Difference in speed at fixed reference points, and changes in speed between fixed reference points, during 100 meter swimming races at the European Championships, 2010

Torsten Buhre

Department of Sport Sciences
Malmö University
20506 Malmö, Sweden

ABSTRACT

The purpose was to examine the differences and relationships between speed variables and performance in 100 meter events at the European Championships long course (LC) and short course (SC) for all strokes and gender. Data was collected from the website www.swim.ee, transformed, and analyzed using statistical methods. Swimming speed (SS) at different reference points was significantly different for in both short course (SC) and long course (LC) swimming, SS15>SS35>SS45<SS65>SS85>SS95. The effect size for all measures was large (Cohen´s d). The changes in SS between reference points was significantly different in all events for both sexes in both SC and LC swimming, δSS15:35> δSS35:45, but only for SC when comparing δSS85:95> δSS65:85. Correlations of placing at the end of the race, split times for each 50 m segment and SS at different reference points, showed no clear pattern. The differences in the swimming speed variables, can be explained based on the theory of complexity and performance, utilizing previous research findings and the standard equation of drag force in fluids. Thus taking into account all different aspects of performance. The managing of speed through out a race needs to be a special focus in both training and competition. Thus, allowing for a more individualized approach both in utilizing training methods training and analysis of performance in 100 m race.

Introduction

Using performance analysis to fine-tune the training process in swimming has been proposed over the last three decades. The logic is two-fold; both to ensure proper training to improve performance (20) and to enhance the recovery allowing optimal training adaptations to occur (14). Performance analysis in swimming can be based on split times. Split times are taken at intermediate distances based on the length of the pool. These split times portray an average of the swimming speed over the distance covered.

Researchers have (8) concluded that differences in performance is often <1% between gold medalists and non-medal. The smallest enhancement of performance impacting an athlete´s chance of a medal in a race has been calculated to be 1/3 of the typical variation in performance (13). In the current sample of events and swimmers (n_E=16, n_S=128) the mean difference in swimming speed (SS) in m/s between first and eight place in the finals was 96,49% ($\pm$ 1,33%). A smaller variation in SS between places can be interpreted as a “higher degree of narrowness” of the competition.

The outcome of performance is based on an individual´s ability to coordinate and develop his/her potential within the domains that constitutes performance, i.e. physiology, technique or biomechanics, tactics and psychological competence (4, 13). Each domain has a multitude of factors that are intra-related and the domains are inter-related.

In swimming, technique is based on the application of biomechanics and anthropometric affordances. High performance athletes change their pattern of coordination in freestyle within a race in order to compensate for increased fatigued (21). Anthropometric measures have been shown to influence the variables of stroke length (SL) and stroke rate (SR). Specifically, cross-sectional area of the axilla accounted for 57% and 24% of the variation in SL and SR, respectively in male swimmers (11). Female swimmers can adopt a more favorable horizontal body alignment and are affected by lower under water torque (29, 30). Growth has an negative effect on drag, as height, body shape and body cross-sectional area increase due to maturation, the drag coefficient of the body increases (26).

Pacing is a combination of tactically distributing the physiological resources using stroke mechanics efficiently in an optimal way. An uneven distribution of effort results in reduced performance capacity, associated with increased physiological demand (8). Other findings suggest that the athletes learn to manage fatigue in training, adjusting the pacing strategy accordingly and reaching critical values of pH near the end of the race (8, 9). The van Ingen Schenau (27) model for pacing implies that effective transfer of power decreases as the athlete fatigues. This could explain both the change in coordination pattern (21) and a loss of SS. The reduced effective power transfer in the end of supra-maximal performances is highly relevant in events where the skill factor is high, such as swimming 100 meter events. An all-out racing strategy seems favorable. It is associated with a greater initial PCr breakdown and as a consequence an increase in VO_2 without changing the aerobic oxygen deficit (3), creating a greater initial speed, without a significant increase in blood lactate and a reciprocal decrease in blood pH.

