Title: Analysis of end-spurt behaviour in elite 800-m and 1500-m freestyle swimming

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Abstract

Purpose: To analyse the influence of distance, time point of competition, round and finishing position on end-spurt behaviour in swimming. ***Methods:*** Race results in 800-m and 1500-m freestyle swimming from the last eight World Championships and five Olympic Games (1998-2016) including 1433 races and 528 swimmers were obtained. The end-spurt for each race was determined by means of an End-Spurt Indicator (ESI). The ESI was calculated by dividing the difference between the swim velocity of the last lap (SVLL) and the mean swim velocity of the middle part of the race (SVMP) by the respective individual standard deviation of SVMP. Subsequently, ESI was used as a dependent variable and influences were analysed using a linear mixed model with fixed effects for distance, time point of competition, round and finishing position. ***Results:*** An end-spurt was evident in most swims for both race distances. The mean change in swim velocity between the middle part of the race and the last lap was 0.06 ± 0.02 m/s (1.2 ± 0.2 s) in the 800-m and 0.07 ± 0.02 m/s (1.5 ± 0.2 s) in the 1500-m. The finishing position within a race significantly affected the ESI (P<.001, t = 7.28). Specifically, when analysing finals only, ESI was significantly greater in medallists (5.76; quantile: 3.61 and 8.06) compared to non-medallists (4.06; quantile: 1.83 and 6.82; P=.001). The between-subject standard deviation was 1.66 (Cl: 1.42 to 1.97) with a relative variance component of 23%, while 77% of ESI variance remained unexplained. ***Conclusion:*** This is the first study using a newly developed indicator of end-spurt behaviour demonstrating that particularly medallists have a more pronounced end-spurt compared to non-medallists.

Keywords: pacing strategy, swim velocity, water, elite swimmers, tactics

Introduction

In order to reach an endurance event´s endpoint in the fastest time possible, athletes should appropriately distribute their energy expenditure in a way that all available energetic resources are used but not too early so as to avoid premature fatigue and a loss of speed.[1] In competitions when the aim is to cover a given race distance in the fastest time possible, this regulation of speed, power or energy expenditure is extremely important for the optimisation of performance.[2] Based on current research, pacing appears to be regulated by complex interactions between the brain and other physiological systems.[3] Despite biomechanical and physiological influences on pacing, competitors might further affect an athlete´s pacing by changes in their race tactics, and their presence means that the ultimate goal is to beat them rather than post the fastest time.[4-7]

Pacing in long-distance swimming in pool competitions is considered an important determinant of success, especially in the case of very similar individual capacities between swimmers.[6,8-13] Indeed, due to the high resistive properties of the water and the low mechanical efficiency, pacing is likely to be more critical in swimming compared to other endurance-based sports.[14] It is suggested that even small changes in swim velocity can result in a substantial increase in energy expenditure and thus premature fatigue.[12] A swimmer´s distribution of speed throughout the race might be especially important in order to use available energetic resources efficiently.[12,15] In long distance freestyle pool events of 800-m and above, a parabolic shaped pacing pattern is usually used,[3] including a fast start, an even middle part and an increase in speed in the last stages of the race, which is suggested to be consistent throughout different competitions and between heat and final races.[16] Such an increase in speed or power at the end of the race is generally called end- or final spurt. It has been typically described in head-to-head competitions, where success is determined by performing marginally better than other competitors in order to achieve a better finishing position. In such events, athletes seem to retain a reserve of energy required for an end-spurt to possibly outsprint an opponent in the last few meters.[17]

The vast majority of the pacing literature considers an end-spurt to be a statistically significant mean difference between the last and the penultimate split. However, an evaluation of group means is of little value with respect to the individual athlete. Moreover, when analysing the end-spurt behaviour within one athlete it seems beneficial to consider the intra-individual variability during the middle part of the individual race. The relevant considerations are consistent with research on individual responses to exercise training.[18] Specifically, a deviation in mean velocity may be interpreted in the context of random variability, which in this case would mean that an athlete has performed an end-spurt if the last lap is performed faster than the middle part of the race by more than the intra-individual variability.[19,20] Consequently, we propose the difference between the last lap and the middle part of the race divided by the respective standard deviation as an end-spurt indicator (ESI). Thus, the ESI used in this work is directly based on the above rationale.

