Staying on track

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Technique and performance

Changes in technique throughout a 1500-m speed skating time-trial in junior elite athletes: differences between sex, performance level and competitive seasons.

Chapter 5

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Abstract

Speed skating is a very technical sport. Still, relatively little is known about technical changes in junior speed skaters. Therefore, changes in technique throughout a 1500-m time-trial and pacing behavior of elite junior speed skaters are investigated to explore differences between sexes, performance level and competitive seasons.

At (inter)national 1500-m competitions, knee and push-off angles were obtained for 120 elite junior speed skaters (56 female, 64 male, age 17.6±1.1 years) per lap at 250m (lap 1), 650m (lap 2), 1050m (lap 3) and 1450m (lap 4). Additionally, 1500m end-time and lap-times were obtained to divide skaters in faster and slower performance groups and to analyze pacing behavior. Fifteen skaters (8 female, 7 male, age 17.3±1.5 years) were measured again at (inter)national competitions after 1.6±0.6 years. (Repeated measures) ANOVAs were used for statistical analyses ($p<0.05$).

Elite junior speed skaters increased their knee angles throughout the race ($p<0.005$), regardless of sex or performance level ($p>0.05$). Push-off angles increased from lap 1-3 ($p<0.001$), in which male showed a larger decay than female skaters ($P<0.05$), this holds for both performance groups ($p>0.05$). Faster skaters had lower knee and push-off angles than slower skaters ($p<0.05$). Men showed lower body angles than women ($p<0.001$). A relative slower start and faster 700-1100m race section were observed in faster male and female skaters compared to slower skaters ($p<0.05$). Longitudinal development over competitive seasons showed a shift towards lower push-off angles ($p=0.038$) and less decay in knee angles from lap 2-3 ($p=0.026$).

The present study showed that technique throughout the 1500m deteriorated. Deterioration in technique was regardless of performance level, even though pacing behavior was different. Male and female appear to increase push-off angles differently. The longitudinal development suggests changes in technique towards the senior level. Both cross-sectional and longitudinal results highlight the importance of studying juniors separately from seniors.

Keywords

Knee angles, push-off angles, pacing, athletic performance and talent

Introduction

Speed skating is a peculiar sport in which the technique is characterized by a crouched position and sideward push-off, needed to move forward (Fig 1). How far elite junior speed skaters already resemble Olympic skaters in this respect is hardly known and topic of the present study. In speed skating, a crouched position with small knee angles is necessary to reduce aerodynamic resistance and extend push-off length (de Boer et al., 1987; Konings et al., 2015; van Ingen Schenau, 1982; van Ingen Schenau, de Groot, & de Boer, 1985). However, when speed skaters fatigue, they typically show an increase in knee angles throughout the race, which is disadvantageous for the aerodynamics of the skaters (de Koning, Foster, Lampen, Hettinga, & Bobbert, 2005; Noordhof, Foster, Hoozemans, & de Koning, 2013; Stoter et al., 2016). Increasing knee angles is a way to manage the oxygenation dynamics of the working muscles as low knee angles, together with the high quasi-isometric muscular forces during the gliding phase in speed skating, cause a restriction of blood flow. This results in less oxygen delivered to the working muscles. By increasing their knee angles, a skater can actively decrease the restriction of blood flow and therewith increase oxygen delivery to the legs (Foster et al., 1999; Hettinga, Konings, & Cooper, 2016). Previous literature calculated that when higher knee angles cause 1 sec/lap loss of velocity due to higher aerodynamic resistance at a velocity of 35 sec/lap, they win 1 sec/lap by an increase of blood flow to the working muscle (Foster et al., 1999). However, higher knee angles will also make it harder to have a long push-off and therewith a good technique, since the leg is already closer to extension. This results in an additional negative effect of the increasing knee angles on the speed skating performance.

Dealing with the biomechanical benefits and the physiological disadvantages of a crouched position plays an important role in speed skating (Konings et al., 2015). In the present study we focus on the 1500-m time-trial, which takes around two minutes. Velocities up to 60 km/h can be reached and 50% of the metabolic energy is contributed by the aerobic system for which oxygen delivery is essential (van Ingen Schenau, de Koning, & de Groot, 1990). The distribution of energy over the race, so called pacing, is found to be of importance for 1500-m performance in junior and senior speed skating (Muehlbauer, Schindler, & Panzer, 2010; Wiersma, Stoter, Visscher, Hettinga, & Elferink-Gemser, 2017). The commonly shown pacing behavior in 1500-m speed skating is a fast start, followed by a decrease in velocity towards the end of the race (Muehlbauer et al., 2010; Stoter et al., 2016; Wiersma et al., 2017). This is quite similar to oxygenation dynamics measured during middle distance time-trials (1-2 minutes) in speed skating, with a fast desaturation of the leg muscles in the beginning of the race, followed by a slow recovery due to a higher blood flow in the remaining of the race (Hettinga et al., 2016). The recovery in oxygen delivery might be due to an increase in knee angles, which is observed throughout the 1500-m time-trial (de Koning et al., 2005; Noordhof, Foster, Hoozemans, & de