The two variables influencing SS, are SL and SR (6, 7). Manipulating either one of these variables independently will result in an increase in SS. An increase in SL and decrease in SR will result in an increase in SS for all strokes (7, 16, 19) and in backstroke, breaststroke and butterfly (2, 10). SR and SL has been shown to vary less with an increase in proficiency in 100 m free (5, 21). In swimming the SS is dependent the mechanical efficiency of the individual swimmer (1, 15). The mechanical efficiency measures of the total amount of energy spent for mechanical work in relation to the overall energy expenditure.

When analyzing differences in SS among top swimmers in a swimming race, we will utilize the equation below to explain possible differences:
The standard equation for drag force (F_D) in water is:

$$F_D = \frac{1}{2} \rho \times v^2 \times C_D \times A$$

Where F_D is the force needed to overcome the drag resistance created by moving through the water, ρ is the density of water, v^2 is the velocity of the swimmer, C_D is a drag coefficient that is dependent upon the shape of the swimmers´ body, and A is the cross-sectional area of the swimmers´ body. To increase SS the force applied to overcome drag needs to be increased squared to the relative increase in speed, which negates previous findings (3, 8, 21). Also, ρ is fairly constant and is 784 times greater than air at sea level. The cross sectional area of the body (A) has a minimum of variability, but can change during stroke-cycles due to postural changes. This study assumes that a change in swimming speed must be due inverted reciprocal change in C_D.

It is of interest to quantify the changes in SS and where these changes are greater and smaller. This information should be valuable for coaches for two reasons 1) further the understanding what actually happens with SS within a race, and 2) it can be utilized to make training for performance more effective. The purpose of this study was to investigate how SS changed within a group of highly proficient swimmers during the course of 100 meter races for men and women in all strokes, both short-course (SC) and long-course (LC).

Methods

The current data collection was obtained from a race analysis website http://www.swim.ee, and was used with permission from Haljand (12). This data collection was done with the permission of Ligue Européene de Natation (25). The race analysis was performed using video cameras and taping-machines that included an encoded time displayed on the video picture. The system was linked to the electronic timing system of the pool, and was activated by the starter´s signal of the race. Cameras were placed high in the stands, located at measured distances of 5 m intervals, down the length of the pool. To determine the swimmer´s time at a specific distance during the race, a superimposed digital line on the picture was used to clearly delineate the time, using the head as a reference point and the encoded time displayed on the video picture. Data showing the placing of the individual swimmer in the race was collected from LEN website (18).

Data transformation

Data was collected from the European Championship finals in all 100 meter events for men and women at Eindhoven, Netherlands, 2010 (SC) and at Budapest, Hungary, 2010 (LC). The data recorded as time to certain reference points was transformed into SS for the following reference points: 15 m, 35 m, 45 m, 65 m, 85 m and 95 m. For the SS15 m, the reaction time from the starting block was subtracted from the time at the reference point 15 m, to expose the "true" speed of the swimmer at 15 m. In addition, a variable portraying the change in swimming speed (δSS) between the reference points for the 100 m races was created (δSS15:35, δSS35:45, δSS45:65, δSS65:85 and δSS85:95). To correct for the difference in distances measured δSS was normalized to m/s per 10m segment. Note that all variables are indicative of an 80 m segment of whole 100 m race.

Statistical analysis

The following assumption was made in for the data analysis. (1) The swimmers competing in the finals were the best in Europe at the specific time to distribute their physiological resources in a "best-fit" tactical manner to maximize their performance. This assumption allows for both a comparison within the race and a comparison between short course (SC) and long course (LC) performance.

To analyze for differences in SS between reference points and δSS between reference points of the race within a race a ANOVA for repeated measures used for each stroke, course and gender. Tukey´s post hoc procedure was applied when statistical significance to delineate between which measure a significant difference was found. Also, ANOVA was used to delineate significant differences due to course for all variables of SS and δSS. Cohen´s d was calculated to determine the effect size of the different measures that revealed statistical significance. In addition, Spearman Rho correlations for the variable placing, split times for each 50 m segment and speed at different reference points was calculated in order to elucidate if there was a given pattern, both in general, within gender, due to course and/or type of stroke in relation to placing in the race. The level of significance was set to ($p<0,05$) a priori.

Results and analysis

The results are reported in three sections; 1) difference in swimming speed at different reference point. Secondly the change in swimming speed within different segments. And thirdly, the correlations between placings, swimming speed and split times.

