Pacing Behavior Development of Youth Short-Track Speed Skaters: A Longitudinal Study

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[1]Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, THE NETHERLANDS; [2]Department of Sport, Exercise and Rehabilitation, Faculty of Health and Life Sciences, Northumbria University, Newcastle, UNITED KINGDOM; [3]Department of Psychology, University of Groningen, Groningen, THE NETHERLANDS; and [4]Faculty of Movement and Rehabilitation Sciences, KU Leuven Campus Brugge, Brugge, BELGIUM

ABSTRACT

MENTING, S. G. P., B. C. HUIJGEN, M. J. KONINGS, F. J. HETTINGA, and M. T. ELFERINK-GEMSER. Pacing Behavior Development of Youth Short-Track Speed Skaters: A Longitudinal Study. *Med. Sci. Sports Exerc.*, Vol. 52, No. 5, pp. 1099–1108, 2020. **Purpose:** This study aimed to analyze the development of pacing behavior of athletes during adolescence using a longitudinal design. **Methods:** Lap times of male short-track speed skaters (140 skaters, 573 race performances) over two or more 1500-m races during Junior World Championships between 2010 and 2018 were analyzed. Races were divided into four sections (laps 1–3, 4–7, 8–11, and 12–14). Using MLwiN ($P < 0.05$), multilevel prediction models in which repeated measures (level 1) were nested within individual athletes (level 2) were used to analyze the effect of age (15–20 yr), race type (fast, slow), and stage of competition (final, nonfinal) on absolute section times and relative section times (percentage of total time spent in a section). **Results:** Between the ages of 15 and 20 yr, total race time decreased (−6.99 s) and skaters reached lower absolute section time in laps 8–11 (−2.33 s) and 12–14 (−3.28 s). The relative section times of laps 1–3 (1.42%) and 4–7 (0.66%) increased and of laps 8–11 (−0.53%) and 12–14 (−1.54%) decreased with age. Fast races were more evenly paced compared with slow races, with slow races having a predominantly slow first half and fast finish. Athletes in finals were faster (2.29 s), specifically in laps 4–7 (0.85 s) and laps 8–11 (0.84 s). **Conclusion:** Throughout adolescence, short-track speed skaters develop more conservative pacing behavior, reserving energy during the start of the race in order to achieve a higher velocity in the final section of the race and a decrease in total race time. Coaches should take into consideration that the pacing behavior of young athletes develops during adolescence, prepare athletes for the differences in velocity distribution between race types, and inform them on how to best distribute their efforts over the different stages of competition. **Key Words:** PACING, DEVELOPMENT, HEAD-TO-HEAD COMPETITION, PERFORMANCE ANALYSIS, ADOLESCENCE, MULTILEVEL MODELING

The goal-directed distribution of energy over a predetermined exercise task (1), a process of decision making regarding how and when to spend energy (2), has been defined as pacing. Pacing has proven to be an essential aspect of athletic performance, both in time-trial (3,4) and head-to-head competition (5–7). The final outcome of an individuals' goal-directed distribution of energy over the race is termed pacing behavior (2). A range of factors that influence pacing during an exercise task have been identified, including among others: the duration of the event (8), the perceived level of exertion (9), and sport specific demands (10). In addition, recent literature emphasizes the importance of the competitive environment in regard to pacing behavior (2). However, little is known on how athletes acquire the skills to successfully pace in races, and there is little information on the development of pacing behavior in youth athletes (11).

Although the first signs of the formation of a pacing template appear during late childhood (~10–11 yr old) (12,13), recent research in both time-trial and head-to-head events established that throughout adolescence, the pacing behavior of youth athletes further develops to ultimately resemble that of seniors (14,15). Menting et al. (11) provided a theoretical basis behind this development. First, adolescence is characterized by both cognitive and physical changes associated with growth and maturation (16,17). One key development is that of the prefrontal cortex (18), which has been associated with self-regulatory learning and executive functioning (19), both of which are imperative for adequate pacing (20). Second, in most athlete development programs, the amount and quality of training and competition increases profoundly during adolescence, providing youth athletes

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with an increase in the quantity and quality of opportunities to gather exercise experience. Lastly, coaches could influence the pacing behavior development by influencing the athlete's motivation, providing advice in goal setting, and providing high-quality learning environments in which the pacing behavior can be optimally developed (11). Emphasizing the importance of pacing development during adolescence, a longitudinal study in long-track speed skaters suggests that the development of pacing behavior in developing athletes has a decisive influence on the performance level at the senior level (14). In addition, the ability to appropriately distribute energy in the long term also seems vital in safeguarding athletes' well-being. If the athlete's ability to adequately distribute his/her energy is hampered, it could lead to him/her investing too much energy during an exercise task (e.g., a training and competition) (21,22). If this happens repeatedly, it could lead to overtraining, burnout, and dropout (23). This is especially true for developing athletes who, during adolescence, often endure high training loads for a long period of time in order to reach the elite level (24). In order to optimally guide developing athletes, it seems to be essential to have a good understanding of both the general and sport-specific development of pacing behavior during adolescence (11).

