Staying on track

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Pacing and performance

Development of 1500m pacing behavior in junior speed skaters: a longitudinal study.

Chapter 4

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Abstract

Purpose: To provide insight on the development of pacing behavior in junior speed skaters and analyze possible differences between elite, subelite, and nonelite juniors. Methods: Season-best times (SBTs) in the 1500-m and corresponding pacing behavior were obtained longitudinally for 104 Dutch male speed skaters at age 13–14 (U15), 15–16 (U17), and 17–18 (U19) y. Based on their U19 SBT, skaters were divided into elite (n = 17), subelite (n = 64), and nonelite (n = 23) groups. Pacing behavior was analyzed using the 0- to 300-m, 300- to 700-m, 700- to 1100-m, and 1100- to 1500-m times, expressed as a percentage of final time. Mixed analyses of variance were used for statistical analyses. Results: With age, pacing behavior generally developed toward a slower 0- to 300-m and 1100- to 1500-m and a faster midsection relative to final time. While being faster on all sections, the elite were relatively slower on 0- to 300-m (22.1% ± 0.27%) than the subelite and nonelite (21.5% ± 0.44%) ($P < .01$) but relatively faster on 300- to 700-m (24.6% ± 0.30%) than the nonelite (24.9% ± 0.58%) ($P = .002$). On 700- to 1100-m, the elite and subelite (26.2% ± 0.25%) were relatively faster than the nonelite (26.5% ± 0.41%) ($P = .008$). Differences in the develop- ment of pacing behavior were found from U17 to U19, with relative 700- to 1100-m times decreasing for the elite and subelite (26.2% ± 0.31% to 26.1% ± 0.27%) but increasing for the nonelite (26.3% ± 0.29% to 26.5% ± 0.41%) ($P = .014$). Conclusions: Maintaining high speed into 700 to 1100 m, accompanied by a relatively slower start, appears crucial for high performance in 1500-m speed skating. Generally, juniors develop toward this profile, with a more pronounced development toward a relatively faster 700- to 1100-m from U17 to U19 for elite junior speed skaters. The results of the current study indicate the relevance of pacing behavior for talent development.

Keywords
Exercise performance, speed skating, time trial, talent development and talent identification

Introduction

In many individual time-trial sports such as speed skating, optimal energy distribution is essential for successful performance (Foster et al., 1993). Before finishing the race, all available energy stores must be used, but not so early in a race that a meaningful slowdown can occur (Foster et al., 1993). This pacing behavior of an athlete can be characterized by the velocity profile during the race. During middle-distance events in various sports of duration similar to that of 1500-m speed skating (~2 min), a fast start followed by a decrease in velocity toward the end of the race is commonly observed (Foster et al., 2003; Foster et al., 2004; Muehlbauer, Schindler, & Panzer, 2010; Sandals, Wood, Draper, & James, 2006; Thompson, MacLaren, Lees, & Atkinson, 2003). However, how fast this fast start should be in a 1500-m speed-skating time trial could not be unambiguously concluded based on previous studies(Hettinga et al., 2011; Muehlbauer et al., 2010; Stoter et al., 2016). In elite speed skaters it appeared that better-performing athletes start, in relation to total time, relatively slower on the first 0 to 300 m but are relatively faster on the 700- to 1100-m section than lesser-performing athletes (Muehlbauer et al., 2010). On the other hand, modeling studies in cycling and speed skating calculated that starting relatively faster than self-paced performance would result in faster finishing times(Hettinga et al., 2011). Nevertheless, imposing a relatively faster start in speed-skating practice did not result in faster finishing times, probably due to neurophysiological limitations related to the technical demands of speed skating (Hettinga et al., 2011; Stoter et al., 2016). These findings seem to indicate that although a rather fast start is important in relation to optimal pacing behavior in 1500-m speed skating, the ability to maintain velocity throughout the remainder of the race might be just as or even more important and should be further investigated.