Swimming speed at different reference points

For all strokes the factor of SS at different reference points was statistical significant ($p<0,05$) regardless of gender and course. Post hoc procedures generally revealed the same pattern of differences, i.e. SS15>SS35>SS45<SS65> SS85>SS95. Two exceptions from this pattern was evident, the women´s 100 free SC SS65=SS85 and women´s 100 fly SS45=SS65. Cohen´s d revealed that in all cases the effect size was large between adjacent reference points, except for SS45<SS65 in men´s 100 fly (SC) and women´s 100 free (SC), and SS65>SS85 for women´s 100 back (SC), moderate effect. The further on into the race the swimmers swam, the slower the average swimming speed at successive reference points, except for SS45 to SS65 where the was an increase in SS between the two points. Assuming that the swimmers were well trained, have learned to manage fatigue (8, 9) and applied an effective way of transferring power (27), the difference in swimming speed at different reference points throughout the race could then be explained by an increase in fatigue. This fatigue was probably due to the large density of water as compared to air, influencing the swimmers to increase C_D, thus causing a reduction in swimming speed. The explanation for the increase in SS between SS45 and SS65, could be explained by 1) where in the race SS45 was measured for (20 or 45 meters from the previous push-off) as compared to SS65 (15m after the wall); 2) the wall is an opportunity to increase speed and longer time after the wall in a more favorable position (streamline) with less effect on C_D.

Table 1: Differences in swimming speed at different references points in 100 meter races for all strokes SC and LC for both men and women at the European Championships finals, 2010

Measures	SS15		SS35		SS45		SS65		SS85		SS95		Cohen´s d
Men	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	Effect size
100 free (SC)	2,918	2,854 - 2,981	2,217	2,176- 2,258	1,967	1,924 - 2,011	2,078	2,059 - 2,096	2,036	2,009 - 2,064	1,780	1,750 - 1,810	Large
100 free (LC)	2,923	2,860 - 2,987	2,047	2,006 - 2,088	1,968	1,924 - 2,011	2,101	2,082 - 2,119	1,913	1,886 - 1,941	1,789	1,769 - 1,829	Large
100 back (SC)	2,532	2,453 - 2,611	2,045	2,020 - 2,070	1,792	1,767 - 1,818	1,944	1,896 - 1,993	1,869	1,838 - 1,901	1,632	1,600 - 1,663	Large
100 back (LC)	2,616	2,537 - 2,695	1,833	1,808 - 1,858	1,717	1,691 - 1,743	1,998	1,950 - 2,046	1,708	1,677 - 1,739	1,595	1,677- 1,739	Large
100 fly (SC)	2,947	2,876 - 3,017	2,024	2,002 - 2,047	1,865	1,836 - 1,894	1,892	1,862 - 1,922	1,854	1,829 - 1,880	1,632	1,599 - 1,665	Large
100 fly (LC)	2,962	2,892 - 3,032	1,882	1,859 - 1,904	1,848	1,819 - 1,876	1,924	1,894 - 1,953	1,773	1,795 - 1,798	1,692	1,659 - 1,725	Large
100 breast (SC)	2,508	2,460 - 2,556	1,755	1,739 - 1,772	1,523	1,498 - 1,548	1,682	1,671 - 1,692	1,640	1,619 - 1,660	1,433	1,406 - 1,460	Large
100 breast (LC)	2,493	2,445 - 2,541	1,610	1,594 - 1,626	1,578	1,553 - 1,602	1,664	1,653 - 1,674	1,511	1,4890 - 1,532	1,439	1,412 - 1,466	Large