Much of the previous literature studying the effect of age and experience on pacing behavior has been cross-sectional in design, comparing athletes from different age groups, experience, or performance levels (13,15,25). A cross-sectional design can provide a good general image of skill development, given that the sample size is large enough. However, in order to properly study development of a particular skill over a period of time, a longitudinal design is desirable. In longitudinal studies, the same variable(s) is observed repeatedly over a period of time, therefore allowing for an exclusion of time-invariant unobserved individual differences (26). The only study to longitudinally analyze the development of pacing behavior throughout adolescence was a study on long-track speed skaters performing 1500-m races (14). That study concluded that the absolute velocity of junior skaters increased in all sections of the race. However, when normalizing the velocity distribution, it became apparent that with age, skaters developed a more conservative velocity profile. Accompanying the results in long-track speed skaters, a cross-sectional study analyzing short-track speed skaters concluded that the pacing behavior and positioning behavior of skaters change throughout different stages of adolescence (15). With each older age group (<17, <19, and <21 yr), the normalized velocity distribution and the positioning resembled that of senior skaters to a greater extent, with skaters adapting a more conservative pacing behavior. Although there are small physiological differences between long- and short-track speed skating, there seems to be a consensus that the sport disciplines are rather comparable in physiological perspective (27). However, where long-track speed skating is a classic time-trial sport, short-track speed skating features head-to-head competition, involving highly interactive races with up to nine skaters (6). Therefore, athletes incorporate factors such as drafting and avoiding collisions in their pacing behavior (6). Previous research showed that the importance of the competition, the number of competitors, and the stage of the competition, all influence the performance and pacing behavior of short-track speed skaters (28). Furthermore, because of the head-to-head nature of short-track speed skating, the winner is the athlete who crosses the finish line first, regardless of the time it takes the skater to complete the race. Consequently, there is a large variation in total race time compared with long-track speed skating, as short-track speed skaters are not concerned with setting a fast finishing time but with crossing the finish line first. To account for this phenomenon, previous literature categorized races as either "slow" or "fast" (e.g., race type) and found a significant difference in pacing behavior in adult athletes between the race types (6). After the notion that the competitive environment has a critical role in pacing behavior (29), a longitudinal study involving a highly interactive head-to-head sport, such as short-track speed skating, would enrich the current literature.

In order to gain a thorough understanding of the development of pacing behavior in athletes during adolescence, an increase in longitudinal studies seems indispensable. Therefore, the current study investigated the development of pacing behavior of short-track speed skaters, on a year-by-year basis, applying a longitudinally study design. It was hypothesized that the pacing behavior of these athletes would develop throughout adolescence to show a more conservative profile, characterized by a relatively slower start and a faster finish. In addition, the current study investigated the influence of the competitive environment (race type and stage of competition) on the pacing behavior of youth athletes. After the findings in adults (30), it is hypothesized that the pacing behavior of youth skaters will be affected by the behavior of other competitors, facilitating either a slow or fast race. In addition, based on findings in adults (6,28), it is hypothesized that the young skaters will exhibit a more conservative pacing behavior as athletes progress through the stages of competition.

METHODS

Participants and events. The finishing times, lap times, and date of birth of all male competitors competing in the 1500-m (13.5 laps) at the yearly Junior World Championships between 2010 and 2018 were gathered. The lap times were recorded electronically with an accuracy of at least one hundredths of a second, as is demanded by the International Skating Union. All competitive events followed a qualification structure in which skaters qualify directly for the next round by finishing first or second. In addition, participants could qualify indirectly by setting the fastest finishing time of a specific qualification round or through advance by jury decision. All data were publically available through the International Skating Union website (http://www.sportresult.com/federations/ISU/ShortTrack/); therefore, no written consent was asked from the participants. The study was approved by the local ethical committee and is in accordance with the Declaration of Helsinki.

A total of 1487 race performances were collected. The occurrence of a fall or disqualification could affect pacing behavior. For this reason, races including disqualified skaters were

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excluded, as were race data of skaters who had fallen or included missing data, consistent with the previous literature (6) (43.5% of total race performances collected). The age of a skater was calculated by taking the date of the competition and subtracting the date of birth. The variable of age was converted to a categorical variable in order to show differences between skaters of specific ages. For example, a 16-yr-old skater was defined as a skater within the age range 15.50–16.49 yr. To control for outliers of age, the decision was made to exclude race performances of skaters who were not between 14.5 and 20.5 yr old (0.6% of total race performances collected). Previous studies established that the number of competitors and the stage of the competition significantly influenced pacing behavior and performance of elite short-track speed skaters (28). Hence, data from races with more than seven or less than five skaters were excluded (1.3% of total race performances collected), and data were split in finals (quarterfinals, semifinals, and finals) and nonfinals (heats and preliminaries). To account for race type, a race was classified as "fast" or "slow" when the winner of a particular race was faster or slower than the average completion time of all race winners. In order to properly study longitudinal development, only data from skaters who performed in at least two different age groups, during Junior World Championships, in various seasons, were included. Therefore, all data from skaters who performed in just one age group (i.e., during one Junior World Championship) were excluded (16.1%). It should be noted that because of the qualifying nature of the Junior World Championships, included skaters can have multiple race performances in one age category. After exclusions, 573 race performances (38.6%) of 140 different skaters were included from the original sample. Of the included skaters, 53.6% performed in two, 30.7% in three, 13.6% in four, and 2.1% in five different age groups. Table 1 shows the mean age of included skaters and the number of included race performances, per age category.

Study design. The 1500-m race was split into four sections: laps 1 to 3, 4 to 7, 8 to 11, and 12 to 14. With lap 1 effectively being a half lap, this adds up to a total of 13.5 laps. In order to analyze how skaters distribute their velocity over a race, total race time and absolute section time (AST; i.e., time to complete a section) over the four sections of the race were taken as outcome measures. Furthermore, in order to analyze pacing behavior independent of possible differences in total race time between skaters, each AST was converted into relative section time (RST), which presents the percentage of total race time spent in one section. A comparative approach has been taken in other longitudinal and cross-sectional studies investigating pacing behavior throughout adolescence (14,15).

TABLE 1. Number of included performances per age category.