Koning, 2014; Stoter et al., 2016). Also, push-off angles were observed to increase throughout the 1500m (Noordhof et al., 2014). Changes in knee and push-off angles throughout the 1500m were found not to be related to changes in velocity (Noordhof et al., 2014).

Literature on changes in technique during 1500m speed skating were mainly done on senior speed skaters (Noordhof et al., 2014; Stoter et al., 2016). Lower push-off angles have been shown for male, compared to female speed skaters, and also lower push-off angles for better performing speed skaters (Noordhof et al., 2014). Only one article was found on junior athletes, but this study was limited to 8 athletes and combined male and female speed skaters in the analyses (de Koning et al., 2005). For junior speed skaters (age < 19 years), growth is of influence on body posture and performance development and therewith possibly on technique and maintenance of technique (de Koning, Bakker, de Groot, & van Ingen Schenau, 1994; Malina, 2010). For pacing behavior, junior speed skaters have a different pacing behavior than senior speed skaters for the 1500-m, but they develop during adolescence towards the senior pacing profile, which is a relatively slower start and faster 700-1100-m race section (Muehlbauer et al., 2010; Wiersma et al., 2017). These differences in pacing profiles between senior and junior speed skaters might also be present in the profiles of changes in technique. If so, this has practical implications for trainers and coaches to evaluate and improve technique for junior speed skaters.

The present study investigates the profile of changes in knee and push-off angles throughout a 1500-m time-trial of elite junior speed skaters and investigates differences between sexes and performance level. Additionally, longitudinal development of maintenance of technique will be explored over competitive seasons to provide perspectives on the development of elite junior speed skaters towards senior level. It is hypothesized that female junior speed skaters will have higher push-off angles than male junior skaters and that better performing junior speed skaters have lower push-off angles than their less performing peers. Knee angles are hypothesized to be similar across sexes, but might be better maintained by the older and better performing junior speed skaters.

Materials and methods

Participants

In total, 123 Dutch junior speed skaters (58 female, 65 male, age 17.6 ± 1.1 years), who skated at national and international level, participated in the study. Measurements were done during national and international public championships, hosted in the Netherlands. No informed consents were obtained as the skaters were filmed at a public event and performance data was publicly available online. This study and the waiver of the informed consent was approved by the local ethical committee (University Medical Center Groningen, NL) on number ECB/2012.01.31_2 and is in accordance with the Declaration of Helsinki.

Experimental procedures

Measurements were performed at four national and international junior competitions from 2010-2014. All competitions were in The Netherlands on indoor 400-m ice-tracks and held at the end of the competitive season (February/March). Skaters competed within the age-category under 17 (U17) when they were 15 or 16 years at the start (July 1st) of the speed skating season or in the age category under 19 (U19) when they were 17 or 18 years at the start of the season. Age at competition date was based on year and month of birth, which was obtained online (McClennan, 2018). The 1500-m season best time per skater was also extracted from online data (McClennan, 2018). Only the best Dutch junior speed skaters were selected to compete in the competitions. The 1500-m season best times of the junior speed skaters were on average 115.7 ±3.6 of the prevailing senior world record, which was 111.79 seconds for female and 101.04s for male skaters between 2010 and 2014 (International Skating Union, 2019).

Split-times at 0-300 m, 300-700 m, 700-1100 m, 1100-1500 m, and 1500-m competition end-times were obtained from the organizing committee, who used electronic timing systems with an accuracy of one hundredth of a second. Performance was defined as the end-time presented as a percentage of the prevailing world record. Pacing behavior was defined as split-times converted to a percentage of the corresponding 1500-m competition end-time. This was done to compare skaters from different performance levels on their pacing behavior (Wiersma et al., 2017). To exclude any irregular events, i.e. falling, speed skaters with an 1500-m competition end-time over 8% above their season best time, which was obtained online (McClennan, 2018), were excluded from analyses (2 female and 1 male). The 8% was based on boxplot analyses of all competition end-times converted to a percentage of season best time. In total, 120 Dutch junior speed skaters (56 female, 64 male) were included for further analyses.

