International Journal of
Sports Science
& Coaching

Original research article

Longitudinal analysis of the 800-m performances of the world's best female long-distance pool swimmer: A case study using critical speed and D'

International Journal of Sports Science
& Coaching
1–6

DOI: 10.1177/17479541221104721
journals.sagepub.com/home/spo
SAGE

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Abstract

The purposes of this study were to ascertain how physiological adaptations, as reflected by critical speed and distance above critical speed (D'), impact the competitive performance of a world-class female long-distance swimmer; and to determine whether a model including the expenditure and recovery of D' could be used to understand pacing in swimming. From August 2011 to August 2021, we retrieved 800-m performance and splits data from races in which she improved her time, and also the 400-m and 200-m freestyle performances from the same competitions. Performances from the 200, 400, and 800 m were used to estimate critical speed and D'. The 800-m splits were used to calculate the usage of D' during the race and to investigate pacing. The differential W' balance model (W'_{BAL}) was used to calculate its analogous in swimming, the D'_{BAL}. Critical speed increased from 1.516 to 1.616 ms^{-1} while D' fluctuated ∼15 m from 2011 to 2016. D'_{BAL} approached 0 m at the end of the races and may be useful to understand pacing. Critical speed and 800-m speed presented a nearly perfect correlation (0.99, $p < 0.001$) suggesting that critical speed is of paramount importance for long-distance swimming performance. While critical speed is clearly important, D' did not directly correlate with 800-m performance. This result suggests that the work capacity above critical speed is not a primary determinant of 800-m swimming performance. However, we cannot say it is unimportant, as minor improvements represent an opportunity to set world records. Outstanding long-distance performance seems to depend more on aerobic fitness than on the capacity to work above critical speed.

Keywords

Aerobic fitness, aquatic sport, efficiency, endurance

Bullet points

- Performance enhancement in 800-m freestyle paralleled improvements in critical speed (CS).
- D' is not a strong determinant factor in her 800-m freestyle performance.
- The differential W'_{BAL} model can be used to analyze the pacing patterns.

Introduction

The women's 800 m freestyle event lasts slightly longer than 8 min for elite swimmers. For instance, swimmers in the final of the 2019 World Championships completed the distance in 8 min 13 s–8 min 25 s. The energy requirements for exceptional performance in this race are still unknown, but considering that the aerobic contribution during the 400 m freestyle approaches 90% of total energy cost, it is thought that more than 90% of the energy is provided by the aerobic metabolism during the 800 m freestyle.[1]

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A theoretical model that includes mechanical efficiency, aerobic and anaerobic fitness has been proposed to explain endurance performance.[2–4] Mechanical efficiency is associated with the speed achieved at a given oxygen consumption (VO_2). The higher the efficiency, the higher the speed for the same VO_2. Aerobic fitness refers to physiological parameters such as lactate threshold and maximal oxygen consumption (VO_{2max}), while anaerobic fitness is thought to relate primarily to phosphagen stores, the total buffering capacity, and the ability to endure homeostatic disturbances. The combined effects of these factors predict endurance performance. However, assessing these parameters is time consuming and requires sophisticated equipment and specialized personnel, which can make these assessments unfeasible in the real world.

The two-parameter critical power (CP) model offers an alternative indirect method for assessing both the performance and physiology of an exercising athlete[5] (equation (1)). Importantly, it can be calculated from performance data, rather than through direct physiological measurement.

$$P = \frac{W'}{t} + CP \qquad (1)$$

where P is the power in watts, and t is the duration in seconds for which a particular power is sustained.[6] The W' represents the finite work capacity that the athlete has available when exercising at intensities in excess of the CP. The construct is useful for modeling the power–duration relationship for maximal exercise within the severe domain[5,7,8] and is in wide use by coaches and athletes.[9,10] It is possible to adapt the model to swimming exercise by replacing CP with critical speed (CS), and W' with the total distance that could be completed above CS (D').[5,11–16] The estimation of CS and D' is a viable way to assess the physiology of elite and non-elite athletes,[9,17] which can provide insights on what physiological adaptations are necessary to improve performance.