Therefore, the aim of the current study was to analyse the end-spurt behaviour in long-distance pool swimming events in relation to distance, time point of competition, round and finishing position using this newly ESI. It was hypothesised that the ESI magnitude is related to the swimmers´ finishing position, distance, but not time point of competition or round.

Methods

Subjects

All procedures were in accordance with the declaration of Helsinki. It was not considered necessary to obtain informed consent from swimmers because only publicly accessible information was used and all data were anonymized during the entire analysis. Races from all swimmers participating in the World Championships and Olympic Games between 1998 and 2016 were analysed. One hundred and twenty-nine races were excluded since finishing position for heats or finals were not accessible. Therefore, a total of 1433 races from 528 different elite swimmers (1115 heats; 318 finals) over 800-m (men: n = 283; age: 21.6 ± 3.1 years, women: n = 448; age: 21.0 ± 3.7 years) and 1500-m (men: n = 497; age 21.9 ± 3.2, women: n = 205; age: 21.1 ± 4.0 years) freestyle were retrospectively analysed. Semi-finals do not exist for these race distances in swimming, thus heats and finals only were analysed. Several swimmers competed in more than one competition (n =220) and/or distance (n=199; table 1) resulting in an unequal number of races per swimmer.

Events

Overall, the current analysis examined eight World Championships and five Olympic Games between 1998 and 2016. Race data were obtained using the web site www.swimrankings.net (Splash Software Ltd., Switzerland; 20.12.2017), which is based on information from the European Swimming Federation (LEN) database and the results from the Belgian, Canadian, Dutch, Polish, Portuguese and Swiss federations. Each race report included a subject identification number for each swimmer, the name of the competition, distance, round (heat vs. final), overall finishing position, 50-m split times (s) and the total completion time (s). All events were swum in a long-course (50-m) pool. Total and all 50-m split times were downloaded from the official site www.swimrankings.net. In all events automatic officiating equipment was used under the supervision of appointed officials and recorded to 0.01 s to determine total times, as well as 50-m split times (according to FINA swimming rules).

End-spurt indicator

To evaluate the end-spurt an "End-Spurt Indicator" (ESI; arbitrary units) was designed by the authors. This ESI was based on the mean swim velocity (m/s) and the respective standard deviation (SD*)* of each individual swimmer. Due to the rapid acceleration caused by the diving start, swimmers typically complete the first 50-m faster than any other section of the race.[16,21] Thus, the first 50-m split was not included when calculating mean swim velocity. The last lap was also excluded as it was used as the reference split for the ESI calculation. The first and final lap is reported to be an important parameter to characterize pacing in swimming,[12] whereas medallists swim a relatively faster last lap than non-medallists.[22] Therefore, the velocity of the middle part (SVMP) of the race was calculated using the individual mean (± SD) speed in the laps 2 to 15 and 2 to 29 in the 800-m and 1500-m race, respectively. To define an individual ESI per race and subject, the difference between the swim velocity in the last lap (SVLL) and the corresponding SVMP was divided by the respective individual SD of SVMP.

1)

$$\text{ESI} = \frac{SVLL - \ meanSVMP}{meanSVMP\ SD}$$

For example, if the final lap was swam in 2.0 m/s and lap 2-15 had a mean swim velocity of 1.5 m/s with a mean SD of 0.5 m/s in the 800-m, an ESI of 1.0 would have been calculated. The approach to define ESI as the difference between the last lap and mean swim velocity divided by the individual standard deviation is similar to methods used when analysing individual response, e. g. in medicine.[19] The standard deviation provides an estimate of gross variability in the mean SVMP. Similarly to the classification of responders and non-responders, the definition of ESI can be based on different rationales.[23] In the current manuscript the following fixed threshold value was used: ESI was defined when the value was > 0.