The present study measured knee and push-off angles to quantify technique, which is a commonly used method in speed skating (de Boer et al., 1987; Noordhof et al., 2013; Noordhof et al., 2014; Stoter et al., 2016; van Ingen Schenau, de Groot, & Hollander, 1983; van Ingen Schenau & de Groot, 1983; van Ingen Schenau et al., 1985). The measurement set-up is illustrated in Fig 1. During the 1500 m, elite junior speed skaters were recorded with two high resolution camera's (1920x1080 pixels) at 25 frames per second at the straight at 250m (lap 1), 650m (lap 2), 1050m (laps 3) and 1450m (lap 4).

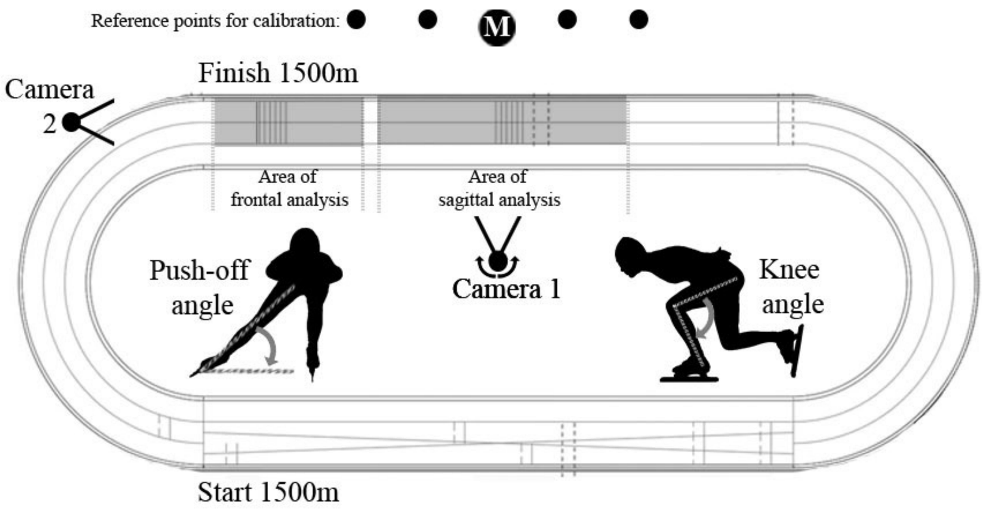

Figure 1. Measurement set-up to obtain knee angles (sagittal plane) and push-off angles (frontal plane) of the speed skaters. M represents the main reference point for the rotatable camera 1.

Knee angles

Camera 1 was positioned on the middle of the ice-track, 25m from the inner lane, at a height of 1.35m with a fixed zoom focusing on the area of analysis of the sagittal plane (Fig 1). Skaters were followed by the camera from the beginning of the straight to the end of the straight to get a good focus on the moving skater, keeping the skater in the middle of the video.

When the viewing angle of the rotatable camera to the skaters was not perpendicular to the straight, and therewith not perpendicular with the direction of the skaters, knee angles were corrected for the off-set of the viewing angle of the camera. To define the viewing angle of the camera a main reference point was marked right in front of the camera perpendicular to the straight (Fig 1). The off-set of the viewing angle of the camera was defined by obtaining the perpendicular distance of the camera to the main reference point and the distance from the main reference point towards the calibration point in line with the viewing angle of the camera towards the skater (Fig 1).

Knee angles were obtained when the skater was closest to the camera, with one leg in gliding phase and the other leg in recovery phase, see Fig 1. Per measurement five frames were used, the frame in which the skater was closest to the position illustrated in Fig 1 and the 2 frames before and after this moment in which the skater was still in gliding phase were used for analysis. The knee angle was obtained using the location of the hip (trochanter major), the knee (epicondylus lateralis) and the ankle (malleolus lateralis) of the gliding leg. Further analyses were done with the average of the five frames per measurement.

Push-off angles

Camera 2 was placed outside the 400-m ice-track in the extension of the straight at a height of 1.35m, with a fixed zoom focusing on the area of analysis of the frontal plane (Fig 1). Camera 2 filmed the frontal plane of the approaching skater to record the push-off angles. The push-off angle is the angle between the push-off leg with the horizontal line at the end of the push-off phase just before the first instance a part of the skate leaves the ice, see Fig 1. The position of the push-off leg was obtained using the location of the front-tip of the skate and the hip of the extending leg. Push-off angles were obtained from two following strokes, left and right, at the end of the straight. Per stroke two frames were used to analyze the angle between the push-off leg and the horizontal. Further analyses were done with the average of the four frames.