Age Category	Age (Mean ± SD), yr	No. Race Performances				
		2	3	4	5	Total
15	15.19 ± 0.26	11	9	9	3	32
16	16.11 ± 0.29	24	29	16	3	72
17	17.05 ± 0.29	35	48	28	5	116
18	18.03 ± 0.31	77	48	26	3	154
19	18.97 ± 0.31	69	58	23	4	154
20	19.56 ± 0.03	20	14	11	0	45
Total included race performances		236	206	113	18	573

Data analyses. Because the qualifying nature of the short-track speed skating competition, there is considerable variability in the number of measurements among skaters. Hence, traditional repeated measurements analyses were not possible. Longitudinal changes in pacing behavior were investigated using multilevel modeling program MlwiN (31). Multilevel modeling was developed to analyze nested data, allowing for longitudinal analyses of data sets, which include a varying number of measurements between participants as well as a variety in temporal spacing between measurements. In the current study, hierarchy was defined as repeated measures (level 1) nested within the individual skaters (level 2). Dependent variables in these models were total race time, AST (AST1–3, AST4–7, AST8–11, and AST12–14), and RST (RST1–3, RST4–7, RST8–11, and RST12–14) for the four race sections. The predictive variables included were as follows: age category (15–20), race type (fast, slow), and stage of competition (final, nonfinal). Goodness of fit for each model was evaluated using the $-2 \times$ log likelihood differences in outcome measures between age categories were evaluated by comparing the mean of the coefficient and its standard error (SE; coefficient/SE >1.96 = significant).

RESULTS

The models created for the outcome measures can be found in Table 2 (AST and total race time) and Table 3 (RST). Each model consists of a constant value and a coefficient for the appropriate predictive variable. Because all predictive variables (e.g., age, race type, and stage of competition) in the model are categorical of nature, the coefficient will represent the difference between one chosen sample category and the other possible categories. The age category 15 was used as a sample category for age. In the case of race type, races categorized as "slow" are the sample category. For stage of competition, "finals" are the sample category. This effectively means that if a race is categorized as "slow," "final," or "15," the coefficient for race type, stage of competition, and age, will be multiplied by 0. Conversely, if a race is categorized as "fast," "nonfinal," and age category 16 through 20, the various coefficients will be included into the models prediction. This way, the models are used to make predictions for outcome measures for the different combinations of predictive variables: age, race type, and stage of competition. For example, the AST1–3 for a 17-yr-old in a fast nonfinale was predicted as:

$$\text{AST1–3} = (\text{constant}) + (17) + (\text{fast}) + (\text{nonfinal})$$

$$\text{AST1–3} = 38.486 + 0.590 - 5.977 + 0.251$$

$$\text{AST1–3} = 33.350$$

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TABLE 2. Multilevel model for the AST presented for each race section and total race time.

Race Phase	Coefficient	SE	P	95% CI (−)	95% CI (+)
Laps 1–3					
Fixed effects					
Constant	38.486	0.664	<0.001	37.158	39.814
Fast*	−5.977	0.293	<0.001	−6.563	−5.391
Nonfinal	0.251	0.294	0.393	−0.337	0.839
16	0.361	0.739	0.625	−1.117	1.839
17	0.590	0.695	0.396	−0.800	1.980
18	0.182	0.677	0.788	−1.172	1.536
19	0.680	0.678	0.316	−0.676	2.036
20	0.470	0.813	0.563	−1.156	2.096
Random effects					
Level 1: season	11.802	0.787			
Level 2: individual	0.261	0.396			
Deviance	3052.499				
Deviance empty model	3397.162				
Laps 4–7					
Fixed effects					
Constant	47.300	0.521	<0.001	46.258	48.342
Fast*	−5.012	0.230	<0.001	−5.472	−4.552
Nonfinal*	0.853	0.231	<0.001	0.391	1.315
16	−0.084	0.581	0.885	−1.246	1.078
17	0.206	0.546	0.706	−0.886	1.298
18	−0.493	0.532	0.354	−1.557	0.571
19	−0.274	0.532	0.607	−1.338	0.790
20	−0.864	0.639	0.176	−2.142	0.414
Random effects					
Level 1: season	7.292	0.486			
Level 2: individual	0.150	0.243			
Deviance	2775.802				
Deviance empty model	3134.143				
Laps 8–11					
Fixed effects					
Constant	41.368	0.340	<0.001	40.688	42.048
Fast	0.057	0.134	0.671	−0.211	0.325
Nonfinal*	0.840	0.130	<0.001	0.580	1.100
16*	−1.373	0.342	<0.001	−2.057	−0.689
17*	−1.609	0.325	<0.001	−2.259	−0.959
18*	−2.050	0.329	<0.001	−2.708	−1.392
19*	−2.315	0.331	<0.001	−2.977	−1.653
20*	−2.329	0.414	<0.001	−3.157	−1.501
Random effects					
Level 1: season	2.030	0.138			
Level 2: individual	2.430	0.359			
Deviance	2272.711				
Deviance empty model	2366.554				
Laps 12–14					
Fixed effects					
Constant	32.103	0.367	<0.001	31.369	32.837
Fast*	0.844	0.137	<0.001	0.570	1.118
Nonfinal	0.208	0.132	0.115	−0.056	0.472
16*	−1.624	0.349	<0.001	−2.322	−0.926
17*	−2.093	0.334	<0.001	−2.761	−1.425
18*	−2.598	0.340	<0.001	−3.278	−1.918
19*	−3.080	0.342	<0.001	−3.764	−2.396
20*	−3.284	0.429	<0.001	−4.142	−2.426
Random effects					
Level 1: season	2.073	0.141			
Level 2: individual	4.404	0.596			
Deviance	2352.867				
Deviance empty model	2470.692				
Total race time					
Fixed effects					
Constant	160.327	1.204	<0.001	157.919	162.735
Fast*	−10.438	0.510	<0.001	−11.458	−9.418
Nonfinal*	2.292	0.500	<0.001	1.292	3.292
16*	−3.704	1.295	0.004	−6.294	−1.114
17*	−3.621	1.222	0.003	−6.065	−1.177
18*	−5.544	1.217	<0.001	−7.978	−3.110
19*	−5.758	1.221	<0.001	−8.200	−3.316
20*	−6.989	1.507	<0.001	−10.003	−3.975
Random effects					
Level 1: season	31.491	2.133			
Level 2: individual	10.857	2.321			
Deviance	3722.275				
Deviance empty model	4072.143				

*Significant difference from sample category ($P < 0.05$).
CI, confidence interval.