Statistical analysis

Statistical analyses were conducted using Statistica 8 (StatSoft, Hamburg, Germany) and the R statistical programming language (R Core Development Team, 2016). Overall performance data were normally distributed (Kolmogorow-Smirnow-Test), thus, data is presented as means and standard deviation (SD). Because ESI within individual subjects was not normally distributed descriptive data are presented as medians with 25^{th} and 75^{th} percentiles.

Changes in ESI were analysed using a linear mixed model with fixed effects for distance (two levels: 800-m and 1500-m), time point of competition (thirteen levels: year of competition), round (two levels: heat and final) and finishing position (fifty-one levels: overall finishing position) and a random effect for a swimmer´s identity. The fifty-one levels for overall finishing position refer to the maximum number of participants in heats. A separated linear mixed model was performed including only final races, with the additional fixed effect of medal (two level: medallist and non-medallist). An α-error of $p < 0.05$ was accepted as level of significance.

Results

Overall Results

Total times in 800-m and 1500-m in both heat and finale races for men and women are shown in Table 2. Total time in finals was significantly faster in both distances compared to heats (P<.001). In the 800-m, finals were on average 15.53 s faster than heats (P<.001); in the 1500-m performance improved by 24.87 s from heat to final (P<.001). With regard to pacing pattern, swimmers adopted a parabolic shaped pattern in both distances, racing the first split significantly faster than all others (P<.001) and showing a higher split velocity in the last 50-m compared to all others (P<.001).

End-spurt

Mean swim velocity of SVMP was 1.57 ± 0.08 m/s during the 800-m races and 1.60 ± 0.08 during the 1500-m, respectively. The mean change in swim velocity between the middle part of the race and the last lap was 0.06 ± 0.02 m/s; 3.68% (1.18 ± 0.19s) in the 800-m and 0.07 ± 0.02 m/s; 4.20% (1.52 ± 0.23s) in the 1500-m distance. This was reflected by a mean ESI of 4.24 (Cl: 3.73 to 4.00) in the 800-m and 4.58 (Cl: 4.30 to 4.86) in the 1500-m race. A total of 83 swimmers showed a negative ESI of -1.87 ± 0.75 on average, which numerically would indicate the absence of an end-spurt (interquartile range 4.70). Figure 1 shows the median ESI of each individual swimmer as well as their minimum and maximum for the 800-m (A) and 1500-m (B) distance with at least two races. There was no effect (P>.05) on EI-S for sex, therefore male and female swimmers were analysed together.

No significant effect on ESI was observed for either distance (P=.64, t=-10.0), time point of competition (P>.08) and round (P=.42, t=-.79). Between-subject standard deviation was 1.66 (Cl: 1.42 to 1.97; relative variance component subject ID = 23.2%), while 76.8% of ESI variance remained unexplained. Overall finishing position significantly influenced ESI with better ranked swimmers showing a greater ESI (P<.001, t=7.28; figure 2). Swimmers with a better finishing position in heats or finals showed an ESI of 2.79 (finishing 9th to 50th), whereas in swimmers finishing 1st to 8th ESI was 5.20. When analysing final events only, ESI was significantly higher in medallists (5.99; Cl: 5.32 to 6.66) compared to non-medallists (4.52; Cl: 4.01 to 5.02; $P = .001$).