Previous observations, based on two raters, rating 56 individuals, defined the intraclass correlation coefficient (single measures) for push-off angles (ICC=.76) and knee angles (ICC=.55). For push-off angles this indicates a good ICC, for knee angles a moderate ICC (Koo & Li, 2016).

Cross-sectional data

Per age-category and sex, the 120 skaters were divided into faster and slower performance groups, based on their 1500-m end-time. Skaters with a 1500-m end-time below the average of their age-category and sex in the present study (female: 15-16 yrs=121.1±4,1 %WR and 17-18 yrs= 120.6±4.3 %WR and male: 15-16 yrs = 120.3±5.5 %WR and 17-18 yrs= 117.1±2.7 %WR) were assigned to the faster performance group (26 female, 37 male). The others were assigned to the slower performance group (30 female, 27 male).

Longitudinal data

Fifteen (8 female, 7 male) of the 120 skaters were measured twice in the above mentioned elite junior 1500-m competitions, with at least one year in between measurements. The two measurements of the 15 skaters were used to explore longitudinal development of changes in knee and push-off angles throughout the 1500 m in speed skating.

Statistics

All statistical analyses were performed using SPSS version 25, and significance was set at $p < 0.05$.

Cross-sectional data

Descriptive statistics were computed using independent t-tests to reveal differences in 1500-m season best time, age at competition, and the relative time spend on four race segments between performance categories for female and male skaters separately, with Cohen's d (d) representing effect sizes. Effect sizes are considered small (d=0.2), moderate (d=0.6), large (d=1.2), very large (d=2.0) and extremely large (d=4.0) (Hopkins, Marshall, Batterham, & Hanin, 2009).

Repeated measures analysis of variance (ANOVA) explored changes in knee and push-off angles throughout the 1500-m time-trial for 120 skaters, with laps as within subject factor and sex and performance group as between subject factors. When sphericity was assumed, Greenhouse-Geisser correction was applied. Contrasts (repeated) were used when main or interaction effects with laps were found.

Longitudinal data

Descriptive statistics were computed using a paired t-test to find differences between the first and second measurement for 1500-m season best time, 1500-m competition end-time and the relative time spend on four race segments, with Cohen's d (d) representing effect sizes.

Repeated measures ANOVA was used for finding differences in the development of the 15 junior speed skaters regarding changes in knee and push-off angles within the race, with measurement (first or second) and laps (1-4) as within subject variables and sex as between subject variable. When sphericity was assumed, Greenhouse-Geisser correction was applied. Contrasts (repeated) were used when main or interaction effects with laps were found.

Results

Cross-sectional data

Descriptive statistics on 1500-m season best times, age at competition, 1500-m competition end-time, and relative time spend on the four race segments of the 1500 m, are specified per performance category for female and male skaters separately in table 1. Season best times were faster in the faster group for both women and men ($p<0.001$). Age at competition was no different for the faster and slower groups per sex ($p>0.05$). Compared to the slower group, the faster group showed a higher relative time spend on the 0-300-m section in women ($p=0.007$) and men ($p<0.001$). Relative times spend on the 300-700-m section was similar for both performance groups in women and men ($p>0.05$). Relative time spend on the 700-1100 m was lower for the faster group (i.e., they were faster) for women ($p=0.036$) and men ($p=0.001$) than the slower group. Final race segment did not show differences between performance groups for female skaters ($p=.311$), but male faster skaters were relatively faster in the 1100-1500-m race segment ($p=0.048$).

Table 1. Descriptive statistics (mean±SD) of 120 elite junior speed skaters with 1500-m season best time and age, 1500-m end-time and relative time spend on the four race segments of the 1500-m competition. Presented per performance group for female and male separately.

	Female			Male		
	Faster (n=26)	Slower (n=30)	d	Faster (n=37)	Slower (n=27)	d
1500-m season best time seconds	126.63 ±3.58	131.18** ±2.28	-1.52	115.18 ±2.77	119.82** ±3.62	-1.44
(Inter)national junior 1500-m competition:						
Age years	17.4 ±1.0	17.4 ±1.2	0.0	17.9 ±0.93	17.7 ±1.2	0.19
1500-m end-time seconds	128.92 ±2.74	135.49** ±2.64	-2.44	116.28 ±2.13	122.18** ±3.78	-1.92
Relative time 0-300m % of end-time	21.60 ±0.44	21.29* ±0.41	0.73	22.04 ±0.35	21.60** ±0.42	1.14
Relative time 300-700m % of end-time	24.78 ±0.29	24.81 ±0.33	-0.1	24.69 ±0.26	24.66 ±0.35	0.10
Relative time 700-1100m % of end-time	26.18 ±0.32	26.34* ±0.22	-0.58	25.96 ±0.23	26.17* ±0.24	-0.89
Relative time 1100-1500m % of end-time	27.43 ±0.47	27.56 ±0.46	-0.28	27.31 ±0.40	27.57* ±0.63	-0.49

Effect sizes are presented in column 'd'.
Differences between performance categories are indicated by * ($p<0.05$) and ** ($p<0.001$).