Measures	SS15		SS35		SS45		SS65		SS85		SS95		Cohen´s d
Women	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	Effect size
100 free (SC)	2,523	2,466 - 2,579	1,989	1,959 - 2,020	1,778	1,762 - 1,804	1,836	1,813 - 1,859	1,821	1,791 - 1,851	1,623	1,592 - 1,654	Large
100 free (LC)	2,550	2,494 - 2,605	1,833	1,802 - 1,864	1,777	1,751 - 1,803	1,890	1,867 - 1,912	1,711	1,680 - 1,741	1,625	1,594 - 1,655	Large
100 back (SC)	2,164	2,102 - 2,225	1,796	1,778 - 1,814	1,572	1,559 - 1,585	1,694	1,669 - 1,720	1,675	1,650 - 1,699	1,477	1,451 - 1,503	Large
100 back (LC)	2,211	2,149 - 2,272	1,618	1,600 - 1,635	1,557	1,544 - 1,569	1,741	1,715 - 1,766	1,520	1,496 - 1,545	1,451	1,424 - 1,477	Large
100 fly (SC)	2,528	2,449 - 2,606	1,768	1,743 - 1,794	1,592	1,567 - 1,618	1,700	1,676 - 1,723	1,631	1,598 - 1,664	1,440	1,406 - 1,473	Large
100 fly (LC)	2,540	2,461 - 2,619	1,735	1,711 - 1,760	1,681	1,656 - 1,707	1,711	1,688 - 1,735	1,593	1,561 - 1,626	1,502	1,468 - 1,536	Large
100 breast (SC)	2,043	2,004 - 2,082	1,548	1,531 - 1,564	1,369	1,347 - 1,392	1,466	1,437 - 1,494	1,439	1,420 - 1,458	1,263	1,242 - 1,284	Large
100 breast (LC)	2,057	1,980 - 2,134	1,439	1,414 - 1,465	1,404	1,382 - 1,426	1,480	1,448 - 1,512	1,373	1,353 - 1,393	1,327	1,310 - 1,345	Large

ANOVA between SC and LC races for men (p<0,05) 1) Free SS35 & SS85; 2) Back SS35, SS45, SS65 & SS85; 3) Fly SS35, SS85 & SS95; 4) Breast SS35, SS45 & SS8

ANOVA between SC and LC for women (p<0,05) 1) Free SS35, SS65 & SS85; 2) Back SS35, SS65 & SS85; 3) Fly SS45 & SS95; 4) Breast SS35, SS45, SS85, SS95

Effect size for all signifcant differences was large as interpreted by Cohen´s d.

When examining the course, the pattern was not as clear. For all events, except the women´s 100 fly (SC vs LC), the effect of course was large at SS35 and SS85. The fact that measure SS15 had no effect on course, strengthens the assumption that these swimmers where trained to use an all-out race strategy regardless of type of course (3, 8, 9, 27).

<u>Change in swimming speed between reference points</u>

In order to clarify the results of changes in swimming speed, the measure of δSS45:65, was excluded since this phase of the race actually adds swimming speed (see Table 2). Both the difference in swimming speed alone and the interaction of course showed statistical significance (p<0,05) for all strokes and gender. Follow-up procedure revealed a pattern, although not exclusive in all cases, as far as δSS15:35>δSS35:45 except for SC backstroke for men (n.s.) and women (δSS15:35<δSS35:45) for the first 50 m segment of the race. This could be related to the in-water start that is used in backstroke might not achieve the addition to swimming speed as the out-of-water start gives the other strokes. Additionally, for SC regardless of stroke and gender δSS65:SS85< δSS85:SS95. For LC all possibilities were present, i.e δSS65:SS85< δSS85:SS95, δSS65:SS85>δSS85:SS95 and δSS65:SS85= δSS85:SS95. The course interaction showed a large effect size when comparing SC and LC for the variables δSS35:SS45 and δSS85:SS95 where SC was greater than LC, with the exception of men´s 100 fly. Based on these evidence, we speculate that LC could invite to a stronger focus on maintain a streamlined body position through the stroke cycles thus reducing the increase in C_D to minimizing the loss in swimming speed during the length of the pool versus SC that is interrupted by turn. The addition of two turns in SC could invite the swimmer to be more focused on creating power off the walls rather than reducing the coefficient of drag while swimming. In addition to this, the "degree of narrowness" of the competition, as interpreted by the variation in mean swimming speed between first and eight place, could impact the psychological state of the swimmer´s within the race, as suggested previously (24).