While the CP/CS model permits the static understanding of the CS and D', the W' balance model (W'_{BAL}) offers a means of accounting for the discharge and reconstitution of the W' or D', both in the laboratory and in the field.[18–22] In effect, the D' is treated as a capacitor or battery, which is drained when the athlete exercises above CS, and recovers when the athlete reduces speed below CS. Complete depletion of the D' is typically associated with the need to reduce speed below CS and task failure. In other words, if the athlete swims above their CS, D' is reduced, and if swimmer speed drops below CS, D' may be recovered, but often at the expense of competitive placement. The model has been used to interrogate the performance and pacing strategies of competitive athletes in training and racing[20]; however, there are no published data on its use in swimmers so far.

Although there are several investigations regarding the effect of training on endurance performance, most of these data are from regional- to national-competitive-level participants.[23–25] Hence, they do not provide evidence on what physiological adaptations are necessary to achieve and improve in performers of international standards. As exceptional athletes present an opportunity to understand the determining factors of outlier performances, we selected the world's best long-distance pool female swimmer in the 800 m freestyle, retrieved data when she improved her performance in this event, and also the data for the 400 m and 200 m freestyle at the same competition (e.g. comparable level of conditioning) to allow the calculation of CS and D' as indicators of physiological adaptations, correlated these variables with performance and investigated her pacing using W'_{BAL} model. Thus, the primary purpose of this case study was to ascertain how physiological adaptations, as reflected by CS and D', would impact the competitive performance of a world-class female long-distance pool swimmer during her competitive career. Even though the evidence is available relating physiological capacity to performance,[26] limited data exist on the long-term training-induced adaptations in elite athletes. This case study may provide a benchmark that lower-level athletes have to pursue in order to achieve world-class level. A secondary purpose was to determine whether the W'_{BAL} model could be used to analyze pacing strategy in swimming.

Methods

Sample

This is a case study of the world's number one ranked female distance swimmer. She currently holds the world record (WR) in the 400 m, 800 m, and 1500 m freestyle events; has broken the 800-m WR five times and has the 20 fastest 800-m performances of all time (up to August 2021). Utilizing www.swimrankings.net, we retrieved her competitive performances between 2011 and August 2021, selecting only data from races in which she improved her 800 m performance. We also retrieved the splits for the 800 m, and 400 m and 200 m freestyle performances from the same competition.

Performances from the 200 m, 400 m, and 800 m were used to estimate CS and D' using the linearized distance-time formulation of the two-parameter CS model.[3] Split times for each 50 m were converted into speed and normalized by the CS for that meet.

D'_{BAL}, the equivalent of W'_{BAL} in swimming, was calculated according to Skiba et al.[27] (equation (2))

$$D'_{BAL} = D'_0 - D'_{exp}\, e^{-D_{CS}t/D'_0} \qquad (2)$$

where D'_0 represents the initial D' calculated from the two-parameter CS model, D'_{exp} is the expended D', and D_{CS} is the difference between CS and speed below CS. D'_{BAL} was calculated for each 50 m split during the 800 m race.

Statistical analysis

Data for CS and D' are presented as absolute values. Normality was tested using the Shapiro-Wilk test. Pearson correlation coefficients were calculated between CS, D', and 800 m performances. The correlations were interpreted as (when significant): <0.30: small, 0.31–0.49: moderate, 0.50–0.69: large, 0.70–0.89: very large, and 0.90–1.00: nearly perfect. The statistical significance level was accepted at $p \leq 0.05$.

Results

A total of 10 competitions were selected, yielding 28 performances: 9 for the 200 m, 9 for the 400 m, and 10 for the 800 m. Results for the 200-m, 400-m, and 800-m performances, and CS and D' are presented in Table 1. This athlete improved 800-m performance from 2011 to 2016, but not after 2016, and improved the WR in five out of these 10 races.