For knee angles, a main effect for laps ($F(2.7,307.9)= 112.1$, $p<0.001$) was found, with knee angles increasing from lap 1 to lap 2 ($F(1,116)=122.9$, $p<0.001$), from lap 2 to lap 3 ($F(1,116)=22.7$, $p<0.001$), and from lap 3 to lap 4 ($F(1,116)=4.9$, $p=0.028$). No interactions effects were found, indicating similar decay in knee angles, regardless sex and performance level ($p=0.110$). Between subject effects were found for sex ($F(1,116)=17.1$, $p<0.001$) and performance level ($F(1,116)=10.6$, $p=0.002$). With 109.4± 5.7 °, male speed skaters showed overall lower knee angles than female skaters, who showed an average knee angle of 114.2± 6.5 °. Also the faster group showed overall lower knee angles than the slower group. No interaction effect of the between subject variables sex and performance level were found ($p>0.05$). Changes in knee angles for female and male skaters can be seen in Fig 2A-B.

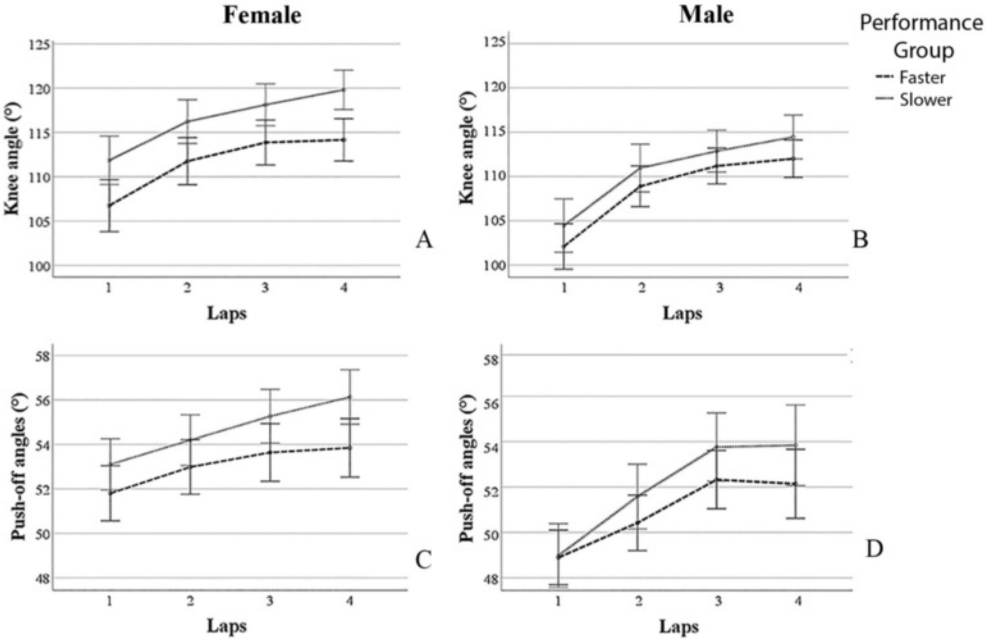

Figure 2. Changes in knee (A and B) and push-off (C and D) angles for the faster and slower performance groups, for female (A and C) and male (B and D) skaters separately. Error bars representing 95% confidence interval of the mean.

The analyses for push-off angles showed a main effect for laps ($F(2.8,321.4)= 65.186$, $p<0.001$), with push-off angles increasing from lap 1 to lap 2 ($F(1,116)=49.483$, $p<0.001$) and from laps 2 to lap 3 ($F(1,116)=33.723$, $p<0.001$), but not from lap 3 to lap 4 ($p=0.394$). An interaction effect was found for laps*sex ($F(2.8,321.4)= 5.681$, $p=0.001$), indicating that women had less decay in push-off angles than men from laps 1 to lap 2 ($F(1,116)=4.160$, $p=0.044$) and from lap 2 to lap 3 ($F(1,116)=5.548$, $p=0.022$). There was no interaction effect with performance level ($p>0.05$). Between subject effects were found for sex ($F(1,116)=16.3$, $p<0.001$) and performance level ($F(1,116)=5.2$, $p=0.024$). Male speed skaters showed overall lower push-off angles (average = 51.4 ± 3.5°) than women (average = 53.9± 2.9°). Also the faster group showed overall lower push-off angles than the slower group. No interaction effect of the between subject variables sex and performance level were found ($p>0.05$). Changes in push-off angles for female and male skaters can be seen in Fig 2C-D.