Most speed skaters skate their first 1500-m time trial around the age of 13 years. Before transitioning to senior level (age 19 y), they progress through national competition for junior speed skaters on the 1500-m classified into 3 age categories; 13 to 14 years (U15), 15 to 16 years (U17), and 17 to 18 years (U19). During these years, the athletes change due to influence of maturation, learning, and training (Elferink-Gemser, Jordet, Coelho-E-Silva, & Visscher, 2011). As literature has shown that athletes reaching the elite level appear to be more efficient learners than nonelite athletes(Anshel & Porter, 1996; Cleary & Zimmerman, 2001; Jonker, Elferink-Gemser, & Visscher, 2010; Toering, Elferink-Gemser, Jordet, & Visscher, 2009), there might also be a difference in the learning and development of pacing behavior for speed skaters who reach different performance levels in their later career (Elferink-Gemser et al., 2011). As pacing behavior can be seen as a goal-directed process of decision making (Smits, Pepping, & Hettinga, 2014) in which athletes need to decide how and when to invest their energy during the race, it could be proposed that pacing behavior is a cognitive skill that needs to be developed during adolescence and should be incorporated in talent-development programs. Furthermore, experience is known to play an important role in the development of pacing behavior(Mauger, Jones, & Williams, 2009; Micklewright, Papadopoulou, Swart, & Noakes, 2010), and the skill to adopt adequate pacing behavior during physical activity has been found to develop in schoolchildren during childhood from age 4 onward (Micklewright et al., 2012). The development of adequate pacing behavior is important for performance and therefore potentially of great interest for talent-development programs. To our knowledge, it is not known how pacing behavior develops during adolescence in general, and for junior speed-skating athletes in particular.

Therefore, the purpose of the current study was to provide insight on pacing behavior of junior athletes by analyzing how elite, subelite, and nonelite junior speed skaters pace their 1500-m time trials during adolescence throughout different age categories and whether there are differences between performance groups for the development of pacing behavior during adolescence.

Methods

Subjects

Longitudinal data on pacing behavior and performance were collected from 104 junior male speed skaters who had been active in official speed-skating competitions over the past 6 years. Their mean age was 19.0 (± 0.6) years at the end of the competitive season 2014–15. Race data from the 1500-m in the 2010–11, 2012–13, and 2014–15 seasons were obtained, when the subjects were in age categories U15, U17, and U19 respectively. All boys were in the top 150 of the national Dutch SARA rankings of the Royal Dutch Speed Skating Association (KNSB) for the 1500-m during season 2014–15. The study was approved by the ethics committee of Human Movement Sciences at the University of Groningen in the spirit of the Helsinki Declaration.

Procedure

Using a database from the KNSB and the skating association of Haarlem, the Netherlands (www.osta.nl), a complete data set was obtained, with the season-best times (SBTs) for the 1500-m time trials for season 2010–11 (U15), season 2012–13 (U17), and season 2014–15 (U19) (N = 312). Only 1500-m time trials at Dutch speed-skating rinks at sea level were included to exclude the effect of altitude. Some races might have been performed on outdoor or semi-outdoor speed-skating rinks. Nevertheless, high-quality conditions can be achieved on these artificial-ice rinks in calm weather conditions. Of the SBTs, the absolute time spent on 4 race sections—0 to 300 m (S1), 300 to 700 m (S2), 700 to 1100 m (S3), and 1100 to 1500 m (S4)—was obtained. To operationalize pacing behavior, the absolute section times (ASTs) were converted into relative section times (RSTs) similar to Muehlbauer et al. 2010. This was done by expressing section times as a percentage of the total time, leading to relative 0- to 300-m

(RST1), 300- to 700-m (RST2), 700- to 1100-m (RST3), and 1100- to 1500-m (RST4) section times. The times were measured using electronic systems and transponder systems with accuracy of one-hundredth of a second (International Skating Union, 2016). Finally, the number of 1500-m races the subjects skated in official competition before the moment of skating their SBT U19 was obtained as indication of their race experience in the 1500-m.

As only a few can make it to the top, it is of interest for talent development to study the average versus those few who are at the end of the performance spectrum. Therefore, the current study divided the athletes into 3 performance groups based on the U19 SBTs and the corresponding standard deviation (SD). The subelite performance group (n = 64) consisted of all subjects with an SBT within 1 SD of the mean SBT of the entire group (SBT = SBT mean ± SD), the elite performance group (n = 17) consisted of subjects with faster times (SBT < SBT mean − SD), and the nonelite performance group (n = 23) consisted of subjects with slower times (SBT > SBT mean + SD). Information about the performance groups is shown in Table 1.

Statistical analysis

Statistical analysis was done with IBM SPSS Statistics 20. A 1-way ANOVA, with Bonferroni post hoc analysis, was used to test differences between groups in SBT and race experience per age category.

Mixed analysis of variance was performed for SBT, AST1,AST2, AST3, AST4, RST1, RST2, RST3, and RST4 separately, with age category (U15, U17, and U19) as within-subject variable and performance group as between-subjects variable. If the assumption of sphericity was violated, degrees of freedom were corrected (Huynh–Feldt). A pairwise comparison with Bonferroni correction was used as a post hoc test to find out which performance groups differed significantly. In addition, 95% confidence intervals (CI) were defined for the between-subjects effects. The level set for significance was $P < .05$.