The RST12–14 for a 15-yr-old in a slow nonfinal was predicted as:

$$\text{RST12–14} = (\text{constant}) + (15) + (\text{slow}) + (\text{nonfinal})$$

$$\text{RST12–14} = 20.49 + 0 + 0 + -0.16$$

$$\text{RST12–14} = 20.33$$

TABLE 3. Multilevel model for the RST presented for each race section.

Race Segment	Coefficient	SE	P	95% CI (−)	95% CI (+)
Laps 1–3					
Fixed effects					
Constant	24.068	0.339	<0.001	23.390	24.746
Fast*	−2.294	0.146	<0.001	−2.586	−2.002
Nonfinal	−0.258	0.144	0.073	−0.546	0.030
16*	0.615	0.370	0.096	−0.125	1.355
17*	0.892	0.349	0.011	0.194	1.590
18*	0.959	0.345	0.005	0.269	1.649
19*	1.252	0.346	<0.001	0.560	1.944
20*	1.420	0.424	0.001	0.572	2.268
Random effects					
Level 1: season	2.673	0.180			
Level 2: individual	0.543	0.151			
Deviance	2271.992				
Deviance empty model	2485.771				
Laps 4–7					
Fixed effects					
Constant	29.484	0.242	<0.001	29.010	29.958
Fast*	−1.200	0.104	<0.001	−1.404	−0.996
Nonfinal	0.111	0.103	0.281	−0.091	0.313
16*	0.732	0.264	0.006	0.215	1.249
17*	0.817	0.249	0.001	0.329	1.305
18*	0.741	0.246	0.003	0.259	1.223
19*	0.866	0.247	<0.001	0.382	1.350
20*	0.664	0.302	0.028	0.072	1.256
Random effects					
Level 1: season	1.363	0.092			
Level 2: individual	0.276	0.077			
Deviance	1885.939				
Deviance empty model	2014.313				
Laps 8–11					
Fixed effects					
Constant	25.947	0.221	<0.001	25.505	26.389
Fast*	1.685	0.096	<0.001	1.493	1.877
Nonfinal*	0.222	0.096	0.021	0.030	0.414
16*	−0.514	0.244	0.035	−1.002	−0.026
17*	−0.632	0.229	0.006	−1.090	−0.174
18*	−0.576	0.225	0.010	−1.026	−0.126
19*	−0.701	0.225	0.002	−1.151	−0.251
20*	−0.525	0.273	0.054	−1.071	0.021
Random effects					
Level 1: season	1.232	0.083			
Level 2: individual	0.097	0.050			
Deviance	1784.004				
Deviance empty model	2039.665				
Laps 12–14					
Fixed effects					
Constant	20.487	0.243	<0.001	20.001	20.973
Fast*	1.887	0.100	<0.001	1.687	2.087
Nonfinal	−0.159	0.097	0.101	−0.353	0.035
16*	−0.706	0.253	0.005	−1.212	−0.200
17*	−0.988	0.240	<0.001	−1.468	−0.508
18*	−1.086	0.242	<0.001	−1.570	−0.602
19*	−1.371	0.243	<0.001	−1.857	−0.885
20*	−1.539	0.302	<0.001	−2.143	−0.935
Random effects					
Level 1: season	1.147	0.078			
Level 2: individual	0.818	0.135			
Deviance	1889.767				
Deviance empty model	2169.998				

*Significant difference from sample category ($P < 0.05$).
CI, confidence interval.

Following the principles of the models, the coefficients also indicated the effect that a variable (age, race type, stage of competition) has on the outcome measure (AST, RST, and total race time). For example, in the model for total race time, the coefficient for race type is −10.44. This means that the model predicts that fast races have a total race time, which is 10.44 s less compared with slow races.

Because AST and total race time are indicated in seconds, a lower outcome of these variables represents a higher velocity. The models created for AST and total race time can be found in Table 2. Visual representations of the predictions of these models can be found in Figure 1. The RST is reported in percentages of the total race spend in a specific section. Therefore, a lower RST indicates that a skater was relatively faster and therefore distributed more effort in that section of the race. The predictions made by the models for the RST can be found in Table 3, as well as visually presented in Figure 2. In order to visualize the pacing behavior of skaters over a full race, the predictions of the four models for the AST and the four models for the RST are presented alongside each other in Figure 3.