Longitudinal data

Descriptive statistics for the first and second measurement are provided in table 2. Differences in the longitudinal data were found in corresponding 1500 m season best time ($p=0.003$), with better season best times at an older age. No difference in 1500 m competition end-times (p=.120) or race segments, 0-300 m (p=.550), 300-700 m (p=.758), 700-1100 m (p=.511) and 1100-1500 m (p=.338), were found between the two measurements.

Table 2. Descriptive statistics (mean±SD) of first and second (1.6±0.6 years later) measurements of elite junior speed skaters (female, male and total), with 1500-m season best time and age, 1500-m end-time and relative time spend on the four race segments of the 1500-m competition.

	Female (n=8)			Male (n=7)			Total (n=15)		
Measurement	First	Second	d	First	Second	d	First	Second	d
1500-m season best time seconds	128.30 ±5.02	125.32** ±3.81	0.67	113.47 ±3.12	112.31 ±3.53	0.35	121.38 ±8.68	119.20** ±7.64	0.27
1500-m competition:									
Age years	17.0 ±1.5	18.6** ±1.3	-1.14	17.6 ±1.4	19.1** ±1.2	-1.15	17.3 ±1.5	18.9** ±1.2	-1.18
1500-m end-time seconds	131.50 ±4.56	129.50 ±3.47	0.49	114.66 ±2.45	114.08 ±2.8	0.22	123.64 ±9.41	122.33 ±8.55	0.15
Relative time 0-300m % of end-time	21.66 ±0.43	21.60 ±0.56	0.12	22.10 ±0.06	22.03 ±0.24	0.40	21.87 ±0.38	21.80 ±0.48	0.16
Relative time 300-700m % of end-time	24.72 ±0.38	24.77 ±0.24	-0.16	24.65 ±0.11	24.53 ±0.21	0.72	24.69 ±0.28	24,66 ±0.25	0.11
Relative time 700-1100m % of end-time	26.23 ±0.23	26.16 ±0.31	0.26	25.88 ±0.24	25.85 ±0.14	0.15	26.07 ±0.28	26.02 ±0.29	0.18
Relative time 1100-1500m % of end-time	27.39 ±0.54	27.47 ±0.44	-0.16	27.36 ±0.25	27.59 ±0.32	-0.80	27.38 ±0.42	27.52 ±0.38	-0.35

Effect sizes are presented in column 'd'.
Differences between first and second measurements are indicated by ** (p<0.001).

Development of changes in knee and push-off angles throughout the 1500 m for all 15 elite junior speed skaters from the first measurement (mean age = 17.3 yrs) to the second measurement (mean age = 18.9 yrs) can be seen in Fig 3.

For knee angles, a main effect for laps were found (F(3,39)= 53.793, p<0.001), with knee angles increasing from lap 1 to lap 2 (F(1,13)=22.021, p<0.001), from lap 2 to lap 3 (F(1,13)= 22.644, P<0,001) and from lap 3 to lap 4 (F(1,13)=9.397, p=0.009). No main effect for measurement was found (p>0.05). An interaction effect of laps* measurements was found (F(3,39)= 3.241, p=0.032), with less decay from lap 2 to 3 in the second measurement (F(1,13)= 6.295, p=0.026). No interaction with sex was found (p>0.05). A between subject effect for sex