CS improved along with her career but D' fluctuated around a mean value of 15-m with no directional changes. The pacing pattern (speed distribution normalized by the critical speed) during each event is shown in Figure 1(a) and (b). She showed a U-shaped pacing pattern, which was consistent in all races. D'_{BAL} is shown in Figure 1(c) and (d). Scatter plots with correlation coefficients are shown in Figure 2.

Discussion

This case study investigated what physiological adaptations, accounted by CS and D', were necessary for a world-class female long-distance pool swimmer to improve her 800-m performance throughout her competitive career. Our results indicate that: (a) the CS increased over time; presented a nearly perfect correlation with the 800-m speed; and (b) D′ did not correlate with the 800-m speed. In addition, we observed that D'_{BAL} can be used to analyze the pacing pattern in 800-m swimming, given the D'_{BAL} is close to 0 only at the end of the race.

It has been shown that training improves CS in swimming after 11, 12, and 14 weeks in adolescent swimmers,[28–30] and during the early season in elite swimmers.[31] Although the studies reported positive changes in CS with training, the relationship between CS and performance was only reported by Mitchell et al.[31] However, the events investigated were restricted to 100 m and 200 m and observed that CS could not be used to assess changes in performance during a training season. On the other hand, we observed that 800-m performance improvement closely paralleled changes in CS. For example, in 2011 her CS corresponded to 1.516 ms^{-1} or 66 s every 100 m and improved to 1.616 ms^{-1} or ∼62 s every 100 m in August 2016. This information may be relevant to coaches and athletes worldwide. Critical speed is conceptualized as a variable that represents the speed at which maximal sustainable oxidative metabolic rate is achieved,[32] and separates exercise intensities in the heavy and severe domains. It encompasses both aerobic fitness (e.g. VO_{2max} and the "anaerobic" threshold) and mechanical efficiency (e.g. swimming economy). From our results, it is not possible to identify if her improvements were a consequence of improved aerobic fitness or higher mechanical efficiency. However, the finding that 800-m speed presents a nearly perfect correlation with CS indicates that the latter is of paramount importance for long-distance swimming performance and supports the concept that the 800-m is largely dependent on aerobic energy supply.

While the importance of CS is clear and reveals the ability to swim at higher speeds in a sustainable oxidative metabolic state, D' does not directly correlate with 800-m performance. This suggests that the work capacity above CS is not a *primary* determinant of this event's performance. However, D' may have practical relevance, as it represents the difference between the CS and the ultimate performance speed. Minor differences in D' would have performance implications, especially when marginal improvements are sought.

Table 1. Results for the 200 m, 400 m, and 800 m, and CS and D'.

	200 m (s)	400 m (s)	800 m (s)	CS (ms^{-1})	D' (m)
Aug 2011	120.79 (2′00″79)	250.39 (4′10″39)	516.05 (8′36″05)	1.516	18.3
Feb 2012	120.01 (2′00″01)	249.30 (4′09″30)	510.14 (8′30″14)	1.537	16.0
May 2012	119.05 (1′59″05)	245.79 (4′05″79)	505.85 (8′25″85)	1.549	17.0
Jul 2012	118.66 (1′58″66)	245.00 (4′05″00)	499.78 (8′19″78)	1.574	13.7
Aug 2012[1]	–	–	494.63 (8′14″63)	–	–
Aug 2013	116.32 (1′56″32)	239.82 (3′59″82)	**493.86 (8′13″86)**	1.587	17.0
Jun 2014	116.45 (1′56″45)	243.09 (4′03″09)	**491.00 (8′11″00)**	1.604	12.0
Aug 2015	115.16 (1′55″16)	239.13 (3′59″13)	**487.39 (8′07″39)**	1.612	14.5
Jan 2016	114.43 (1′54″43)	239.54 (3′58″54)	**486.68 (8′06″68)**	1.613	14.7
Aug 2016	113.73 (1′53″73)	**236.46 (3′56″46)**	**484.79 (8′04″79)**	1.616	16.9

[1]Improved performance, but she did not swim the 200 m nor 400 m. World Records are in bold.