Discussion

This study was designed to analyse end-spurt behaviour in elite 800-m and 1500-m freestyle swimming. An end-spurt indicator has been applied and evaluated to investigate the influence of potential determinants such as distance, time point of competition, round and finishing position. Firstly, ESI among medallists is greater compared to non-medallists which illustrates its construct validity. Secondly, the retrospective analysis of elite competitions during the last 18 years revealed that swimmers seem to consistently execute an end-spurt of a similar magnitude in both the 800-m and 1500-m races. However, there was no significant effect of time point of competition or round. To the authors´ knowledge, this is the first attempt to quantify an end-spurt statistically according to the individual responses paradigm and to estimate potential influencing factors. The current results expand on previous research which mainly assessed mean differences within the velocity pattern[11,12] by developing an indicator that considers different variance components as well as within-subject variability during the middle part of the race.

The presence of an end-spurt in the 800-m and 1500-m is in accordance with previous research[11,12] and expectations. In a recent review, McGibbon et al. summarised that similar to middle-distance pool events, parabolic pacing is typically observed in freestyle pool events of 800-m or above with the highest swimming velocity at the start and the end of the race.[3] Lipinska et al. reported a 3.6% and 5.8% faster last lap compared to the middle part in 800- and 1500-m competitions over a period of 13 years.[11] Whilst the change in pace in the 800-m is similar to our analysis, the last lap in the 1500-m was only 4.2% faster. This discrepancy in the 1500-m could be related to the fact that Lipinska et al. only included the fastest race at a competition into their analysis, leaving out performances in heats or slower races.[11]

Based on the random between-subject and random within-subject variability the ESI seems fairly consistent between and within competitions. This supports its use because stable pacing profiles between and within swimmers are in accordance with recently published findings in simulated and real competitions.[3,16,24] It indicates that world-class swimmers do not seem to modify their end-spurt due to varying race tactics or different types of competition. The random within-subject variability of ESI was higher than the random between-subject variability indicating that the variation in ESI comes from the variability of the swimmers themselves rather than from different general race tactics. Nonetheless, further complexities such as the position of a competitor within the race during different time points may alter the ESI which should be subject of future research. It should further be considered that the current analysis only included World Championships and Olympic Games. As these are the major events in a swimmer's career it can be assumed that the athletes tried to produce a best time during these competitions. Future research should evaluate if the end-spurt changes throughout a season and/or an athlete's career and if such a potential change is associated with the general performance development.

The finding that medal placing had a significant effect on ESI is in agreement with previous research. For example, Mytton *et al*. observed that medallists showed a greater increase in speed at the end of a 400-m freestyle race compared to non-medallists,[22] which seemed to be the main factor differentiating medallists and non-medallists in their analysis. Further, it was described that medallists swam below their mean race velocity for the first half of the race and non-medallist above their mean race velocity, whereas the opposite was seen in the final 100-m of the race. Therefore, it was concluded that medallists start more conservatively compared to non-medallists in the 400-m freestyle.[22] Alternatively, it is possible that some non-medallists have not produced an end-spurt because of too little prospect of winning. Although the similarity/comparability of pool and open-water swimming is questionable, a faster end-spurt was highly correlated with a better overall finishing position in 5 and 25-km events with better positioned swimmers showing a significantly faster last lap compared to lower ranked athletes.[8,10] Indeed, when analysing finishing position, we also observed a significantly greater ESI in swimmers with a higher finishing position compared to swimmers with a lower finishing position. It is suggested that better athletes are able to keep a reserve capacity for the end-spurt, whereas swimmers with a lower fitness level already have to perform at their individual "limit" to keep up with the faster swimmers (i.e. medallists) during the middle part of the race. A potential explanation might be that medallists experience less physiological disturbance during the start and middle part of the race, taking longer to reach their VO_2max than non-medallists and therefore retain a greater reserve for the end spurt.[22]

