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Article Title: Pacing Behaviour and Tactical Positioning in 1500 m Short-Track Speed Skating

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“Pacing Behaviour and Tactical Positioning in 1500 m Short-Track Speed Skating”

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Abstract

Purpose: To gain more insight in pacing behaviour and tactical positioning in 1500 m short-track speed skating, a sport in which several athletes directly compete within the same race.

Methods: Lap times and intermediate rankings of elite 1500 m short-track skating competitors were collected over the season 2012/13 (N=510; 85 races). Two statistical approaches were used to assess pacing behaviour and tactical positioning. Firstly, lap times were analysed using a MANOVA and for each lap differences between sex, race type, final-rankings, and stage of competition were determined. Secondly, Kendall’s tau-b correlations were used to assess relationships between intermediate and final-rankings. In addition, intermediate rankings of the winner of each race were examined. **Results:** In 1500 m (13,5 laps of 111,12m), correlations between intermediate and final-ranking gradually increased throughout the race (e.g. Lap 1: $r = 0.05$; Lap 7: $r = 0.26$; Lap 13: $r = 0.85$). Moreover, the percentage of race winners skating in the leading position was over 50% during the last three laps. Top finishers were faster compared to bottom-placed finishers only during the last five laps, with on average 0.1 – 1.5 sec faster lap times of the race winners compared to the others during the last five laps). **Conclusions:** Although a fast start led to faster finishing times, top finishers were faster than bottom-placed finishers only during the last five laps. Moreover, tactical positioning at one of the foremost positions during the latter phase of the race appeared to be a strong determinant of finishing position.

Key Words: Elite athletes, Interpersonal competition, Race-analysis, Opponents, Decision-making

Introduction

Pacing has been defined as the goal-directed regulation of exercise intensity over an exercise bout,¹ in which athletes need to decide how and when to invest their energy.² Both experimental³⁻⁵ as well as modelling studies⁶⁻⁸ revealed interesting insights on the regulation of exercise intensity, although, up until now this has been restricted to time-trial races.³⁻⁸ In contrast, pacing behaviour in competition against direct opponents has been rarely studied.^{2,9} Theoretical frameworks such as the central governor model^{10,11} or the recently proposed neurophysiologic model that related pacing behaviour to the neurophysiology of fatigue¹² led to many novel insights, but again mainly focused on the individual athlete.

Recently the importance of the environment in relation to pacing behaviour and decision-making has been stressed in reviews on the process of pacing from both a heuristic⁹ and an ecological psychological viewpoint.² Both papers aimed to add onto the existing body of knowledge, proposing a framework where pacing is seen as a decision-making process^{2,9} that is affected by, and responding to the environment.² To further expand our understanding of pacing behaviour in relation to the environment, the present study focussed on the pacing behaviour within 1500 m short-track speed skating. The tactical decision-making processes involved in sports using heats (such as short-track speed skating), is becoming more complex due to the emphasis of finishing position over completion time. In regular time-trial exercise, decisions about the variation of speed over the race are mainly based on the monitoring of energy expenditure.¹³ However, when racing against direct opponents, tactical decisions about when to accelerate or decelerate during a race can also be based on avoiding collisions, drafting possibilities, motivational aspects and expectations and responses to opponent's behaviours affecting winning chances.² An analysis of intermediate rankings (i.e. the ranking of each athlete per lap) in addition to speed changes throughout the race might provide a way

to get better insight as to how pacing behaviour is influenced by the interactions between competitors.

First attempts to study some form of pacing and tactics in the individual short-track distances have been made.¹⁴⁻¹⁶ Results showed that a starting position closest to the inside of the track (inside lane) was positively correlated with the final-ranking in 500 m short-track competitions, indicating better chances of winning the race when starting in the inside lane.^{14,15} The importance of the start-position seemed to decrease in 1000 m and 1500 m short-track races as no correlations were reported here between starting lane and final-ranking.¹⁵ These results might be an indication of a more tactical approach to the race when distance increases. In the present study, therefore, we have chosen to look into pacing behaviour and tactics in the relatively long 1500 m short-track speed skating event. A first insight has already been provided based on only seven races, indicating an increasing importance of the top intermediate rankings in the final laps.¹⁶ We will further explore competitive behaviour and study pacing and tactics of elite competitors over multiple races, to be able to identify most appropriate pacing and tactical strategies.