Results

For each of the 104 speed skaters, three 1500-m time trials (1 in each age category) each with 4 race sections were analyzed. There were no missing values. Descriptive statistics of the 3 performance groups are provided in Table 1, with age, SBT, race experience, and the percentage per performance group representing the fastest group in each age category. The means and SDs of the SBTs, the ASTs, and the RSTs are shown in Tables 2 and 3. Figure 1 shows the development of SBTs and the RSTs over the 3 age categories for the 3 performance groups.

SBT Development per performance group

Figure 1.1 shows the SBTs for the different performance groups in different age categories. The means and SDs are shown in Tables 2 and 3. A main effect for performance group ($F_{2,101}$ = 53.54, P <.01) was found. The post hoc analysis showed significant differences between the elite and subelite performance groups (P < .01, 95% CI [−10.67, −4.32]), between the elite and nonelite performance groups (P < .01, 95% CI [−19.38, −11.93]), and between the subelite and non-elite performance groups (P < .01, 95% CI [−10.99, −5.33]), with the elite performance group having the fastest SBTs, followed by the subelite performance group. The nonelite performance group had the slowest SBTs. For SBT, a main effect for age category ($F_{1.38,139.80}$ = 199.81, P < .01) was found, indicating a general improvement of SBT (faster) when speed skaters get older. An interaction effect of age category by performance group ($F_{2.77,139.80}$ = 2.77, P = .049) was found for SBT, showing different development of SBT for the 3 performance groups from U15 to U17 (P = .012) and from U17 to U19 (P = .011). From U15 to U17 the SBTs of the 3 performance groups converge, with the higher the performance group, the lower the SBT improvement. From U17 to U19, the elite and the subelite performance groups continued improving their SBTs, whereas the nonelite performance group deteriorated in SBTs.

RST1 Development per performance group: How fast is their start compared with their final time?

Figure 1.2 shows RST1s (expression of 0- to 300-m section time as a percentage of SBT) for the different performance groups in different age categories. The means and SDs are shown in Tables 2 and 3. A main effect for performance group ($F_{2,101}$ = 11.31, P < .01) was found for RST1. Post hoc analysis showed that the elite performance group spent relatively more time in the first 300 m (22.0% ± 0.24 of SBT) than the subelite (21.6% ± 0.44, P <.012, 95% CI [0.11, 0.65]) and nonelite (21.4% ± 0.39, P < .01, 95%CI [0.30, 0.92]) performance groups. For RST1 a main effect for age category ($F_{1.71,172.65}$ = 10.18, P < .01) was found, indicating relatively more time spent on the first 300 m from U15 to U17 (from 21.4%± 0.54% to 21. 7% ± 0.50% of SBT) (P < .01). No interaction effect was found for RST1 ($F_{3.42,172.65}$ = 1.77, P = .148), indicating that no differences in development of the relative time spent in the first segment between the performance groups were demonstrated during adolescence.

Table 1. Age, season best-time (SBT), race experience, and percentage representing fastest group in different age categories for the 3 performance groups, mean ± SD

	Elite (n=17)			Subelite(n=64)			Nonelite(n=23)		
	U15	U17	U19	U15	U17	U19	U15	U17	U19
Age (y)	15.25 ± 0.55	17.25 ± 0.55	19.25 ± 0.55	15.91 ± 0.56	17.91 ± 0.56	18.91 ± 0.56	15.93 ± 0.63	17.93 ± 0.63	18.93 ± 0.63
SBT (s) elite-sub-non**	126.82 ± 6.45**	117.82 ± 2.89**	114.97 ± 2.27**	135.61 ± 8.26**	124.59 ± 5.05**	121.90 ± 3.30**	145.25 ± 11.41**	130.32 ± 5.02**	131.02 ± 1.93**
Experience (No. of 1500-m races), elite-sub-non*, elite-sub-non**	20.65 ± 7.2**	44.94 ± 11.2**	61.8 ± 14.1**	12.75 ±8.6*	30.78 ± 14.1**	45.3 ± 15.6**	8.04 ± 6.1*	21.48 ± 8.7**	30.4 ± 9.7**
Representation fastest group in age cat. (%)	58.8%	64.7%	100%	41.2%	35.3%	0%	0%	0%	0%

Abbreviations: U15, 13- to 14-year-olds; U17, 15- to 16-year-olds; U19, 17- to 18-year-olds; elite-sub-non, significant post hoc difference between elite and subelite skaters, elite and nonelite skaters, and subelite and nonelite skaters. $^{*}P < .05$. $^{**}P < .01$

Table 2. Season-best time (SBT), absolute section time (AST), and relative section time (RST) per performance group, mean ± SD