Age categories. Comparing total race time between the age categories (in years), the following age categories reported a higher total race time: 15 versus 16–20, 16 versus 18–20, 17 versus 18–20, and 18 versus 20. No difference between age categories was found for AST1–3 and AST4–7. AST8–11 was higher in the following age categories: 15 versus 16–20, 16

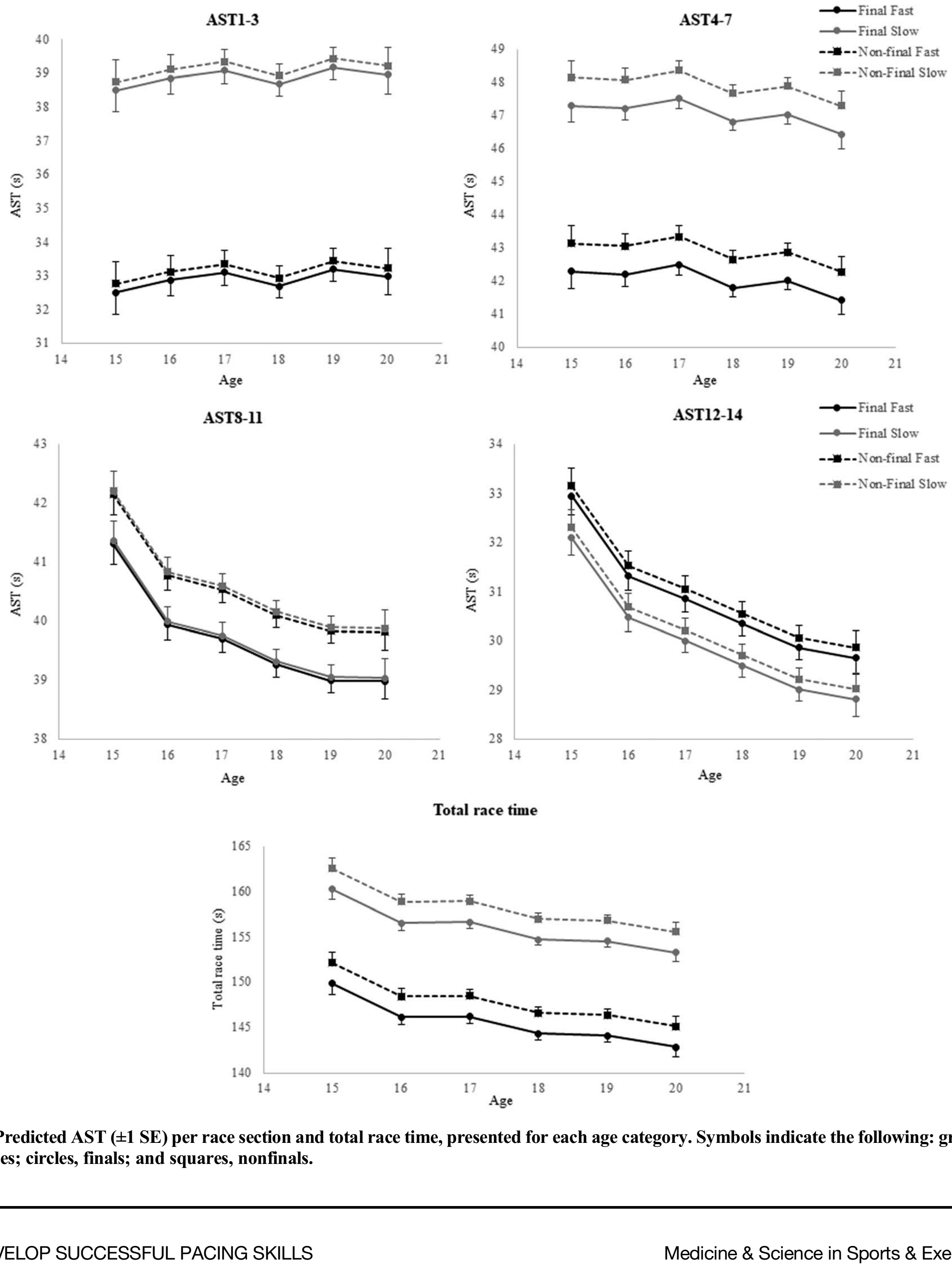

FIGURE 1—Predicted AST (±1 SE) per race section and total race time, presented for each age category. Symbols indicate the following: gray, slow races; black, fast races; circles, finals; and squares, nonfinals.

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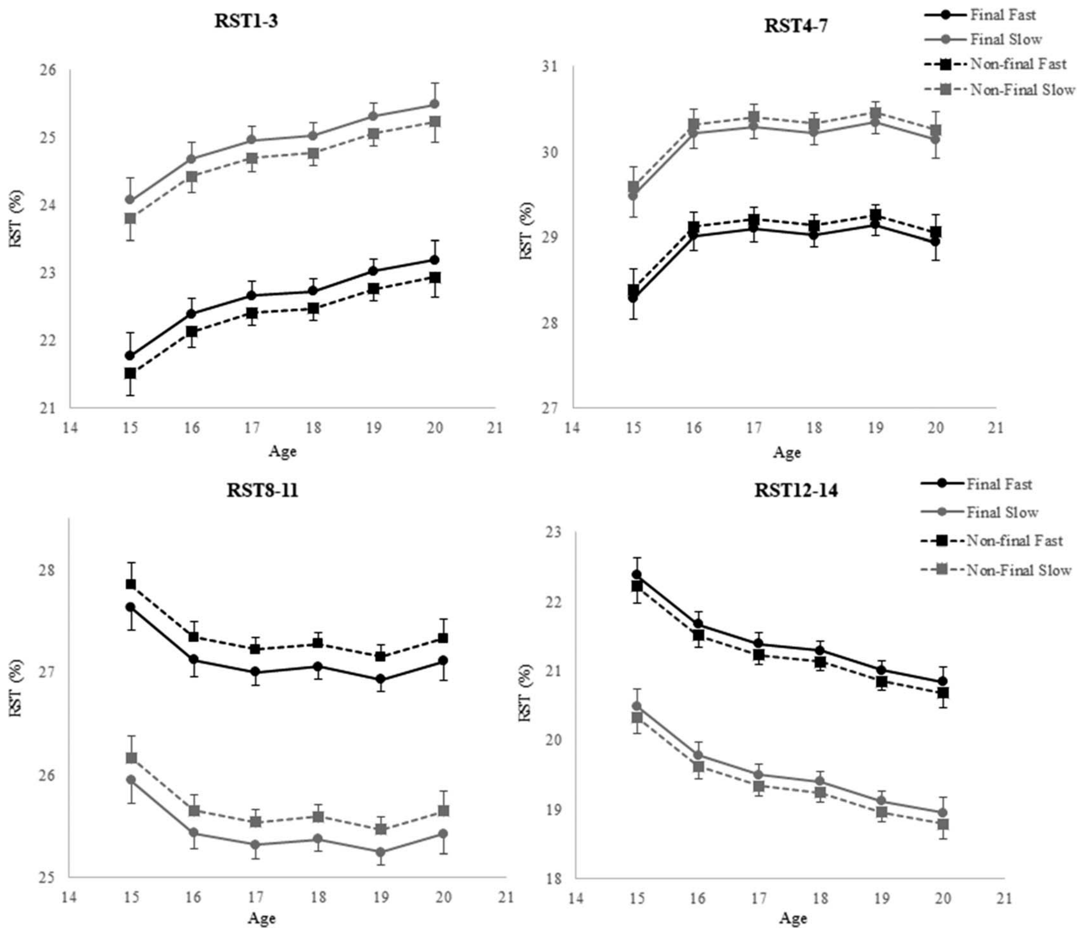