Several studies have attempted to describe pacing behaviour during long-distance swimming in the pool[11,12,22] and in open-water races.[8-10] However, the majority of these studies investigated changes in swim velocity throughout the race, without a specific focus on the end-spurt. In head-to-head competitions the capability to outperform an opponent in the last meters of a race is especially important for the single athlete. Therefore, a better understanding of individual end-spurt behaviour could help athletes and coaches in their individual race preparation. As mentioned earlier the majority of pacing literature defines an end-spurt as a significant increase in speed in the last lap of a race or the effect size of it.[11,22] However, an evaluation of group means is of little value with respect to the individual athlete. Thus, it seems beneficial to consider the intra-individual variability during the middle part of the individual race. Similarly to approaches to evaluate individual responses in performance changes,[19,25] it seems important to understand sources of variation that may contribute to overall gross variability. Therefore, the current ESI includes the standard deviation of the mean swim velocity in the middle part of the race as an indicator of within-subject variation. According to the literature this might help to determine the true individual difference in speed throughout the race and at the end,[25] which can lead to a better understanding of individual end-spurt behaviour in swimming. Although this definition and mathematical model is based on statistical principles, it needs further verification. Nonetheless, this analysis presents a first attempt for an objective measure to quantify an end-spurt in relation to the individual swim speed variability.

The current investigation was purely observational and retrospective. Influencing factors such as motivation, shaving, different swimming suits or diets could not be controlled for. Even though Skorski et al.[24] observed similar pacing profiles in simulated and real competitions the internal validity of our approach might have been lower than in lab-based experiments. Since analysed data were taken from real competitions in high-level swimmers, however, a high external validity is ensured and results are applicable to the highest performance level. Furthermore, Mauger et al.[6] recently described that pacing patterns seem independent of swimsuit design.

Practical Implications

This study provides an insight into the pacing pattern of elite swimmers in the final stages of 800-m and 1500-m freestyle races. Coaches and sport scientists should take into account that an increase in velocity is used by the majority of the swimmers, particularly by medallists, even though any fluctuations in velocity could create higher relative energy costs.[4] Therefore, swimmers might benefit from using pacing training sessions to accommodate yield from an end-spurt. However, it is important to note that this study only contains a retrospective analysis of the end-spurt adopted by elite freestyle swimmers. Due to the fact that no experimental data was collected, the underlying physiological and/or psychological mechanisms can only be speculated upon. Based on previous laboratory-based studies, it might be suggested that improved O_2 kinetics,[26,27] the distribution of anaerobic capacity[26] and reduction in oxygen deficit[27] in combination with several biomechanical factors could be the cause for a certain pacing pattern including the end-spurt.

Conclusion

It was shown and quantified that elite swimmers execute an end-spurt in freestyle long-distance pool swimming races over 800-m and 1500-m. The extent of the end-spurt is not associated with competition, round, or distance, but is associated with finishing position. In particular, medallists have a more pronounced end-spurt compared to non-medallists. The current analysis proposes a new indicator to evaluate end-spurt behaviour in elite swimmers, which considers within-subject variability of swim speed and might be useful for future research in this area.