The aim of this study was to examine the pacing behaviour and tactical positioning in elite short-track speed skating during 1500 m events. To provide a better understanding of tactical positioning in a particular lap in relation to performance, the use of correlations between the intermediate and final-rankings were explored. In addition, all overtakings within a race as well as the intermediate lap positions of the winner of a race were analysed. Lastly, pacing behaviour was examined by the use of the “traditional” lap time analysis as done in time-trial sports. Consequently, both pacing behaviour as well as tactical positioning was evaluated in order to provide understanding about whether the athletes adapted their pacing behaviour based on the tactical importance of a lap.

Methods

Participants and events

Final and split times, as well as start, intermediate and finishing positions were collected from 1500 m Short Track Skating World Cups, the European Championships and World Championships during the season 2012/13. In total, ten indoor competitions (eight World Cups, one European Championship and one World Championship), divided over eight locations and dates were analysed. Each short-track competition consisted of qualification stages in which a skater had to qualify for the next stage by finishing first or second, and the final race where the goal was to win overall. The rankings for each lap and final ranking were coded from 1 (leading skater) to 6 (last skater). The starting lanes were also coded from 1 (inner) to 6 (outer), in line with previous short-track studies.^{14,15} In all 1500 m short-track races the winner was the athlete who first passed the finish line after 13.5 laps, where the distance of a short-track oval is 111.12m.

In total, 358 races were analysed (men: 210 races, women: 148 races). However, whereas falls and disqualifications could affect the lap times and positioning of the athlete as well as those of the other competitors (especially for the bottom-placed finishers) possibly leading to a misinterpretation of the results, data from races with a disqualification (n=116), a fall (n=27) and/or races with one or more missing values (n=6) were excluded. Lastly, to ensure consistency over the data set races with another number of competitors than six (i.e. the most commonly occurring number of competitors) were excluded (n=124). This resulted in 85 of 358 races (23,7%) that were examined. Lap times were measured using electronic time-measuring systems based on optical detectors that started automatically by the firing of a starting-gun and that recorded automatically the reaching of the finishing line by each competitor. ISU demands that lap times are recorded with the accuracy of at least a hundredth of a second. Therefore, for every automatic timekeeping system a certificate stating the

reliability and accuracy of the system had to be presented to the referee before the competition, ensuring that all systems recorded with the accuracy of at least a hundredth of a second. No written consent was given by participants as all data used are publicly available at the ISU website (<http://www.sportresult.com/federations/ISU/ShortTrack/>) and no interventions occurred during the data collection in this observational research. The study was approved by the university's local ethical committee in accordance to the Declaration of Helsinki.

Statistical analysis

Two different statistical approaches were used to assess pacing behaviour and tactical positioning during 1500 m short-track speed skating. Firstly, a MANOVA was performed to determine pacing behaviour based on lap times and to examine if differences existed in pacing behaviour between several subtypes for each lap time. These subtypes were: race type, final-ranking, sex, and stage of competition. Race type was classified as fast or slow when the winner of the heat was respectively faster or slower than the average winning completion time of the race winners. For stage of competition, final competition stages (finals and semi-finals) were distinguished from non-final stages (repeated semi-finals, repeated heats, heats, and preliminaries). Finally, men and women (sex), and 1st, 2nd, 3rd, 4th, 5th or 6th final ranked athletes (final-ranking) were differentiated. In addition, a univariate ANOVA was performed to examine the effect of each subtype for the finishing time. If a significant effect was found for final-ranking, Tukey post-hoc tests were performed.