Table 2: Changes in swimming speed between different segments within race and between races at the 2010 European Championships

Measures	δSS15:35		δSS35:45		δS65:85		δSS85:95		Cohen´s d
Men	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**effect size**
100 free (SC)	-0,035	(-0,038) - (-0,032)	-0,025	(-0,027) - (-0,022)	-0,002	(-0,004) - (-0,001)	-0,026	(-0,028) - (-0,023)	L; L; L
100 free (LC)	-0,044	(-0,047) - (-0,041)	-0,008	(-0,011) - (-0,005)	-0,009	(-0,011) - (-0,008)	-0,011	(-0,014) - (-0,009)	L; M; L
100 back (SC)	-0,024	(-0,040) - (-0,009)	-0,025	(-0,029) - (-0,022)	-0,004	(-0,006) - (-0,002)	-0,024	(-0,025) - (-0,022)	N; L; L
100 back (LC)	-0,029	(-0,045) - (-0,013)	-0,012	(-0,015) - (-0,008)	-0,016	(-0,017) - (-0,012)	-0,011	(-0,013) - (-0,010)	L; L; L
100 fly (SC)	-0,046	(-0,049) - (-0,043)	-0,016	(-0,019) - (-0,013)	-0,002	(-0,004) - (-0,000)	-0,022	(-0,025) - (-0,020)	L; L; L
100 fly (LC)	-0,054	(-0,057) - (-0,051)	-0,003	(-0,007) - (0,000)	-0,008	(-0,009) - (-0,006)	-0,008	(-0,011) - (-0,005)	L; L; N
100 breast (SC)	-0,038	(-0,040) - (-0,035)	-0,023	(-0,025) - (-0,021)	-0,002	(-0,003) - (-0,001)	-0,021	(-0,024) - (-0,013)	L; L; L
100 breast (LC)	-0,044	(-0,047) - (-0,042)	-0,003	(-0,005) - (-0,001)	-0,008	(-0,009) - (-0,007)	-0,007	(-0,010) -(-0,004)	L; L; S

Measures	δSS15:35		δSS35:45		δS65:85		δSS85:95		Cohen´s d
Women	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**mean**	**95% CI**	**effect size**
100 free (SC)	-0,027	(-0,029) - (-0,024)	-0,021	(-0,024) - (-0,018)	-0,001	(-0,002) - (0,000)	-0,020	(-0,022) - (-0,018)	L; L; L
100 free (LC)	-0,036	(-0,039) - (-0,033)	-0,006	(-0,008) - (-0,003)	-0,009	(-0,010) - (- 0,008)	-0,009	(-0,010) - (-0,007)	L; L; N
100 back (SC)	-0,019	(-0,021) - (-0,016)	-0,022	(-0,025) - (-0,020)	-0,001	(-0,002) - (-0,000)	-0,020	(-0,023) - (-0,017)	L; L; L
100 back (LC)	-0,030	(-0,034) - (-0,026)	-0,006	(-0,008) - (-0,005)	-0,011	(-0,012) - (-0,010)	-0,007	(-0,009) - (-0,005)	L; L; L
100 fly (SC)	-0,038	(-0,042) - (-0,024)	-0,018	(-0,020) - (-0,015)	-0,004	(-0,005) - (-0,002)	-0,019	(-0,024) - (-0,015)	L; L; L
100 fly (LC)	-0,040	(-0,046) - (-0,036)	-0,006	(-0,008) - (-0,003)	-0,006	(-0,008) - (-0,004)	-0,009	(-0,014) - (-0,005)	L; N; L
100 breast (SC)	-0,025	(-0,040) - (-0,035)	-0,018	(-0,025) - (-0,021)	-0,001	(-0,003) - (-0,001)	-0,018	(-0,024) - (-0,013)	L; L; L
100 breast (LC)	-0,031	(-0,034) - (-0,027)	-0,004	(-0,006) - (-0,002)	-0,005	(-0,006) - (-0,001)	-0,005	(-0,006) - (-0,003)	L; L; N

ANOVA between SC and LC was significant for men ($p<0,05$); FR & Fly all segments ; BK & BR δSS35:45, δS65:85 & δSS85:95
Effect size for all signifcant differences was large as interpreted by Cohen´s d.

ANOVA between SC and LC was significant for women ($p<0,05$); FR, BK & BR all segments; Fly δSS35:45, δS65:85 & δSS85:95
Effect size for all signifcant differences was large as interpreted by Cohen´s d.