	Elite (n=17)	Subelite (n=64)	Nonelite (n=23)
SBT (s), [a] elite-sub-non	119.9 ± 3.4	127.4 ± 5.0	135.5 ± 5.1
AST1 (s),[a] elite-sub-non	26.3 ± 0.6	27.5 ± 0.9	28.9 ± 1.1
RST1 (%),[a] elite(sub,non)	22.0 ± 0.2	21.6 ± 0.4	21.4 ± 0.4
AST2 (s),[a] elite-sub-non	29.7 ± 0.9	31.8 ± 1.5	34.0 ±1.6
RST2 (%),[a] elite-non	24.8 ± 0.2	24.9 ± 0.3	25.1 ± 0.4
AST3 (s),[a] elite-sub-non	31.3 ± 0.9	33.5 ± 1.6	35.9 ± 1.6
RST3 (%),[a] elite (sub,non)	26.1 ± 0.1	26.3 ± 0.3	26.4 ± 0.3
AST4 (s),[a] elite-sub-non	32.5 ± 1.2	34.7 ± 1.3	36.7 ± 1.3
RST4 (%)	27.2 ± 0.3	27.2 ± 0.4	27.1 ± 0.6

Abbreviations: elite-sub-non, significant post hoc differences between elite and subelite skaters, elite and nonelite skaters, and subelite and nonelite skaters; elite-(sub,non), significant post hoc differences between elite and subelite skaters and elite and nonelite skaters, not between subelite and nonelite skaters. [a] Main effect performance group.

Table 3. Season best time (SBT), absolute section time (AST), and telative section time (RST) for each performance group per age category, mean ± SD

	Elite (n=17)			Subelite (n=64)			Nonelite (n=23)		
	U15	U17	U19	U15	U17	U19	15	U17	U19
SBT (s), 15-U17-U19,[a] U15-U17-U19[b]	126.8 ± 6.5	117.8 ± 2.9	115.0 ± 2.3	135.6 ± 8.3	124.6 ± 5.1	121.9 ± 3.3	145.3 ± 11.4	130.3 ± 5.0	131.0 ± 1.9
AST1 (s), U15-U17-U19[a]	27.7 ± 1.1	25.9 ± 0.5	25.4 ± 0.4	29.0 ± 1.4	27.1 ± 0.9	26.4 ± 0.8	30.8 ± 2.2	28.1 ± 1.0	27.8 ± 0.9
RST1 (%), U15-U17[a]	21.8 ± 0.4	22.0 ±0.3	22.1 ± 0.3	21.4 ± 0.6	21.7 ± 0.5	21.6 ± 0.6	21.3 ± 0.5	21.6 ± 0.5	21.2 ± 0.7
AST2 (s), U15-U17-U19[a]	31.7 ± 1.8	29.1 ± 0.8	28.3 ± 0.5	34.1 ± 2.4	31.0 ± 1.5	30.1 ± 1.0	36.9 ± 3.3	32.6 ± 1.6	32.6 ± 0.9
RST2 (%), U15-U17-U19[a]	25.0 ± 0.3	24.7 ±0.3	24.6 ± 0.3	25.1 ± 0.3	24.9 ± 0.3	24.7 ± 0.3	25.4 ± 0.5	25.0 ± 0.5	24.9 ± 0.6
AST3 (s), U15-U17-U19,[a] U15-U17-U19[b]	33.3 ± 1.8	30.8 ± 0.8	29.9 ± 0.7	35.9 ± 2.6	32.6 ± 1.6	31.9 ± 1.1	38.6 ± 3.3	34.3 ± 1.6	34.7 ± 0.8
RST3 (%), U15-U17,[a] U17-U19[b]	26.2 ± 0.2	26.1 ± 0.2	26.0 ± 0.2	26.4 ± 0.4	26.2 ± 0.3	26.1 ± 0.3	26.6 ± 0.3	26.3 ± 0.3	26.5 ± 0.4
AST4 (s), U15-U17[a]	34.2 ± 1.9	32.1 ± 1.1	31.4 ± 1.1	36.6 ± 2.2	33.9 ± 1.5	33.5 ± 1.1	39.0 ± 2.6	35.4 ± 1.5	35.6 ± 1.2
RST4 (%), U15-U17-U19[a]	27.0 ± 0.4	27.2 ± 0.4	27.3 ± 0.5	27.0 ± 0.5	27.2 ± 0.5	27.5 ± 0.6	26.8 ± 0.7	27.1 ± 0.8	27.5 ± 0.9

Abbreviations: U15, 13- to 14-year-olds; U17, 15- to 16-year-olds; U19, 17- to 18-year-olds; U15-U17-U19, significant post hoc differences for all age categories. When only 2 age categories are named, post hoc differences were limited to the indicated age categories.
[a] Main effect age category. [b] Interaction effect of age category by performance group.