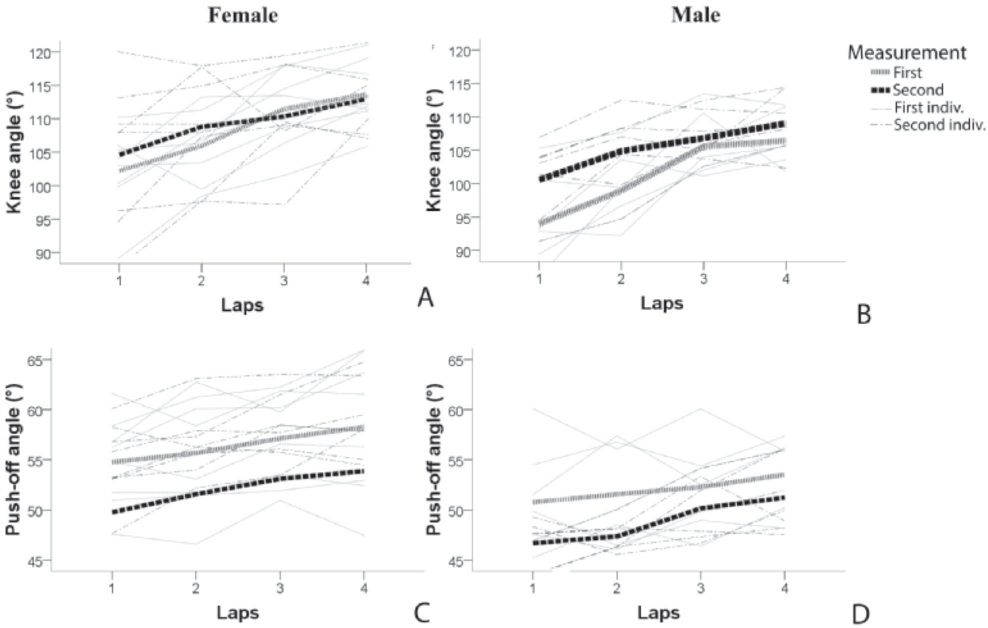

Figure 3. Changes in knee (A & B) and push-off (D & C) angles throughout the 1500 m for female (left) and male (right) elite junior speed skaters for the first measurement (mean age 17.3 yrs) and the second measurement 1.6±0.6 years later (mean age 18.9 yrs).

was found ($F(1,13)=7.263$, $p=0.018$), with higher knee angles for female skaters. Average and individual changes in knee angles for female and male skaters can be seen in Fig 3A-B.

For push-off angles a main effect was found for laps ($F(1.9,24.1) = 15.341$, $p<0.001$), with push-off angles increasing from lap 2 to lap3 ($F(1,13)=11.331$, $p=0.005$), and from lap 3 to lap 4 ($F(1,13)=5.101$, $p=0.042$), but not from lap 1 to lap 2 ($p=0.115$). A main effect for the two measurements ($F(1,13)= 5.340$, $p=0.038$) was also found, with lower push-off angles in the second measurement than in the first measurement. No interaction effect were found ($p<0.05$). A between subject effect for sex was found ($F(1,13)=11.582$, $p=0.005$), with higher push-off angles for female skaters. Average and individual changes in push-off angles for female and male skaters can be seen in Fig 3C-D.

Discussion

The aim of the present study was to investigate the profile of changes in technique throughout a 1500-m time-trial of elite junior speed skaters and investigates differences between sexes and performance level. It additionally explored possible longitudinal development of technique over competitive seasons to provide perspectives on the development of elite junior speed skaters towards senior level.

Cross-sectional data

The general profile for changes in knee and push-off angles for junior speed skaters was found to be an increase in body angles over the race, as expected. Knee angles in junior speed skaters increased in every lap, whereas push-off angles remained similar in the last two laps. The increase in knee and push-off angles can be considered as a deterioration of technique although various aspects play a role. The changes in knee angles might be a pacing like behavior to lessen the blood flow towards the working muscles throughout the race. A less crouched position, with higher knee angles, reduces the restriction of blood flow to the working muscles, but might simultaneously increase aerodynamic resistance (Foster et al., 1999; Hettinga et al., 2016). The trade-off between aerodynamic resistance and blood flow restriction was previously studied and showed to be neutralizing the effect of higher knee angles on velocity per lap (Foster et al. 1999). It remains unknown whether at some point, lowering knee angles even further has a larger effect on the restriction of blood flow than on aerodynamic resistance. More detailed studies are needed to confirm this.

Males showed lower knee and-push-off angles than female. Also the better performing junior speed skaters had lower knee and push-off angles. Differences between sex were only found for changes of push-off angles. Male junior speed skaters showed a larger decay in the first three laps than female junior skaters. Performance level appeared to have no impact on the changes of technique throughout the race.

A distinction in the profile of changes in body angles between the performance groups was expected, but not supported. The present study did show differences in pacing behavior between performance levels. A lower relative time spend on the 700-1100m section was found for the faster male skaters as well as for the faster female junior speed skaters (table 1). This is in accordance with previous literature on male speed skaters (Wiersma et al., 2017), though the present study is the first to show this in female junior speed skaters. This is a relevant finding for future research and for speed skating practice. Differences in pacing behavior were hypothesized to be related with changes in technique, but it might be that our measurement frequency, once per lap, was not sufficient to find this relationship. Furthermore, it should be kept in mind that the present study used a basic method for capturing body angles which limits the accuracy level with respect to more advanced systems using body markers (van der Kruk & Reijne, 2018). To ensure ecological validity and practical relevance the present study was done at official elite competition. As such, all included speed skaters were performing at one of the most important competition of the season, due to which a maximal effort can be expected to be given by all participants. A drawback of this choice is that using body markers was not possible. This impacted the ICC of our measurements, which was good for push-off angles, but moderate for knee angles. Caution was therefore taken in drawing conclusions on the knee angle data in the present study.