FIGURE 2—Predicted RST (±1 SE) per race section, presented for each age category. Symbols indicate the following: gray, slow races; black, fast races; circles, finals; and squares, nonfinals.

versus 18–20, and 17 versus 18–20. Subsequently, AST12–14 was higher in the following age categories: 15 versus 16–20, 16 versus 18–20, 17 versus 18–20, and 18 versus 19–20. There was a difference in RST between the age categories throughout the race. The RST1–3 was lower in the following age categories: 15 versus 17–20 and 16 versus 19–20. The RST4–7 was reported to only be significantly lower in age category 15 compared with all other age categories. Conversely, the RST8–11 was modeled to only be higher in age category 15 compared with all other age categories. The RST12–14 was higher in the following age categories: 15 versus 16–20, 16 versus 18–20, 17 versus 19–20, and 18 versus 19–20. In summary, skaters in an older age group set a faster total race time by reaching a higher velocity in the second part of the race. Furthermore, older skaters were relatively slower during the first half of the race and relatively faster during the second half of the race. The differences in normalized velocity in the first three sections of the races significantly contrasted the 15- and 16-yr-old skaters against the skaters in the older age categories. In the last section, with every step to an older age category, skaters were relatively faster compared with all younger skaters.

Race type. For the total race time, AST1–3 and AST4–7 were higher in races classified as slow compared with those classified as fast. AST12–14 was lower in fast races compared with slow races. There was no effect for race type on AST8–11. These findings point out that skaters in slow races had a lower velocity during the first half of the race, but were faster during the final three laps of the race, compared with skaters in races classified as fast. The RST1–3 and RST4–7 were lower in races classified as fast compared with those classified as slow. *Vice versa*, the RST8–11 and RST12–14 were higher in fast races, compared with slow. Therefore, skaters in fast races are relatively faster in the first half of the race and slower in the second half of the race. Contrariwise, skaters in a slow race are relatively slow in the first half of the race and have a high relative velocity in the second part of the race.

Stage of competition. For the total race time, AST4–7 and AST8–11 were higher in nonfinals compared with finals. There was no difference between the stages of competition for AST1–3 and AST12–14. Altogether, the finals were in total faster compared with the nonfinals, with the skaters in the finals reaching a higher velocity in the middle part of the race. There was only a significant difference in RST8–11 between the stages of competition. Skaters in finals were found to have a lower RST8–11. It should, however, be acknowledged that there is a trend suggesting that RST1–3 is higher in finals compared with nonfinals ($P = 0.07$). Therefore, it can be suggested that skaters

