc^{-1}$)
FR, 50 m	2.12±0.02	4.63±0.23	2.39±0.13	2.08±0.01†	4.41±0.25	2.33±0.13
FR, ꓕ00	1.96±0.02	4.50±0.26	2.32±0.10	1.92±0.01†	4.28±0.28	2.22±0.15
FR, 200 m	1.80±0.02	3.91±0.26	2.04±0.14	1.76±0.02†	3.88±0.14	2.03±0.08
FR, 400	1.70±0.02	4.16±0.41	2.17±0.20	-	-	-
FR, 1500m	1.61±0.02	3.82±0.29	2.03±0.19	-	-	-
BA, ꓕ00 m	1.72±0.02	9.69ꓕ0.ㄥ8	1.94±0.13	ꓕ.70±0.02	3.63±0.21	1.94±0.13
BA, 200 m	1.61±0.01	3.45±0.14	1.82±0.09	1.58±0.02†	3.49±0.09	1.85±0.04
BR, ꓕ00 m	1.54±0.02	2.84±0.23	1.55±0.14	1.50±0.02†	2.60±0.17	1.36±0.08
BR, 200 m	1.44±0.02	3.14±0.27	1.71±0.15	1.43±0.01	2.88±0.19	1.57±0.09
FL, 100 m	18ꓕ±0.02	3.48±0.16	ꓕ.88ㄥ0ꓕ0	1.78±0.01*	3.44±0.11	1.85±0.02
FL, ZOO	1.66±0.02	3.16±0.10	1.68±0.05	1.64±0.01*	3.03±0.10*	1.66±0.07

† = Different from finalist group, $p<0.01$, * = Different from finalist group, $p<0.05$. FR = Freestyle, BA = Backstroke, BR = Breaststroke, FL = Butterfly, $BL\cdot cyc^{-1}$ = Body lengths per stroke cycle

RESULTS: Analysis of variance showed that there were not any significant differences ($p>0.05$) in height, SL, NSL, or Neff between finalist ənd semifinalist groups (Tables 1-4). Eff differed in only onɐ event (men's 200 m FL), while swimming velocity differed in nearly all of them. Additionally, when Pearson Correlation coefficients were calculated, significant relationships between SL, NSL, Eff ənd Neff were found to bɐ limited. SL ənd NSL were found to correlate with final time only in the men's 200 BK (r =-0.659 and -0.609). Eff correlated with final time in men's 100 ꓒ ! (r =0.724), 200 FL (r =0.618) and 200 BR (r =0.533). Neff was correlated with final time in the men's 100 ꓒ ! (r=0.586), 100 BR (r=0.596), 200 BR (r=0.702) and the women's 200 BA (r=0.587). Swimming velocity was strongly correlated with final time in every event. No other significant relationships were found between the performance variables of interest in this study and swimming time.

DISCUSSION: The findings of this study do not lend support to the hypothesis that normalized SL and Eff are better predictors of, or are more strongly correlated to, performance than absolute values. These results were similar to those of Mason (1999 and 2000), who examined absolute SL and found that it typically was not significantly correlated to performance in elite swimmers.

Table 3 Female Height, SL and NSL Values

	Female Finalists			Female semifinalists		
	Height (m)	SL ($m \cdot cyc^{-1}$)	NSL ($BL \cdot cyc^{-1}$)	Height (m)	SL ($m \cdot cyc^{-1}$)	NSL ($BL \cdot cyc^{-1}$)
FR, 50 m	1.77±0.05	1.84±0.11	1.04±0.07	1.81i0.05	1.87i0.09	1.04i0.06
FR, 100 m	1.76±0.06	1.99i0.05	1.13±0.03	1.76t0.05	2.00i0.08	1.14i0.06
FR, 200 m	1.77±0.07	2.03±0.13	1.15i0.10	1.78i0.04	2.23i0.12	1.26i0.06
FR, 400 m	1.73±0.09	2.20±0.19	1.27±0.06	-	-	-
FR, 800 m	1.73±0.07	1.95±0.12	1.13±0.06	-	-	-
BA, 100 m	1.71i0.04	1.94i0.07	1.14i0.05	1.76i0.05	2.02±0.11	1.15k0.07
BA, 200 m	1.72i0.07	2.10i0.10	1.22i0.04	1.77i0.06	2.11i0.08	1.19k0.06
BR, 100 m	1.71i0.05	1.65±0.12	0.97±0.08	1.72i0.05	1.71i0.22	0.99±0.13
BR, 200 m	1.74±0.06	1.97±0.21	1.13i0.10	1.70i0.06	2.02±0.22	1.20±0.14
FL, 100 m	1.73±0.05	1.74±0.08	1.00±0.05	1.75±0.04	1.74i0.09	1.00±0.05
FL, 200 m	1.70i0.04	1.75i0.12	1.03i0.06	1.69k0.03	1.72±0.13	1.02±0.07