Secondly, tactical positioning during 1500 m races was determined by assessing relationships between intermediate and final-rankings. Kendall's Tau b correlations were used in line with previous short-track studies.^{14,15} Positive correlations would indicate that respectively, top and bottom final-ranked short-trackers were also top and bottom-ranked in that particular lap. In contrast, negative correlations would indicate that foremost

intermediate rankings are related to rearmost final-rankings and vice versa. Positive and negative correlations were perceived as not present/low ($r < 0.50$), moderate ($0.50 < r < 0.70$) or high ($r > 0.70$). In addition, the tactical positioning of the winner of each heat was explored. Therefore, for each lap the percentage wherein the winner had skated at a particular intermediate ranking was determined. Lastly, the number of overtakings in each lap was calculated based on the lap times and intermediate rankings. All analyses were performed using SPSS 19.0, and differences were accepted to be significant if $P < 0.05$.

Results

Pacing behaviour: lap time analysis

Mean (SD) lap times, for each subtype and overall, are presented in Figure 1. The MANOVA revealed a main effect for sex ($P < 0.001$), final-ranking ($P < 0.001$), race type ($P < 0.001$), and stage of competition ($P < 0.001$). An interaction effect was found for sex*race type ($P = 0.001$), sex*stage of competition ($P < 0.001$), race type*stage of competition ($P < 0.001$), and sex*race type*stage of competition ($P < 0.001$). These interaction effects showed a relatively slower start during the finals compared to the non-finals. Moreover, this effect was found to be stronger for men than women. The laps wherein a main effect ($p < 0.05$) was found for each subtype are shown in Figure 1.

Mean finishing times are presented in Table 1. A univariate ANOVA for the finishing times revealed significant main effects for sex ($P < 0.001$), race type ($P < 0.001$), and final-ranking ($P < 0.001$), but not for stage of competition ($P = 0.251$). In addition, the difference in finishing time between final-ranking was larger during the non-finals compared to the finals ($P = 0.024$), while the difference in finishing time between race type was lower during non-finals ($P < 0.001$). Lastly, the difference in finishing time between race type was higher for women than for men ($P = 0.008$).

Mean lap times of the winners and the differences in lap time between the winners compared to the 2nd, 3rd, 4th, 5th, and 6th finishers are presented in Table 2. Moreover, the laps wherein the winning athletes were significantly faster than one or more of the other finishers were reported. This revealed that in the beginning stages of the race all athletes seemed to adopt the same pace. However, the winners were faster than the fourth, fifth and sixth final placed athletes during the last three laps. Although the winners were on average faster during the final two laps compared to the second and third final-ranked athletes, this difference in lap time was not significant. The winning short-track athletes were only faster than the fifth ($P < 0.001$) and sixth ($P < 0.001$) placed athletes in their finishing time, but not significantly faster than the second, third and fourth placed finishers.

Tactical positioning: intermediate ranking analysis

The Kendall's Tau b correlations between intermediate rankings and final-rankings are shown in Figure 2. No correlation was found between starting position and final-ranking. In addition, no or low correlations were found during the first ten laps of the race. In lap 11 intermediate ranking was moderately correlated to final ranking while high correlations were found during the last two laps.

In addition to the analysis of the correlations between intermediate and final ranking, that provided a good general impression about the importance of tactical positioning during the race, data of the winner of the race will be presented. Winners are presumably the most successful athletes in applying pacing and tactics, and thereby their strategies are of interest. Descriptive statistics of the intermediate rankings of the winner of the heat throughout the 1500 m competitions are presented in Table 3. During the beginning stages of the race, winners positioned themselves almost equally distributed over the intermediate rankings: in that way no position could be associated with winning. However, after the first five laps, the future winners started to position themselves more and more in the foremost intermediate

rankings. 56% of the winners were already in first position with three laps to go, 66% with two laps to go, and 75% were in first position with one lap remaining. Lastly, descriptive statistics of the number of changes in position were calculated and presented in Table 3, indicating a decreasing number of overtakings throughout the race.