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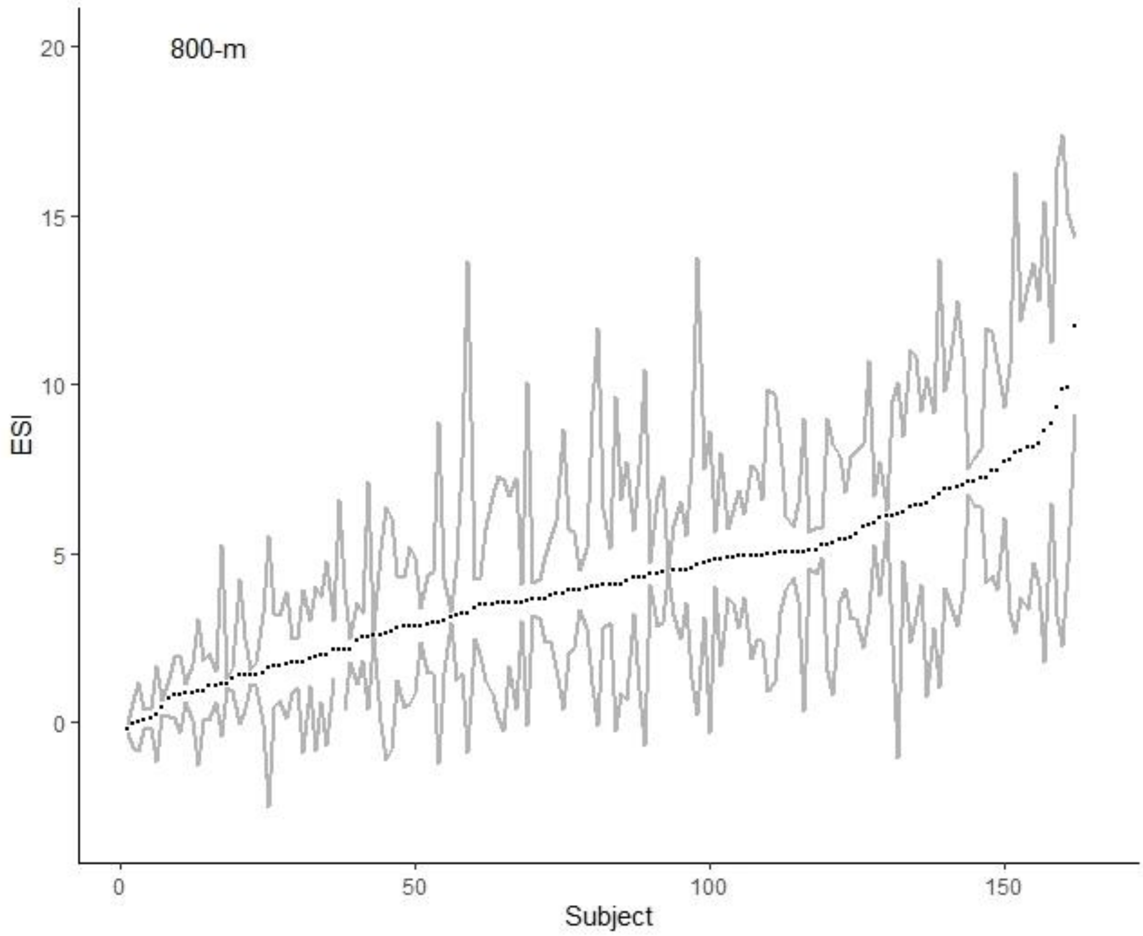