<u>Correlations between swimming speed and placing within a race</u>

Since competing at International Championships is a matter of comparing who is the fastest swimmer in the race, it is of interest to see how well split times and SS at different reference points correlates to the placing at the end of the race. The results show that the ranked order of splits has many significant correlations with placing at the end of the race. Thus saying the faster you swim in the different segments of the race (each 50 meter) the more probable it is that you place higher in the rankings at the end of the race. Split times for the first 50 meters (12 out of 16) had more significant correlations with placing at the end of the race, than split times for the second 50 meters (11 out of 16). This could imply that the speed of the first 50 meter is important in most 100 m races, inviting to an all-out-race strategy (3). However, when examining SS at different reference points, there were more significant correlations between SS at certain reference points and placing for the second 50 meters ($n_c = 25$) versus the first 50 meters ($n_c = 17$). In addition to this the SS15 only showed statistical significance correlation to placing in only 5 out of the 16 races, thus implying managing of fatigue is also of importance.

Table 3: Spearman´s Rho correlations of placing at the end of the race, split times and swimming speed at different reference points

		Split times		Swimming speed					
Events	Course	T 50:1	T 50:2	SS15	SS35	SS45	SS65	SS85	SS95
100 free men	SC	0,934*	0,687*	-0,633*	-0,934*	-0,795*	-0,867*	-0,755*	ns
100 free men	LC	ns	ns	ns	ns	ns	ns	ns	ns
100 free women	SC	0,952*	0,970*	-0,690*	-0,723*	-0,862*	-0,952*	-0,970*	-0,778*
100 free women	LC	ns	0,833*	ns	-0,623*	-0,874*	-0,802*	ns	ns
100 back men	SC	ns	0,690*	ns	ns	ns	-0,683*	-0,762*	ns
100 back men	LC	0,714*	0,958*	ns	ns	ns	-0,719*	ns	ns
100 back women	SC	0,786*	0,929*	ns	-0,738*	ns	-0,795*	-0,929*	ns
100 back women	LC	0,714*	0,690*	-0,643*	ns	-0,881*	-0,905*	-0,667*	ns
100 fly men	SC	0,786*	0.922*	ns	ns	ns	ns	-0,857*	-0,762*
100 fly men	LC	0,714*	ns	ns	ns	-0,833*	ns	ns	ns
100 fly women	SC	ns	0,952*	ns	ns	ns	-0,905*	-0,898*	ns
100 fly women	LC	0,719*	ns	ns	ns	ns	ns	ns	ns
100 breast men	SC	0,810*	ns	ns	-0,707*	-0,854*	-0,833*	ns	ns
100 breast men	LC	0,647*	0,929*	-0,862*	ns	ns	-0,707*	ns	-0,833*
100 breast women	SC	0,929*	0,905*	-0,667*	-0,643*	ns	-0,738*	-0,659*	-0,647*
100 breast women	LC	0,789*	ns	ns	ns	ns	-0,766*	ns	-0,766*

ns = non-statistical significance
* denotes correlations significant at 0,05 level (one-tailed)

The variable of SS65 had the most statistical significant correlations (12 out of 16). The exceptions being 100 free men LC, 100 fly men SC & LC and 100 fly women LC. The narrowness of the competition could influence the number of occurrences of statistical significant correlations between different variables (i.e. split times and SS) and placing, thus the higher “the degree of narrowness” the fewer statistical significant correlations between placing and the different variables. One can assume that the events with no statistical significant correlations at SS65, would have a higher “degree of narrowness” in the competition. The men´s 100 free LC and 100 fly LC, were the two events with the highest “degree of narrowness, 98,88 and 98,24% of the average SS for eight place as compared to first place in the race. If SS65, was a good measure to indicate the placing at the end of the race, the statistical correlations for the subsequent reference points would either become statistically significant or the correlations would become stronger as the race progressed. But the number of statistical correlations decrease from SS65 to SS85 (8 out of 16) to SS95 (5 out of 16) and neither the men´s 100 free nor 100 fly showed a statistical significant correlation between placing at the end of the race and either SS85 or SS95. Thus indicating that swimmers that were in front are swimming slower than swimmers that were behind, but not slow enough to be overtaken. The individual swimmers ability to manage fatigue at the end of the race seems to play an important role, as previously suggested (8, 9, 25), and in relation to our hypothesis, maintaining the highest swimming speed through a minimal increase in C_D should be a strong focus for swimmers (26).