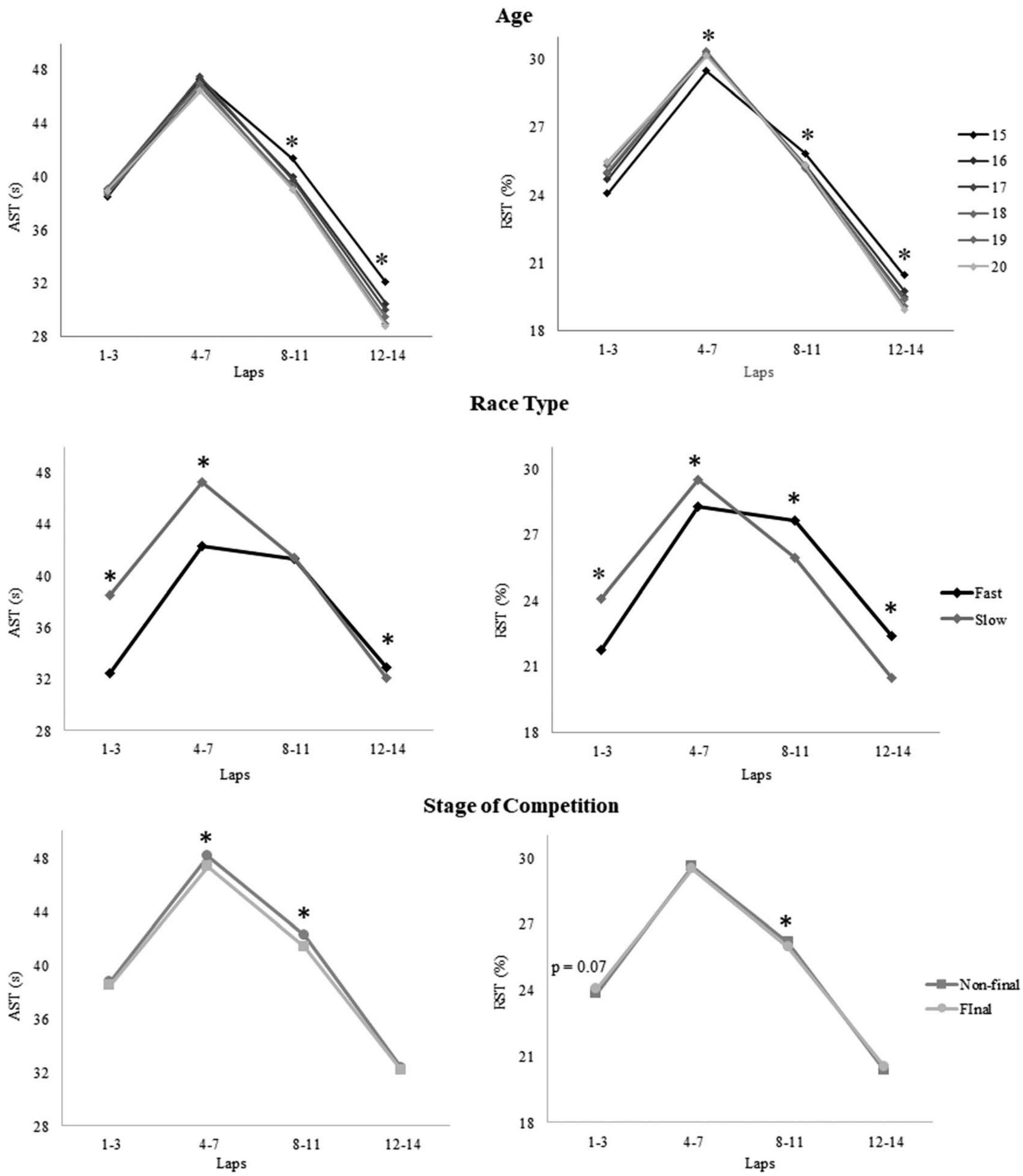

FIGURE 3—Absolute and normalized velocity distribution of skaters: the predicted values for the AST and RST per race section for each age category, race type, and stage of competition. *P < 0.05.

in the finals are relatively slower in the first section and faster during the third section of the race compared with the nonfinals.

DISCUSSION

The current study was the first to use a longitudinal design in order to investigate the development of pacing behavior of youth short-track speed skaters on a yearly basis, as well as investigates the influence of race type and stage of competition on the pacing behavior of youth athletes. As hypothesized, the pacing behavior of short-track speed skaters developed throughout adolescence. With age, the pacing behavior became more conservative, characterized by a relatively slower start and faster finish. Furthermore, the total race time decreased with age, parallel with an increase in velocity during the last half of the race. Lastly, both the race type and stage of competition influenced the pacing behavior of youth short-track speed skaters, indicating that the competitive environment is an aspect of athletic performance to account for, already at a young age.

The model for total race time predicted the largest development between the 15 and 16 yr old: a drop of −3.704 s, equal to a 2.310% decrease in total race time. Between the ages of 16 and 20 yr, there was a −3.285 s (2.142%) decrease in total race time, averaging 0.821 s (0.524%) a year. In addition, there was a notable difference in the distribution of velocity between the age categories. In the first half of the race, there was no predicted difference in velocity between age categories. In the final two sections of the race, however, the predicted absolute velocity was higher with each age category. These findings indicate that older skaters can set a better finish time because they are able to reach a higher velocity in laps 8–11 and laps 12–14. Notable here are the large differences between age categories 15 and 16 (1.373 s for laps 8–11 and 1.624 s for laps 12–14, respectively), compared with the difference between age categories 16 and 20 (0.956 s for laps 8–11 and 1.660 s for laps 12–14, respectively). Previous research showed that the final phase of the race is most crucial to winning the race (6). The current findings suggest that older adolescent skaters also achieve a higher velocity in this critical final part of the race. One explanation for this could be that older skaters possess more developed physical attributes and a better skating technique, therefore being able to achieve a higher velocity in general. However, the models for relative sections times reveal an additional explanation.

The use of RST allows for a comparison of pacing behavior controlled for differences in total race time. In general, the models in the current study predicted that with age, the skaters develop a more conservative pacing behavior, characterized by a relatively slower start and faster finish. Remarkably, the development of normalized velocity distribution was most evident when comparing 15- and 16-yr-old skaters with the other age categories. These findings conform to a previous study that compared cross-sectional data short-track speed skaters, grouped by age: younger than 17 yr, younger than 19 yr, younger than 21 yr, and adults (older than 21 yr) (15). The group with skaters younger than 17 yr presented the largest difference in normalized lap times compared with the other groups, specifically in four initial and four final laps of the race. Combining the development in normalized velocity distribution with the finding that with age, skaters reach a higher velocity in the final half of the race, pointing to the following idea: short-track speed skaters develop their pacing behavior throughout adolescence, increasing the preservation of energy in the starting section of the race, in order to achieve a higher velocity in the critical final laps of the race resulting in a decrease in total race time. This development is most evident around the 15- to 16-yr span, becoming more gradual toward adulthood. Interestingly, Wiersma et al. (14) reported that in the time-trial–based sport of long-track speed skating, elite skaters distinguished themselves from subelite and nonelite by a distinct development of pacing behavior in the period from 15 to 18 yr old. The development in long- and short-track speed skating seems similar: in both disciplines, skaters develop a more conservative behavior in which the conservation of energy during the start of the race results in a higher velocity in another section of the race and an overall decrease in total race time. Furthermore, the 15- to 16-yr-old mark constitutes a relatively large shift in behavior in both disciplines. It could be speculated that this resemblance could entail that, like in long-track speed skating, the development of pacing behavior of young short-track speed skaters could prove to be a marker for future performance level. However, future research should be done to further explore this hypothesis.