Discussion

This study explored pacing strategies and tactical positioning in elite short-track speed skating during 1500 m events in the season 2012/13. The lack of meaningful correlations between intermediate and final positions in the early laps of 1500 m short-track races indicated that tactical positioning did not seem very important early in the 1500 m race (see Figure 2). This was also reflected by the relatively slow mean lap times and the fact that race winners were almost equally distributed amongst all intermediate rankings in the beginning stages of the race. Moreover, while mean lap times decreased throughout the race, the relation between skating at foremost positions and successful performance increased towards the final stages of the race. At the same time, the number of overtakings per lap decreased towards the finish line (see Figure 3) conform results of a previous short-track study,¹⁶ whereas overtaking was most likely more difficult at the final stages of the race.

The present study examined tactical positioning while interacting with competitors in sports involving direct competition, which has been highlighted recently as an important, but not extensively researched, aspect of pacing.^{2,9} It is suggested that in pacing, decisions are made based on the direct perception of action possibilities in the environment.² An athlete continuously assesses the rewards and costs of potential actions based on both internal as well as environmental information (e.g. ‘an athlete who is not fatigued -internal capability- and is positioned behind an opponent -environmental aspect- may decide to wait until his opponent gets fatigued instead of overtaking immediately’).^{2,9} This theoretical framework provides the opportunity to examine not only processes of pacing and tactics in time-trial sports, but also

in sports with a more direct form of competition. Indeed, the present findings showed that the intermediate ranking analysis of tactical positioning throughout a race provides additional important information about pacing behaviour in short track speed skating.

If we compare the present findings with 1500 m long-track speed skating, a time-trial sport, there are marked differences. In agreement with experimental studies³⁻⁵, modelling studies based on an energy flow model suggested that a positive pacing strategy (i.e. starting fast with a decreasing power output throughout the race) should lead to the best end results for middle distance long-track speed skating.^{4,8} Speed skating athletes are advised to perform a relatively faster first half of the race, just as to a lesser extent is advisable for 800 m runners.¹⁷ This is clearly not the case in short-track speed skating. Although a fast start led to a fast finishing time, a fast final part of the race led to a better final ranking, which is the main goal in short-track speed skating. These results corresponded with the tactical strategies that are seen in the sprint in track cycling,¹⁸ another sport involving direct competition against opponents. Moreover, also during 1500 m running and 400 m swimming competitions, the importance of the final stages of the race was indicated as the final lap time differentiated between medallists and non-medallists.^{19,20} Finally, also in long distance sports involving a direct form of competition the ability to finish fast seems to be related to performance. Successful female marathon runners were able to maintain their pace until the end of the race, while sub-elite marathon runners slowed down significantly.²¹

Another explanation for the relatively slow first laps and lack of difference in early lap times between all short-track athletes, despite their eventual final-ranking, could be the high negative effects associated with a too early set in of fatigue in speed skating as shown in previous time-trial research.⁴ Postural changes due to fatigue affect aerodynamics, push-off, coordination and thus technical ability of the speed skater largely.⁴ Though a fast start can be beneficial, the ability to finish adequately while maintaining technical ability even when

fatigue sets in seems important in speed skating competitions.^{4,5,17,22} Moreover, skating in the beginning stages of short-track races at another position than the first could provide the opportunity to better oversee your competitors^{18,23} and to draft in proximity behind your opponents.^{24,25} That is, when positioning yourself close behind one of your opponents, the effect of drafting could reduce your air frictional losses by 23%,²⁵ leading to lower heart rate and lactate responses.²⁴ Due to the associated lower energy costs, more energy could then be saved for a final acceleration in the last stages of the race. Lastly, a slower start may diminish the effects of the reduced blood flow to the working muscles,^{22,26,27} thereby again saving more energy for the final part of the race.