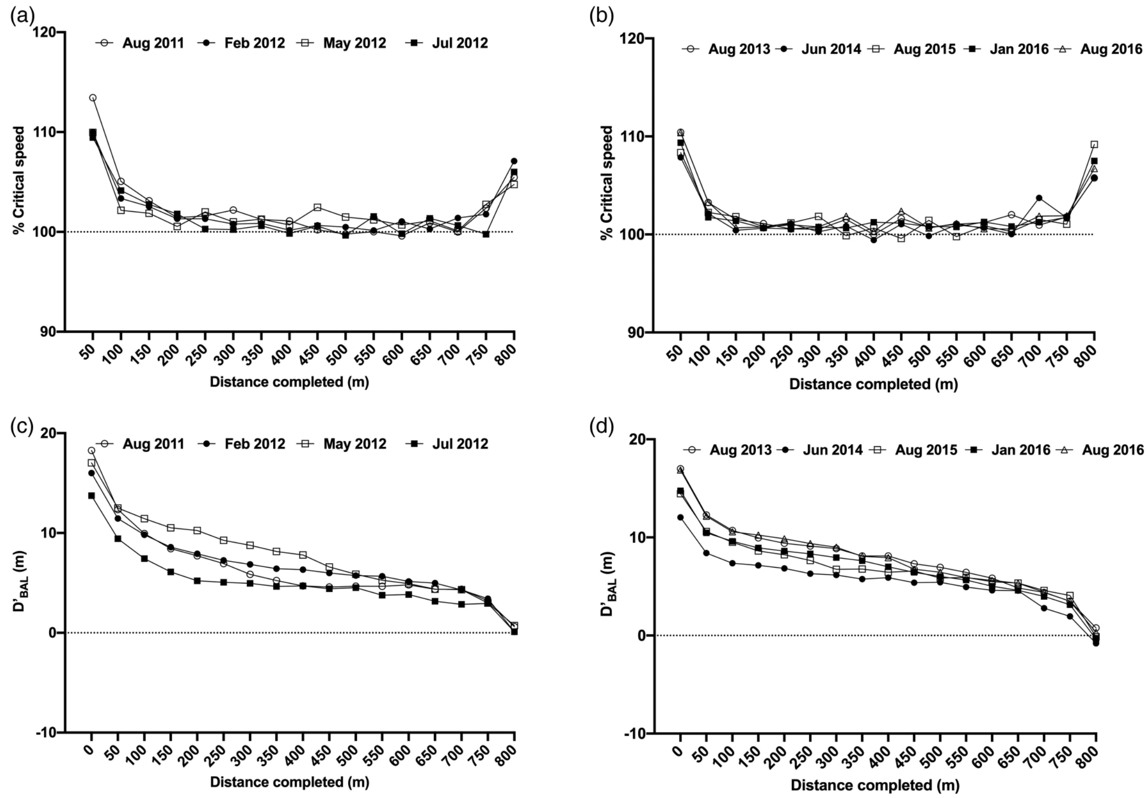

Figure 1. Panel (a)—speed distribution normalized by critical speed during the 800 m event when she did not set World Records. Panel (b)—speed distribution normalized by critical speed during the 800 m event when she set World Records. Panel (c)—D'_{BAL} (m) during the 800 m event when she did not set World Records. Panel (d)—D'_{BAL} (m) during the 800 m event when set World Records.