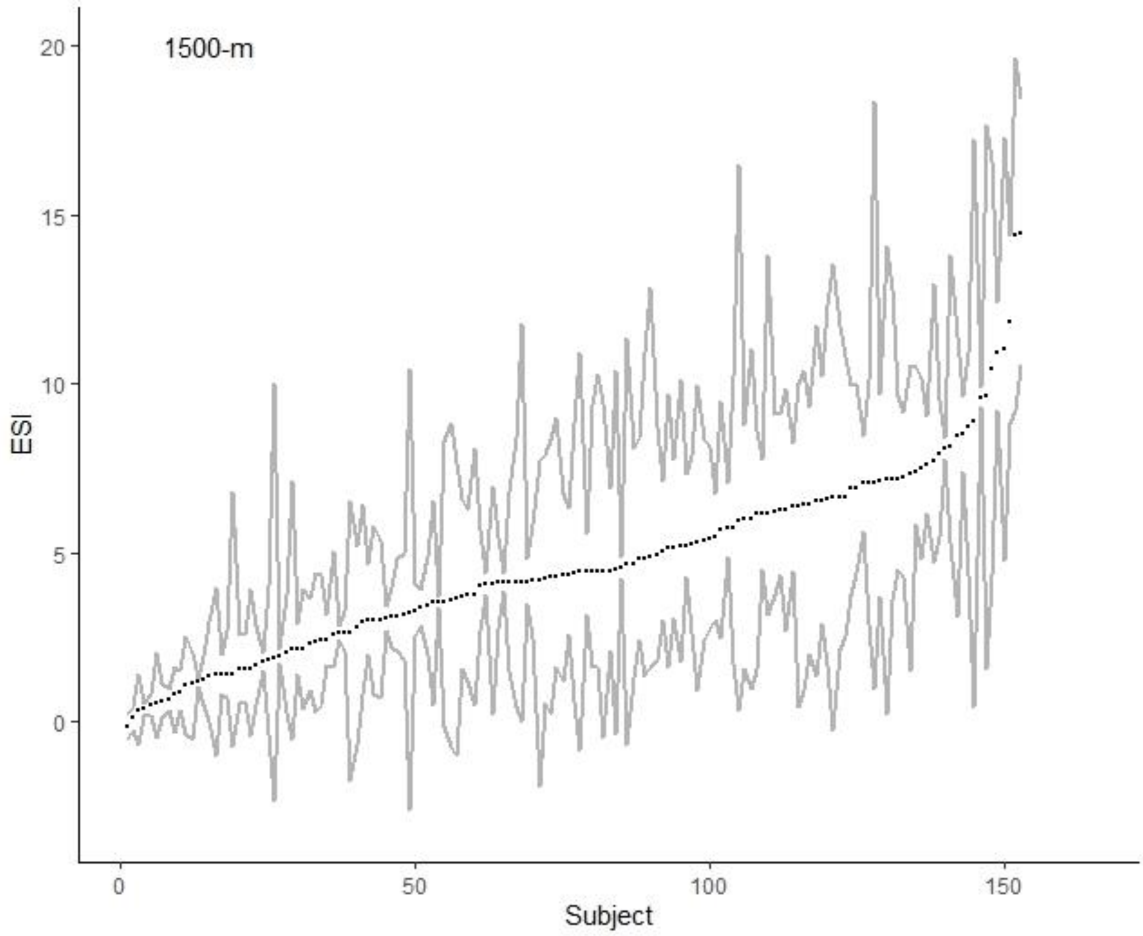
Figure captions:

Figure 1: Individual End-Spurt Indicator (ESI; black dots) for the 800-m (A) and 1500-m (B) distance. The grey lines display the minimum (lower line) and maximum (upper line) ESI observed in each individual. Swimmers are sorted according to their ESI from small to large (swimmer number does not relate to subject ID). Because ESI within individual subjects was not normally distributed, descriptive data are presented as medians with 25th and 75th percentiles.

Figure 2: Scatterplot displaying the individual End-Spurt Indicator (ESI) in relation to final finishing position for the 800-m (grey dots) and 1500-m (black dots).


800-m
ESI
Subject
20
15
10
5
0
0
50
100
150


1500-m
ESI
Subject
20
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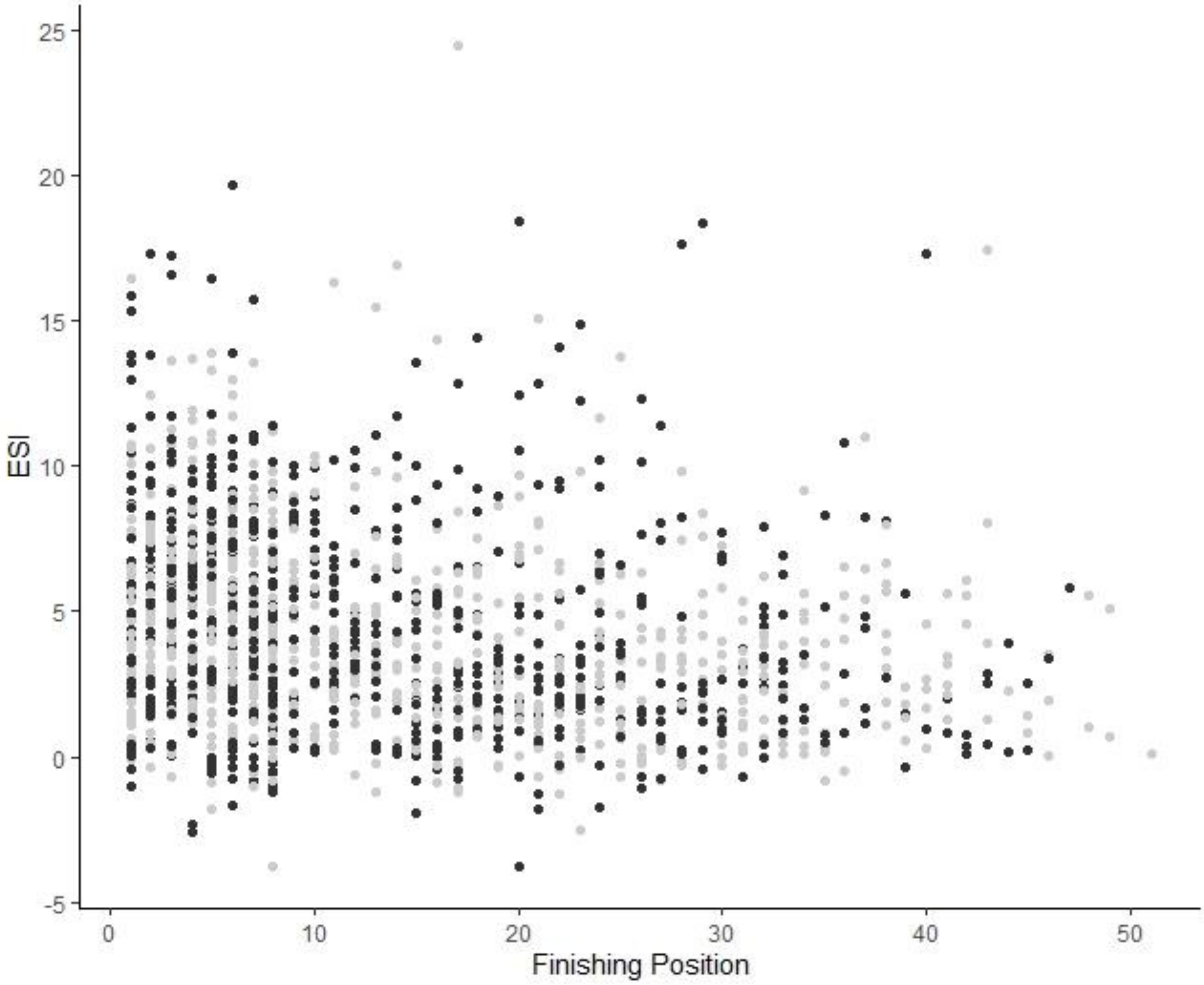
ESI
25
20
15
10
5
0
-5
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10
20
30
40
50
Finishing Position

Table 1: Number of races repeated by all subjects.

	Subjects (n)	Number of competitions (n)								
		one	two	three	four	five	six	seven	eight	nine
800-m	273	111	74	21	26	11	8	4	6	4
1500-m	255	102	64	28	22	15	5	3	1	3

Table 2: Number of races and swim times for all subjects (n = 528; n in table reflects number of races included). Data is shown as mean ± standard deviation (SD).

	Heat total time (min)	Final total time (min)
	Men (n = 780)	
800-m (n = 283)	**08:08,64 ± 21,68**	**7:48,42 ± 6,84**
1500-m (n = 497)	**15:26,07 ± 34,97**	**14:55,82 ± 12,29**
	Women (n = 653)	
800-m (n = 448)	**08:42,32 ± 18,73**	**8:26,12 ± 7,56**
1500-m (n = 205)	**16:34,22 ± 35,15**	**16:04,19 ± 14,31**