In comparison with middle-distance running, another sport using heats, the optimal timing to position yourself at the (foremost) qualifying positions in 1500 m short-track seems to be in a relatively late phase of the race, i.e. after about 1000 m. In 800 m running Olympic qualification races, it was already important to be in a qualifying position halfway through the race^{20,23}. In the 1500 m and 5000 m running event at major championships, running at one of the qualifying positions after 400 m was related to successful performance, although more changes in position were apparent compared to the 800 m distance.^{20,23} This could be related to the lower velocities and the consequential lower air frictional losses and lower benefits of drafting during running compared to short-track speed skating competitions.^{24,25} Moreover, it seems that short-track speed skaters and cyclists are relatively more affected by interaction with their competitors in order to achieve their goal (i.e. winning) compared to middle-distance runners.²⁸

Another interesting finding was the difference in pacing strategy between final and non-final stages of the competition. During the finals, athletes performed a relatively slower start, but faster finish, compared to the non-finals. This might be a consequence of the higher competitiveness (i.e. competing athletes are at a similar level of performance). In the

qualification rounds, the best short-track athletes might beat their opponents as a result of their superior physiological capacities, while in the finals the higher competitiveness between the competitors may result in a more tactical competition. An individualized analysis of the performed pacing strategies is required to examine whether this is the case. The difference between qualification rounds and finals appeared smaller for women than for men. Although this could be an indication of more male athletes being of similar competitive level of performance compared to the female athletes, no such effect was found. Nevertheless, men were faster than women in all laps except for the first two.

Due to the strict inclusion criteria in which only races with six competitors were included and races containing a disqualification or fall were excluded from further analysis, only 23,7% of the races performed in the season 2012/2013 were analysed. . However, the sample size of the current study (n=85 races, 510 athletes) is still very large, especially compared to previous studies on pacing and direct competition. In addition, strategies of the winners were comparable with results of a previous short-track study that not excluded falls or disqualifications, though used a much smaller sample size (n=7).¹⁶ This suggests that at least for the winners, pacing behaviour seems independent of falls or disqualifications of other competitors.

Practical applications

The present study is the first that provides objective, scientific data from a large sample size about the pacing strategies and tactical positioning used during short-track speed skating. Our findings can be used by coaches and athletes to further improve their tactical preparation and decision-making before and during the race. We found that although a fast start led to faster finishing times, it seemed unrelated to finishing position in 1500 m short-track speed skating. In addition, positioning in the beginning stages of the race was unrelated to finishing position. Therefore, we advise coaches to take into account that the most crucial

phase of the race regarding tactical positioning seemed to occur from the 10th lap of the race (i.e. after ± 1000 m) towards the finish line. In this aspect, it seems advisable to save energy for this crucial phase, and not too much energy should be wasted in the early phase of competition. Positioning yourself close behind one of your opponents might be beneficial in this early phase of the race, as it reduces your energy costs due to the beneficial effect of drafting. Winning the race is associated with taking one of the leading positions during the last five laps of the 1500 m race.

Conclusions

Analysis of intermediate positions can be used to examine tactical positioning and could provide better insight into pacing behaviour and tactics in sports involving direct competition. Where optimal pacing for a 1500 m (long-track) speed skating race in a time-trial setting is characterized by a fast initial start,^{4,5} it appears that in short-track speed skating the tactical positioning in the final laps of the race is a strong determinant of the final finishing position. Although a fast start led to faster finishing times, it seemed unrelated to finishing position in 1500 m short-track speed skating. The current findings indicated that short-track speed skaters should not waste too much energy in the beginning stages of the 1500 m race in order to maintain or accelerate pacing during the last five laps of the 1500 m race for successful performance.