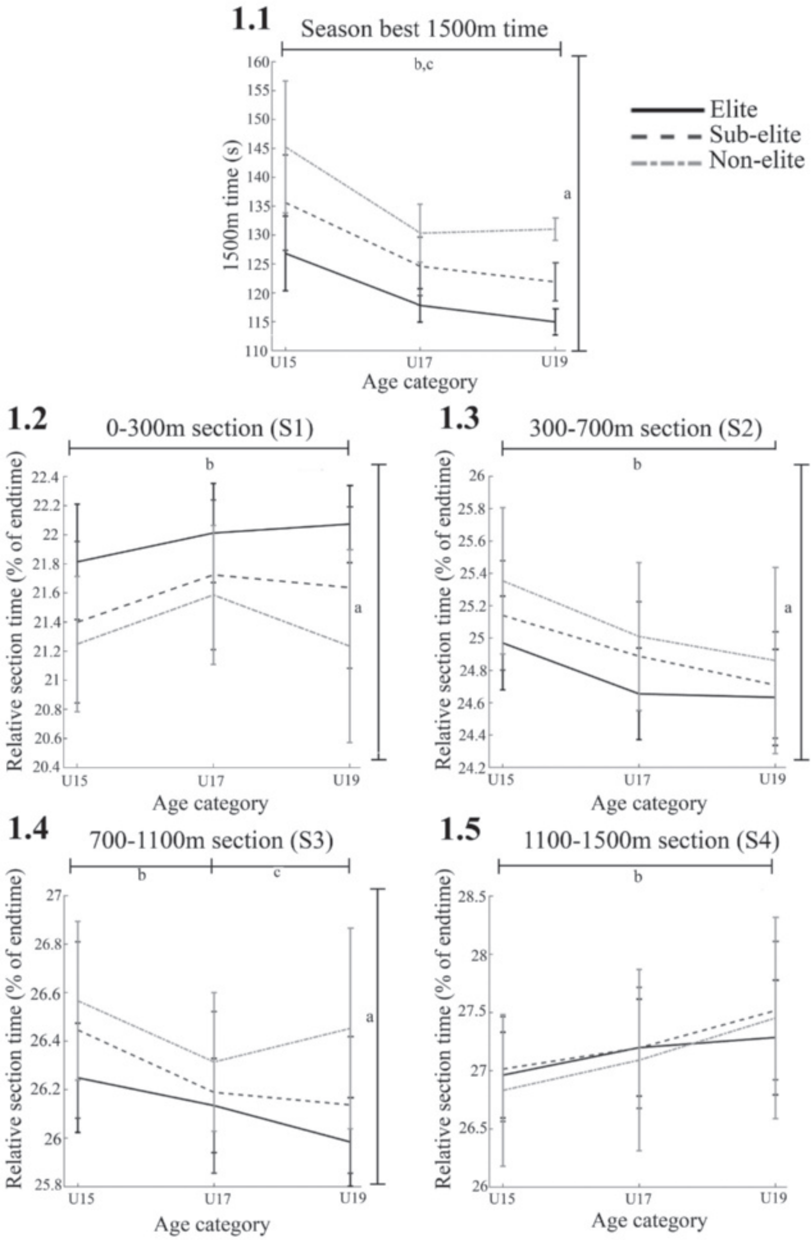

Figure 1. (1.1) Season-best time and relative (1.2) 0- to 300-m-section time, (1.3) 300- to 700-m-section time, (1.4) 700- to 1100-m-section time, and (1.5) 1100- to 1500-m-section time for the different age categories and performance groups, with lines representing means and error bars representing standard deviation. U15 indicates 13- to 14-year-olds; U17, 15- to 16-year-olds; U19, 17- to 18-year-olds.
[a] Main effect performance group. [b] Main effect age category. [c] Interaction effect of age category by performance group.

RST2 Development per performance group: How fast is their 300- to 700-m segment compared with their final time?

Figure 1.3 shows RST2s (expression of 300- to 700-m section time as a percentage of SBT) for the different performance groups in different age categories. The means and SDs are shown in Tables 2 and 3. A main effect for performance group ($F_{2,101}$ = 6.21, P <.013) was found. Post hoc analysis showed differences for the elite performance group versus the nonelite performance group (P <.012, 95% CI [−0.55, −0.10]), with the elite performance group spending relatively less time from 300 to 700 m (24.8% ± 0.20%) than the nonelite performance group (25.1% ± 0.36%). For RST2 a main effect for age category ($F_{2,202}$ = 43.97, P < .01) was found, indicating relatively less time spent from 300 to 700 m for older age categories (from 25.4% ± 0.45% to 24.9% ± 0.58% of SBT). No interaction effect was found for RST2 ($F_{4,202}$ = 0.75, P = .560), indicating that no differences in development of the relative time spent in segment 2 between the performance groups were demonstrated during adolescence.