Table 4 Female Swimming Velocity, Eff and Neff Values

	Female Finalists			Female Semifinalists		
	Swim Vel. ($m \cdot s^{-1}$)	Eff ($m^2 \cdot s^{-1} \cdot cyc^{-1}$)	Neff ($m \cdot s^{-1} \cdot cyc^{-1}$)	Swim Vel. ($m \cdot s^{-1}$)	Eff ($m^2 \cdot s^{-1} \cdot cyc^{-1}$)	Neff ($m \cdot s^{-1} \cdot cyc^{-1}$)
FR, 50 m	1.89±0.04	3.49±0.24	1.98±0.14	1.84±0.02†	3.44±0.19	1.91±0.13
FR, 100 m	1.74±0.02	3.47±0.10	1.97±0.06	1.71±0.01†	3.42±0.14	1.95±0.11
FR, 200 m	1.63±0.01	3.11±0.18	1.76±0.14	1.62±0.02	3.36i10.17	1.89H.09
FR, 400 m	1.56i0.02	3.04.±0.24	1.75±0.13	-	-	-
FR, 800 m	1.53±0.02	2.99±0.19	1.73±0.10	-	-	-
BA, 100 m	1.57i0.03	3.05i0.14	1.79i0.09	1.53±0.02†	3.10i0.22	1.77±0.13
BA, 200 m	1.46i0.03	2.881012	1.68±0.07	1.43±0.01*	2.83i0.10	1.60±0.07
BR, 100 m	1.42±0.01	2.34±0.19	1.37±0.12	1.36±0.01†	2.32±0.30	1.35i0.18
BR, 200 m	1.32±0.02	2.47t0.27	1.42±0.13	1.30±0.01†	2.46±0.24	1.46±0.16
FL, 100 m	1.64±0.02	2.87±0.16	1.66i0.09	1.62±0.02†	2.82±0.14	1.62k0.07
FL, 200 m	1.51±0.01	2.52±0.19	1.48i0.09	1.50±0.01	2.46t0.17	1.45i0.09

† = Different from finalist group, $p<0.01$, * = Different from finalist group, $p<0.05$

An attempt was made to distinguish between different levels of swimmers by examining the swims of the finalists and comparing them to those of the semifinalists. It is reasonable to assume that variations in athlete height will impact the measured SL, and potentially swimming velocity. A trend towards this was seen in the men's events, as finalists tended to be taller and swim with longer SLs than the semifinalists in almost every event. However, these differences were not significant. In looking at the NSLs, we see less of a difference between the two groups when compared to absolute values. In most of the men's events, both groups swam with essentially the same NSLs, signifying they were travelling the same distance with each pull cycle relative to their body size. In a number of events, semifinalists swam with even higher average NSLs. ANOVA tests showed that there was less of a difference between finalists and semifinalists in NSL than SL in almost all of the events (data not shown). Once again, comparisons between groups did not yield significant results. Similar findings were made in examining the swimming efficiency indices. It should be noted that efficiency measures should not be used to compare different strokes. However, comparison of athletes within the same

event can provide an insight into how different athlete populations swim their races. Analysis of the stroke rates (data not shown) showed that there were no significant differences between groups and that the average stroke rates for both groups were almost identical in every event.
Slightly different results were found in the female athletes when compared to the males. While male semifinalists tended to swim with equal or lower SLs and NSLs compared to the finalists, female semifinalists tended to swim with equal or higher values than the finalists. These results indicate that the semifinalists are traveling further with each stroke cycle in absolute terms and relative to their body height. At the same time, the finalists swam significantly faster in nearly every event. This suggests that the finalists swam with increased stroke rates compared to the semifinalists. In fact, while there was not a significant difference between the stroke rates of the two groups, the average stroke rate was higher in the finalist group for every event except the 100 butterfly. Examining the efficiency indices, Eff and Neff, we see that the differences between groups become smaller. This is most likely due to the fact that swimming velocities are higher in the finalist group, while the SLs are higher in the semifinalist group. In some instances, the Eff and Neff values are greater in the semifinalist group. This is somewhat contradictory, since one would expect the fastest swimmers, on average, to be the most efficient. This suggests that additional factors should be taken into account when formulating an efficiency index. This would allow for accurate comparisons to be made between different groups within the same race.

CONCLUSIONS: SL and Eff variables, normalized by body height, do not serve as effective predictors of performance at the elite level. While trends can be found to relate these variables to performance, and distinguish between the finalist and semifinalist groups, none of the relationships proved to be significant. This point was made by Mason (1999, 2000) who indicated that other factors need to be taken into account when assessing performance. However, the athlete population used in this study was very homogeneous; every athlete can be considered elite. Studies of normalized variables in athletes of different abilities may still yield significant results. In the future, attempts to normalize performance parameters by anthropometric measurements may need to take into account variables other than height.

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