A possible underlying mechanism for the rapid development at the 15- to 16-yr-old mark could be found in the occurrence of multitude of physical and cognitive changes in athletes of this age (11). Studies have shown that males on average attain their peak height velocity at 14 yr old. Muscle mass (32), aerobic capacity (33), and morphological characteristics of the heart (34), all develop during this age period. These physiological changes have a direct effect on the physical capacities of young athletes and consequently affect their pacing behavior. Another likely underlying mechanism is the development of the self-regulatory skillset and core executive functions (11). The self-regulatory skillset comprises aspects of motivation, self-efficacy, and (meta-)cognitive functions such as the ability to reflect, plan, monitor, and evaluate a goal-directed process such as pacing (35). Complementary, the literature generally includes under the core executive functions: the ability to maintain information within the working memory for quick retrieval; the ability to deliberately inhibit or override dominant, automatic, or prepotent responses; and the ability to shift between multiple tasks, operations, or mental sets (20). Both skillsets are suggested to be vital for adequate pacing behavior and performance (20,35). A variety of self-regulatory skills and core executive functions are shown to develop between the ages of 12 and 21 yr (35,36). However, there is evidence to suggest that the prefrontal cortex–related (meta-)cognitive skills develop at different rates (36). It could be hypothesized that the cognitive functions that play an important role in the development of pacing behavior in short-track speed skating develop specifically during the 15- to 16-yr period. To confirm this hypothesis, further exploration of the relation between prefrontal cortical related (meta-)cognitive skills, pacing behavior, and athletic performance development is needed.

Considering the difference in pacing behavior between race types, it is evident that the pacing behavior in youth short-track speed skating is influenced by the velocity in the first section of the race. A fast start of the race will lead to a rather evenly paced race, whereas in a race with a slow start, the velocity increases considerably in the second half of the race. These findings are not fully unexpected. Previous research, in adult elite short-track speed skaters, found that skaters adjust their pacing behavior in response to the behavior of other competitors in the early stages of 1500-m competitions (30). A possible reason for the variability in behavior could be tactical. It has previously been brought forward that following the pace of an opponent can be more physiologically demanding compared with self-pacing a race (37). Consequently, some skaters will opt to take the lead in the race in order to control the pace. On the other hand, positioning oneself closely behind an opponent could reduce air frictional losses by 23%, due to drafting (38). In addition, positioning in another position than the leading position allows the athletes to directly observe their opponents (30). The planning of race tactics and the anticipation the behavior of opponents seem to have a substantial effect on the course and outcome of a short-track speed skating race. This further emphasizes the important role of the development of the self-regulatory skillset and core executive functions in short-track speed skating.

Compared with the age of the skaters and the type of race, the stage of competition had a less pronounced influence on the skaters' pacing behavior. The finals were predicted to be faster compared with the nonfinals (2.292 s). The difference in performance was present in all sections of the race, but was most notable in the middle section. The normalized velocity distribution data paralleled these findings, as skaters in the finals were relatively faster in the first and last sections, but slower in the middle sections. Interestingly, previous research in elite adult short-track speed skaters pointed to a pronounced change in pacing behavior throughout a tournament (6,28). The pacing behavior of adult skaters was observed to become more conservative, featuring a slower start and fast finish, toward the finals. It would seem therefore that adult skaters adapt their pacing behavior throughout the stages of competition and adapt the most conservative pacing behavior in the finals (28). It has previously been put forward that athletes not only pace individual races but also regulate their effort over longer periods of time (e.g., stages of competition, seasons, and Olympic cycles) (39). There is some evidence to suggest that young athletes have difficulties with planning an effective regulation of effort (40). It could therefore be suggested that the planning of energy distribution over a longer period than a single race is a skill that is still being developed in young athletes. If this is the case, it should be recognized as a potential concern, as it has previously put forward that inadequate regulation of effort over long-term could lead to overtraining, burnout, and dropout among young athletes (23).

The current study is the first to use multilevel modeling to longitudinally analyze pacing behavior development. Using a repeated measurement of variance approach (as done in the majority of the literature on pacing), the analyses would have only included data of three skaters (in comparison to the 140 included skaters in the current study), as only three skaters performed in all five different age groups. It has been put forward that more (longitudinal) research on pacing behavior development in young athletes is needed (11). Following the example set in the current study, multilevel modeling could be used in future studies to provide the much needed longitudinal analysis of pacing behavior development in other sports in which there are varying numbers of measurements between participants as well as a variety in temporal spacing between measurements.

CONCLUSION

The current study is the first to study the development of pacing behavior in a head-to-head sport, throughout adolescence, using a rigorous longitudinal approach. Between 15 and 20 yr of age, short-track speed skaters become faster by developing the ability to reserve energy in the starting section of the race in order to reach a higher absolute velocity in the second half of the race. The most notably shift in this development seems to occur when skaters are 15–16 yr of age. In young, as in adult skaters, the pace set in the initial laps dictates the velocity changes in the rest of the race. This phenomenon is suggested to stem from the various tactical choices made by athletes, balancing between the advantages afforded by either drafting or pace control. Lastly, the effect of the competitive environment (e.g., the stage of competition) on the pacing behavior of young short-track speed skaters is less pronounced compared with adult skaters. Coaches are advised to monitor the pacing behavior development of athletes, make athletes aware of the tactical advantages of setting a slow or fast initial pace, and instruct them on how to pace themselves throughout the different stages of competition, in order to optimize their pacing behavior and in turn their athletic performance.

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