RST3 Development per performance group: How fast is their 700- to 1100-m segment compared with their final time?

Figure 1.4 shows RST3s (expression of 700- to 1100-m-section time as a percentage of SBT) for the different performance groups in different age categories. The means and SDs are shown in Tables 2 and 3. A main effect for performance group ($F_{2,101}$ = 8.68, P < .01) was found. Post hoc analysis showed significant differences for the elite performance group versus the nonelite performance group (P < .01, 95% CI [−0.52, −0.13]) and for the subelite performance group versus the nonelite performance group (P < .018, 95% CI [−0.33, −0.04]), with the elite (26.1% ± 0.13%) and the subelite (26.3% ± 0.27%) performance groups spending relatively less time from 700 to 1100 m than the nonelite performance group (26.4% ± 0.26%). For RST3 a main effect for age category ($F_{1.94,196.11}$ = 21.65, P < .01) was found, indicating relatively less time spent in the 700- to 1100-m section in U17 than in U15 (26.4% ± 0.35% to 26.2% ± 0.31% of SBT) (P < .01). For RST3 an interaction effect of age category by performance group ($F_{3.88,196.11}$ = 2.72, P = .032) was found from U17 to U19 (P = .014). Results showed relatively less time spent on 700 to 1100 m for the elite (from 26.1% ± 0.19% to 26.0% ± 0.18%) and subelite (from 26.2% ± 0.33% to 26.1% ± 0.28%) performance groups, whereas the nonelite performance group spent relatively more time in 700 to 1100 m (from 26.3% ± 0.29% to 26.5% ± 0.41%).

RST4 Development per performance group: How fast is their 1100- to 1500-m segment compared with their final time?

Figure 1.5 shows RST4s (expression of 1100- to 1500-m-section time as a percentage of SBT) for the different performance groups in different age categories. The means and SDs are shown in Tables 2 and 3. No significant main effect for performance group was found ($F_{2,101}$ = 0.71, P = .495), indicating that the relative 1100- to 1500-m-section times were not different for the different performance groups. For RST4 a main effect for age category ($F_{2,202}$ = 23.47, P < .01) was found, indicating relatively more time spent in 1100- to 1500-m for older age categories (from 26.8% ± 0.65% to 27.5% ± 0.86% of SBT). No interaction effect was found for RST4 ($F_{4,202}$ = 0.82, P = .513), indicating that no differences in development between the performance groups were demonstrated during adolescence.

Discussion

The purpose of the current study was to provide insight on pacing behavior of junior athletes by analyzing how elite, subelite, and nonelite junior speed skaters pace their 1500-m time trials during adolescence throughout different age categories and whether there are differences between performance groups for the development of pacing behavior during adolescence. Our results showed that pacing behavior changes with age during adolescence and that there are differences between performance groups in pacing behavior. While being fastest on all sections, elite speed skaters spent relatively more time, expressed as a percentage of the 1500-m final time, on the start (section 1) and relatively less time in the midsections (sections 2 and 3) of the race than subelite and nonelite speed skaters. When they mature, athletes' pacing profiles generally develop toward the profile demonstrated by the elite group. The data showed that from U17 to U19, the development of pacing behavior was different for the performance groups, with the elite and subelite speed skaters developing more toward pacing behavior characterized by a relatively faster section 3, while the nonelite speed skaters develop toward a relatively slower section 3. For elite performance in the 1500-m, it appears important to make sure that a high speed can be maintained well into the third section of the race, even if this means that the first 300 m of the race needs to be performed more slowly than in previous performances. Again, it has to be acknowledged that "relatively slow" for the elite group still means faster absolute times than the speed skaters from the other performance groups.

The current study showed that during adolescence, pacing behavior of speed skaters changed over time. To our knowledge, the development of pacing behavior in junior athletes has not been studied before. Only 1 study has been conducted on the development of pacing behaviors in young individuals in general, and it included schoolchildren up to the age of 12 (Micklewright et al., 2012). The current study is therefore the first to describe the development of pacing behavior in youth athletes. The general trend visible in the current study is that athletes develop to faster ASTs and final times (see Table 3). However, expressed as a percentage of final time, RSTs develop toward a relatively slower start and relatively faster sections 2 and 3 over time (Figure 1) throughout their development.