Conclusion

Normally swimming performance is based on the evaluation of time. The "degree of narrowness" in a Championship final is high, the current sample exhibited a mean of 96,49% (± 1,33%). The absolute difference in mean swimming speed varied between 0,023m/s (men´s 100 free, LC) to 0,125 m/s (men´s 100 back, SC). The total variation in swimming speed within a race between specific reference points (SS15 versus SS95) varied between 1,315 m/s (men´s 100 fly SC) to 0,687 m/s (women´s 100 back SC). The absolute difference in swim time between 1st and 8th place in all races varied between 0,97 s and 2,87 s (LC) and between 1,53 s and 4,05 s (SC). Depending upon how the difference in swimming speed is portrayed, the differences can be interpreted as larger or smaller.

We have showed that the change in mean swimming speed that occurs within a race is large and it occurs continuously throughout the race, regardless of stroke, gender and course. We have also showed that the change in swimming speed occurs differently between specific segments of the race, regardless of stroke, gender and course. We hypothesize that these different decreases in SS are caused by a reciprocal increase in C_D over the competitive distance. The variations in these constructed variables seem to take into account highly individualized component of technique, management of physiological and psychological assets (1, 8, 19, 22, 23, 24, 25, 26, 27, 28).

Previous research (8, 13) concludes that non-significant differences can have impact on placing in the race. We suggest that there are several segments where potential in improvements in swimming speed can be unfolded throughout the race, focusing on how an athlete manages transfer swimming speed stroke cycle to stroke cycle throughout the race. Training processes could be designed with a focus on the individual athlete´s ability to explore her/his own intrinsic dynamics of stroke mechanics, utilizing both environmental (23) and task (17) manipulations. The focus of transfer of speed from stroke cycle to cycle should be prioritized, rather than maintaining maximum speed throughout the race. An improvement in transfers of speed from cycle to cycle throughout the race could lead to improvements in performance surpassing the different in time between placing 1st and 8th.

References

1. Arelano, R., Brown, P., Cappaert, J. & Nelson, R. C. (1994) An analysis of 50-, 100-, and 200-m freestyle swimmers at the 1992 Olympic Games. *Journal of Applied Biomechanics*, 10:189-199.
2. Barbosa, T. M., Fernandes, R. J., Keskinen, K. L. & Vilas Boas, J. P. (2008) The influence of stroke meachanics into energy cost of elite swimmers. *European Journal of Applied Physiology*, 103:139-149.
3. Bishop, D., Bonetti, D. & Dawson, B. (2002) The influence of pacing strategy on VO_2 and supramaximal kayak performance. *Medicine and Science in Sports and Exercise,* 34(6): 1041-1047.