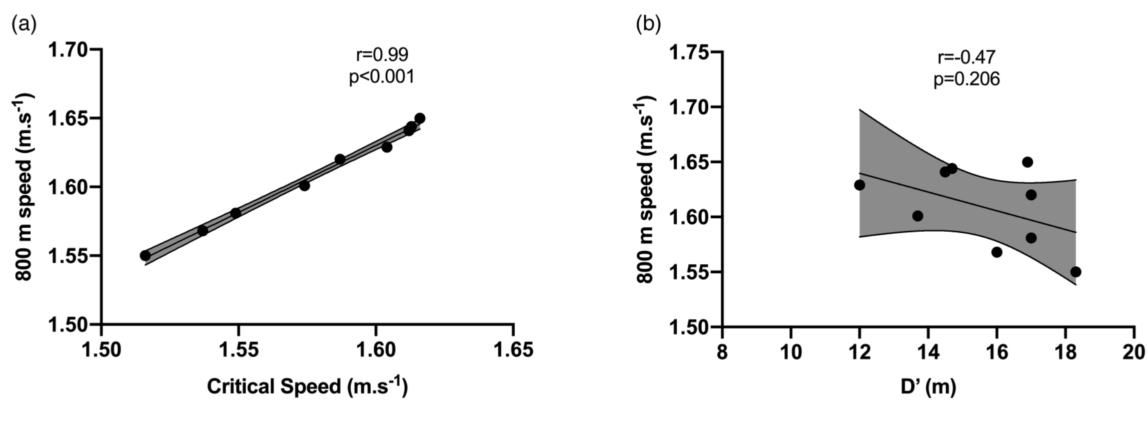

Figure 2. Scatter plots and Pearson correlation coefficients between 800 m speed (ms^{-1}): Panel (a)—critical speed (ms^{-1}) and Panel (b)—D' (m). Shaded areas represent a 95% confidence interval.

There is evidence from training studies of a reciprocal relationship between increases in the CP and decreases in the W'.[19,33–35] It is also known that very high-intensity interval training may increase the amount of work performed above CS.[36] Considering that a 5% increase in D' would result in ~0.7 s improvement in her best time, while a 1% higher CS would result in a ~5 s faster performance, swimming coaches should balance training loads to mostly improve CS while maintaining adequate levels of D'. Unfortunately, details of the temporal pattern of volume, speed, and training intensity distribution of this swimmer are not available. Future studies should examine the relationships between particular training strategies in elite athletes versus changes in CS and D', and performance.

Analysis of D'_{BAL} during her 800 m performances reveals that speed is controlled throughout the distance to avoid depleting D' prematurely, and can be used to determine the pacing strategy. In the parabolic pacing pattern, speed is higher during the initial part of the race, then remains relatively stable and increases in the latter portion of the event. This swimmer uses approximately half of D' during the first 200 m, 25% from 200 to 700 m, and the remaining 25% during the last 100 m. This is consistent with a parabolic pacing pattern, as there is greater usage of D' during the initial part of the race, when speed is higher, then D′ usage decreases when speed flattens and D' is depleted approaching the end of the race. These findings provide an application of D'_{BAL} to coaches who wish to improve the pacing pattern of their athletes. If coaches know the initial D', they can instruct their athletes how much above the CS athletes can swim in the opening stages in order to avoid premature fatigue.

It is interesting to notice that her pacing pattern did not change throughout the years. Foster et al.[37] showed that participants with little experience increased power output during the early and middle parts of a time trial over consecutive trials. We do not have data previous to 2011 to investigate whether her pacing pattern changed before she achieved world-class performances. Thus, we can only speculate that changes in pacing pattern were evident before she achieved world-class performance, but after that remained consistent and changes in performance were a consequence of positive physiological and/or mechanical adaptations. Although we do not know if this pacing pattern is the best to optimize performance, parabolic pacing patterns are typically used in long-distance events (>800 m).[38] Nevertheless, elite athletes used different pacing patterns in a middle distance event (400 m), which highlights that the choice for a particular speed profile depends on the distance of the event and physiological characteristics of the swimmers.[39]

Based on our results, her outstanding 800-m performance seems to depend on both aerobic fitness (as assessed by the CS) and mechanical efficiency. The D'_{BAL} model appears to be a promising analytic tool for the study of the pacing strategy.

Practical applications

The results from this study present reference data for CS of the world's best female long-distance swimmer. Considering that CS combines physiological adaptations and swimming economy, swimming endurance training should emphasize improvements in both aerobic fitness and technique, rather than anaerobic fitness. Also, D'_{BAL} can be used by coaches as a way to understand speed distribution and possibly develop a better pacing pattern by instructing their athletes to deplete D'/W' only when reaching the end of the race.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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