Independent of development, elite junior speed skaters showed different pacing behaviors throughout adolescence compared with nonelite junior speed skaters. While being faster on all sections, elite junior speed skaters demonstrate a relatively slower start, followed by a relatively faster midsection. These results are in accordance with those of Muehlbauer et al. 2010, who showed that the best-performing senior elite speed skaters are relatively slower on the start but are better able to maintain high velocities in section 3 than the lesser-performing senior elites. Together with the observed development of the athletes toward a relatively slower start and final round, as well as the relatively faster midsection, it therefore appears that junior speed skaters develop toward the pacing behavior shown at senior elite level. This development is found in all performance groups during adolescence. However, the elite junior athletes demonstrated a pacing behavior that was already more skewed toward the profile related to elite performance from age 13 to 14 years onward. Moreover, differences in development were found in section 3 at the later stage of adolescence, with a more pronounced development toward a faster section 3 for the better-performing groups from U17 to U19. Elite junior athletes thus not only start with a pacing behavior that is more similar to elite performance at age 13 to 14 years but also distinguish themselves by a more pronounced development toward an elite-performance pacing behavior in the last phase of adolescence. These results of the developmental nature of pacing behavior during adolescence toward pacing behavior of senior elites provide evidence that pacing behavior is a skill associated with optimizing performance and therefore needs to be incorporated in talent-development programs. The ability to maintain high speeds well into the third section of the race could be further explored in relation to training. As pacing behavior is suggested to be based on the distribution of energy resources, the aerobic and anaerobic capacity of an individual are important for optimal pacing (Foster et al., 1993; Hettinga et al., 2011). Whether the elite speed skaters have developed better pacing behaviors throughout their adolescence or whether they are physically predisposed for the 1500-m and adapt their specific pacing behavior based on their changing physical capability during adolescence remains to be further investigated.

The current study was based on a unique sample of athletes, as all 104 athletes remained in speed-skating competition over 6 years during adolescence and were in the Dutch top 150 at age 17 to 18 years, competing at a very high level. As was noted in a recent literature review,[19] not many studies have explored the development of talent-related characteristics in youth skaters, and we are the first to longitudinally explore pacing behavior in youth athletes in this context. Nevertheless, experience of the performance groups differed, which might influence the development of pacing behavior. Being able to learn from previous experiences and use them to form and continuously update an adequate performance template has been mentioned in the literature as an important aspect of optimizing pacing behavior (Foster et al., 2009). For novices, experience in a certain distance improves performance over 6 consecutive time trials, but it is unknown when this effect of experience dissolves (Foster et al., 2009). The deterioration of performance for nonelite after U17, together with an average increase of race experience of this group from 21 to 30 races, reveals that more experience is not necessarily related to better performance. Therefore, we assume that experience was of only limited effect on our results. Nevertheless, more research is needed on the influence of experience on pacing behavior.

Practical applications

The study provides practical information that may be used as a benchmark by coaches and athletes to optimize athlete development. For example, a male speed skater in the category U19 might compare his pacing behavior with the pacing behavior of U19 elite junior speed skaters, who spend 22.1% of total race time in section 1, 24.6% in section 2, 26.0% in section 3, and the remaining 27.3% in section 4. The skater can, if necessary, adjust his pacing strategy toward the profile of elite junior speed skaters, keeping in mind his own physiological predisposition, and monitor whether changes in pacing strategy improve his performance.

Conclusion

The current study showed that during adolescence, pacing behavior generally develops toward a relatively slower start and final round and a relatively faster midsection (all expressed relative to final times) of the race compared with previous performances. For optimal performance, it seems crucial to be able to maintain high speed well into the third section, even if this means that the first 300 m of the race needs to be performed relatively slowly to ensure that speed can be maintained throughout the race. Elite speed skaters distinguish themselves from nonelite speed skaters by doing this from an early age and it is even more pronounced in the later phase (U17–U19) of their adolescence. Results of the current study provide support for the notion that pacing behavior is relevant for talent development.

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References

Anshel, M. H., & Porter, A. (1996). Efficacy of a model for examining self-regulation with elite and non-elite male and female competitive swimmers. *International Journal of Sport Psychology, 27*(3), 321-336.

Cleary, T. J., & Zimmerman, B. J. (2001). Self-regulation differences during athletic practice by experts, non-experts, and novices. *Journal of Applied Sport Psychology,* (13), 185-206.