4. Bompa, T. O. & Haff, G. G. (2009) Preparation of training. In *Periodization – theory and methodology of training* (pp 57-78), Champaign, IL: Human Kinetics.
5. Chollet, D., Pelayo, P., Delaplace, C. & Tourny, C (1997) Stroking characteristics variations in the 100 m freestyle for male swimmers of differing skill. *Perceptual and motor skills*, 85: 167-177.
6. Craig, A. B. & Pendergast, D. R. (1979) Relationships of stroke rate, distance per stroke and velocity in competitive swimming. *Medicine and Science in Sports,* 11: 278-283.
7. Craig, A.B., Skehan, P. L, Pawelczyk, J. A. & Boomer, W. L. (1985) Velocity, stroke rate and distance per stroke during elite swimming competition. *Medicine and Science in Sports and Exercise,* 17: 625-634*.*
8. Foster, C., Schrager, M., Snyder, A. C. & Thompson, N.N. (1994) Pacing strategy and athletic performance. *Sports Medicine*, 17(2):77-85.
9. Foster, C., de Koning, J. J., Hettinga, F., Lampen, J., La Clair, K. L., Dodge, C., Bobbert, M. & Porcari, J. P. (2003) Pattern of energy exenditure during simulated competition. *Medicine and Science in Sports and Exercise*, 35(5): 826-831.
10. Fritzdorf, S. G., Hibbs, A. & Kleshnev, V. (2009) Analysis of speed, stroke rate and stroke distance for world-class breaststroke swimming. *Journal of Sports Sciences*, 27(4): 373-378.
11. Grimston, S. K. & Hay, J. G. (1986) Relationships among anthropometric and stroking characteristics of college swimmers. *Medicine and Science in Sports and Exercise*, 18(1): 60-68.
12. Haljand, R. (2012). Technical and tactical parameters of competitive performances. Rein Haljand [online]. Available from URL:http://www.swim.ee [Accessed 2012 Mar 20]
13. Hopkins, W. G & Hewson, D. J. (2001) Variability of competitive performance of distance runners. *Medicine and Sports in Science and Exercise*, 33(9): 1588-1592.
14. Issurin, V. B. (2010) New Horizons for the methodology and physiology of training periodization. *Sports Medicine,* 40:189-206*.*
15. Kennedy, P., Brown, P., Chengular, S. & Nelson, R. (1990) An analysis of male and female olympic swimmers in the 100 m events. *International Journal of Sports Biomechanics*, 6:187-197.
16. Keskinen, K.L., Tilli, L. J. & Komi, P. V. (1989) Maximum velocity swimming: Interrelationships of stroking characteristics, force production and anthropometric variables. *Scandinavian Journal of Sports Sciences,* 11, 87-92.
17. Kolmogorov, S. V. & Duplischeva, O. A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics*, 25, 311-318.
18. Ligue Européene de Natation (2012). Results*,* swimming [online]. Available from URL: http://www.len.eu/cms?results+swimming [Accessed 2012 Mar 22]
19. Nomura, T. & Shimoyana, Y. (2003). The relationship between stroke parameters and physiological responses at various swimming speeds. In: Chatard (ed) *Biomechanics and medicine in swimming IX*. Publications de l´Úniversté de Saint-Ètienne, Saint-Ètienne, pp 355-360.
20. Olbrecht, J (2000) *The science of winning – planning, periodizing and optimizing swim training*, Luton, England, Swimshop.

21. Seifert, L., Chollet, D. & Chatard, J. C. (2007) Kinematic changes during a 100-m front crawl: effect of performance level and gender. *Medicine and Science in Sports and Exercise*, 39: 1784-1793.
22. Shimadzu, H., Shibata, R. & Ohgi, Y. (2008) Modeling swimmers´ speeds over the course of a race. *Journal of Biomechanics*, 41; 549.555.
23. Smith, D. J., Norris, S. R. & Hogg, J. M. (2002) Performance evaluation of swimmers – scientific tools. *Sports Medicine*, 32(9): 539-554.
24. Stewart, A. M & Hopkins, W.G. (1999) Consistency of swimming performance within and between competitions. *Medicine and Science in Sports and Exercise*, 32(5): 997-1001.
25. Thompson, K. G., Haljand, R. & MacLaren, D. P. (2000) An analysis of selected kinematic variables in national and elite male and female 100-m and 200-m breaststroke swimmers. *Journal of Sports Sciences,* 18:421-431.
26. Toussaint, H., M. & Beek, P.J. (1992) Biomechanics of competitive front crawl swimming. *Sports Medicine*, 13(1): 8-24.
27. Van Ingen Schenau, G. J., de Koning, J. J. & de Groot, G. (1992) The distribution of anaerobic energy in 1000 and 4000 meter cycling bouts. *International Journal of Sports Medicine*, 13: 447-451.
28. Wakayoshi, K., Nomura, T., Takahashi, G., Mutoh, Y. & Miyashito, M. (1992) Analysis of swimming races in the 1989 Pan Pacific swimming Champioships and 1988 Japanese Olympic Trials. In T. Reilly, D. MacLaren & A. Lees (Eds.), *Biomechanics and medicine in swimming: Swimming science VI* (pp135-141). London: E&FN Spon.
29. Zamparo, P., Antonoutto, G., Capelli, C., Francescato, M, Girardis, M., Sangoi, R., Soule, R & Pendergast, D. (1996) Effects of body density, gender and growth on underwater torque. *Scandinavian Journal of Medicine in Science and Sports*, 6: 273-280.
30. Yanai, T. (2001) Rotational effect of buoyancy in front crawl: does it really cause the legs to sink? *Journal of Biomechanics*, 34:235-243.