Longitudinal data

The longitudinal analyses showed that over competitive seasons only push-off angles decreased. Knee angles remained similar, but it appeared that junior speed skaters do develop the changes in knee angles towards less decay from lap 2-3. No changes in the strategy of increasing push-off angles appeared to be present. Though these results should be interpreted with care, as only 15 skaters could be included, and more longitudinal research is needed. Nevertheless the longitudinal analyses can add to the interpretation of differences between junior and senior speed skaters.

From junior to senior

Differences between sexes were found for both knee (female = 114.2°, male 109.4°) and push-off (female 53.9°, male 51.4°) angles. Previous literature on senior elite speed skaters also showed differences between sexes for push-off angles (Noordhof et al., 2014). For knee angles the same study showed no differences between sexes (average 108°) at senior elite level (Noordhof et al., 2014). Older studies did show higher knee angles for female (122°) than male (111.6°) elite senior speed skaters (van Ingen Schenau & de Groot, 1983; van Ingen Schenau et al., 1985). However, the female knee angles were relatively high and it might be that female competition was not as evolved as male competition in the 80's. It might therefore well be that differences in knee angles between sexes are not present at the senior level.

This hypothesis is supported by the longitudinal results of the present study. The elite juniors appear not to develop towards lower knee angles over 1.6 years. Maybe because they already adopt knee angles similar to senior elite skaters, which showed knee angles of around 108 degrees (Noordhof et al., 2014). Adopting lower knee angles might therefore be not beneficial for performance, when already low knee angles are adopted (Fig 3A-B). The only longitudinal difference found for knee angles was less decay from lap 2-3. Though only a small group (n=15) was analyzed and the measurement of knee angles had a moderate ICC, this put some new perspectives on the technical development of speed skaters from junior to senior level. Senior speed skaters were found to increase knee angles to 1100m, but maintain knee angles afterwards (Noordhof et al., 2014). The junior elites from the cross-sectional study showed an increase of knee angles in each lap. In sum, it might be that towards senior level the elite junior speed skaters do not adopt lower knee angles to improve performance, but learn to maintain knee angles throughout the race and probably cope with the restriction of blood flow associated with low knee angles.

The opposite development might be true for push-off angles, which are mainly related to the technical demands of speed skating. The cross-sectional results of the present study showed that junior speed skaters increase push-off angles from lap 1-3, but senior speed skaters were shown to increase push-off angles every lap (Noordhof et al., 2014). The longitudinal results did not show different decay in push-off throughout the race to confirm these changes, but did show a development towards lower push-off angles. It is therefore hypothesized that in order to improve performance towards senior level lower push-off angles are beneficial from the beginning of the race onward, even when this means that push-off angles maintain increasing over the race. More research is needed to confirm these hypotheses on longitudinal development of knee and push-off angles.

Practical guidelines

While keeping in mind its limitations, the present study provides preliminary practical implications for trainers, coaches and their skaters aiming to improve their 1500-m time-trial performance. Faster junior elite speed skaters have lower angles than their slower peers. On average, knee angles are around 103/109 (male/female) degrees in the first sections of the race increasing with around 7-9 degrees towards the end of the race. Push-off angles are at the start of the 1500 m around 49/53 (male/female) degrees and increase with around 2-3 degrees throughout the race. Regarding their pacing behavior, faster junior elite speed skaters distinguish themselves from the slower junior speed skaters by their pacing profile, which is characterized by a relative slower start and faster 700-100m section of the race. This holds for male as well as female skaters. For the development of technique towards the senior level in speed skaters, it might be better to focus on limiting the increase of knee angles during the midsection of the race. For push-off angles it might be more beneficial to train on decreasing the push-off angle over the entire race.

Conclusion

In elite junior speed skating, knee angles increase throughout the entire 1500-m time-trial, regardless of performance level and sex. Push-off angles increase from lap 1-3, regardless of performance level. Male skaters have a larger decay in these first three laps than female skaters. Faster skaters have a better technique than slower skaters throughout the race, but differences in pacing profiles between both performance groups was not visible in the profile of changes in their technique. The longitudinal results suggests changes in technique over competitive seasons, with lower push-off angles and better maintenance of knee angles in the midsection of the race at an older age. The results found in the present study emphasize the importance of studying junior and senior athletes separately, both for practical use and for understanding underlying mechanisms of performance.

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