Elferink-Gemser, M. T., Jordet, G., Coelho-E-Silva, M. J., & Visscher, C. (2011). The marvels of elite sports: how to get there? *British Journal of Sports Medicine, 45*(9), 683-684. doi:10.1136/bjsports-2011-090254 [doi]

Foster, C., De Koning, J. J., Hettinga, F., Lampen, J., La Clair, K. L., Dodge, C., . . . Porcari, J. P. (2003). Pattern of energy expenditure during simulated competition. *Medicine and Science in Sports and Exercise, 35*(5), 826-831. doi:10.1249/01.MSS.0000065001.17658.68

Foster, C., deKoning, J. J., Hettinga, F., Lampen, J., Dodge, C., Bobbert, M., & Porcari, J. P. (2004). Effect of competitive distance on energy expenditure during simulated competition. *International Journal of Sports Medicine, 25*(3), 198-204. doi:10.1055/s-2003-45260

Foster, C., Hendrickson, K. J., Peyer, K., Reiner, B., deKoning, J. J., Lucia, A., . . . Wright, G. (2009). Pattern of developing the performance template. *British Journal of Sports Medicine, 43*(10), 765-769. doi:10.1136/bjsm.2008.054841

Foster, C., Snyder, A. C., Thompson, N. N., Green, M. A., Foley, M., & Schrager, M. (1993). Effect of pacing strategy on cycle time trial performance. *Medicine and Science in Sports and Exercise, 25*(3), 383-388.

Hettinga, F. J., De Koning, J. J., Schmidt, L. J., Wind, N. A., Macintosh, B. R., & Foster, C. (2011). Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *British Journal of Sports Medicine, 45*(1), 30-35. doi:10.1136/bjsm.2009.064774

International Skating Union. Special regulations and technical rules, speed skating and short track speed skating 2016. https://knsb.nl/ wp-content/uploads/sites/98/2013/10/ISU-Reglement-en-Technisch- Reglement-Shorttrack-2016.pdf. Updated 2016.

Jonker, L., Elferink-Gemser, M. T., & Visscher, C. (2010). Differences in self-regulatory skills among talented athletes: the significance of competitive level and type of sport. *Journal of Sports Sciences, 28*(8), 901-908. doi:10.1080/02640411003797157 [doi]

Mauger, A. R., Jones, A. M., & Williams, C. A. (2009). Influence of feedback and prior experience on pacing during a 4-km cycle time trial. *Medicine and Science in Sports and Exercise, 41*(2), 451-458. doi:10.1249/MSS.0b013e3181854957 [doi]

Micklewright, D., Angus, C., Suddaby, J., St Clair Gibson, A., Sandercock, G., & Chinnasamy, C. (2012). Pacing strategy in schoolchildren differs with age and cognitive development. *Medicine and Science in Sports and Exercise, 44*(2), 362-369. doi:10.1249/MSS.0b013e31822cc9ec [doi]

Micklewright, D., Papadopoulou, E., Swart, J., & Noakes, T. (2010). Previous experience influences pacing during 20 km time trial cycling. *British Journal of Sports Medicine, 44*(13), 952-960. doi:10.1136/bjsm.2009.057315

Muehlbauer, T., Schindler, C., & Panzer, S. (2010). Pacing and performance in competitive middle-distance speed skating. *Research Quarterly for Exercise and Sport, 81*(1), 1-6.

Sandals, L. E., Wood, D. M., Draper, S. B., & James, D. V. (2006). Influence of pacing strategy on oxygen uptake during treadmill middle-distance running. *International Journal of Sports Medicine, 27*(1), 37-42. doi:10.1055/s-2005-837468 [doi]

Smits, B. L., Pepping, G. J., & Hettinga, F. J. (2014). Pacing and Decision Making in Sport and Exercise: The Roles of Perception and

Action in the Regulation of Exercise Intensity. *Sports Medicine (Auckland, N.Z.),* doi:10.1007/s40279-014-0163-0 [doi]

Stoter, I. K., MacIntosh, B. R., Fletcher, J. R., Pootz, S., Zijdewind, I., & Hettinga, F. J. (2016). Pacing Strategy, Muscle Fatigue, and Technique in 1500-m Speed-Skating and Cycling Time Trials. *International Journal of Sports Physiology and Performance, 11*(3), 337-343. doi:10.1123/ijspp.2014-0603 [doi]

Thompson, K. G., MacLaren, D. P., Lees, A., & Atkinson, G. (2003). The effect of even, positive and negative pacing on metabolic, kinematic and temporal variables during breaststroke swimming. *European Journal of Applied Physiology, 88*(4-5), 438-443. doi:10.1007/s00421-002-0715-0 [doi]

Toering, T. T., Elferink-Gemser, M. T., Jordet, G., & Visscher, C. (2009). Self-regulation and performance level of elite and non-elite youth soccer players. *Journal of Sports Sciences, 27*(14), 1509-1517. doi:10.1080/02640410903369919 [doi].


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