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References

1. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. *Sports Med.* 2008;38(3):239-52.
2. Smits BLM, Pepping G-J, Hettinga FJ. Pacing and decision making in sport and exercise: the roles of perception and action in the regulation of exercise intensity. *Sports Med.* 2014;44(6):763–775.
3. Hettinga FJ, De Koning JJ, Hulleman M, Foster C. Relative importance of pacing strategy and mean power output in 1500-m self-paced cycling. *Br J Sports Med.* 2012;46(1):30-35.
4. Hettinga FJ, De Koning JJ, Schmidt LJ, Wind NA, Macintosh BR, Foster C. Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *Br J Sports Med.* 2011;45:30-35.
5. Muehlbauer T, Schindler C, Panzer S. Pacing and performance in competitive middle-distance speed skating. *Res Q Exerc Sport.* 2010;81(1):1-6.
6. De Koning JJ, De Groot G, Van Ingen Schenau GJ. A power equation for the sprint in speed skating. *J Biomech.* 1992;25(6):573-580.
7. Van Ingen Schenau GJ, Cavanagh PR. Power equations in endurance sports. *J Biomech.* 1990;23(9):865-881.
8. Van Ingen Schenau GJ, De Koning JJ, De Groot G. A simulation of speed skating performances based on a power equation. *Med Sci Sports Exerc.* 1990;22(5):718-728.
9. Renfree A, Martin L, Micklewright D, St Clair Gibson A. Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. *Sports Med.* 2014;44(2):147–158.
10. Noakes TD, St Clair Gibson A. Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *Br J Sports Med.* 2004;38(6):797–806.
11. Noakes TD, St Clair Gibson A. Logical limitations to the “catastrophe” models of fatigue during exercise in humans. *Br J Sports Med.* 2004;38(5):648–649.
12. Roelands B, De Koning JJ, Foster C, Hettinga FJ, Meeusen R. Neurophysiological determinants of theoretical concepts and mechanisms involved in pacing. *Sports Med.* 2013;43(5):301–311.
13. Foster C, De Koning JJ, Hettinga FJ, Lampen J, Dodge C, Bobbert M, Porcari JC. Effect of competitive distance on energy expenditure during simulated competition. *Int J Sport Med.* 2004;25:198-204
14. Maw S, Proctor L, Vredenburg J, Ehlers P. Influence of starting position on finishing position in World Cup 500 m short track speed skating. *J Sport Sci.* 2006;24(12):1239-1246.

15. Muehlbauer T, Schindler C. Relationship between starting and finishing position in short track speed skating races. *Eur J Sport Sci.* 2011;11(4):225-230.
16. Bullock N, Martin DT, Zhang A. Performance analysis of world class short track speed skating: what does it take to win? *Int J Perform Anal Sport.* 2008;8(1):9-18.
17. De Koning JJ, Foster C, Lucia A, Bobbert MF, Hettinga FJ, Porcari JP. Using modelling to understand how athletes in different disciplines solve the same problem: swimming versus running versus speed skating. *Int J Sports Physiol Perform.* 2011;6(2):276-280.
18. Moffatt J, Scarf PA, Passfield L, McHale IG, Zhang K. To lead or not to lead: analysis of the sprint in track cycling. *J Quant Anal Sports.* 2014;10(2):161-172.
19. Mytton GJ, Archer DT, Turner L, Skorski S, Renfree A, Thompson KG, St Clair Gibson A. Increased variability of lap speeds differentiate medallists and non-medallists in middle distance running and swimming events. *Int J Sports Physiol Perform.* 2014 Sep 17 [Epub ahead of print]. doi:10.1123/ijsp.2014-0207.
20. Aragón S, Lapresa D, Arana J, Anguera MT, Garzón B. Tactical behaviour of winning athletes in major championship 1500-m and 5000-m track finals. *Eur J Sport Sci.* 2015 Feb 9 [Epub ahead of print]. doi: 10.1080/17461391.2015.1009494
21. Renfree A, St Clair Gibson A. Influence of different performance levels on pacing strategy during the female World Championship marathon race. *Int J Sports Physiol Perform.* 2013;8(7):279-285.
22. Konings MJ, Elferink-Gemser MT, Stoter IK, Van der Meer D, Otten E, Hettinga FJ. Performance characteristics of long-track speed skaters: a literature review. *Sports Med.* 2014 Dec 30 [Epub ahead of print]. doi:10.1007/s40279-014-0298-z
23. Renfree A, Mytton GJ, Skorski S, St Clair Gibson A. Tactical considerations in the middle-distance running events at the 2012 Olympic games: a case study. *Int J Sports Physiol Perform.* 2014;9(2):362-364.
24. Rundell KW. Effects of drafting during short-track speed skating. *Med Sci Sports Exerc.* 1996;28(6):765-771.
25. Van Ingen Schenau GJ. The influence of air friction in speed skating. *J Biomech.* 1982; 15(6):449-458.
26. Hesford CM, Laing SJ, Cardinale M, Cooper CE. Effect of race distance on muscle oxygenation in short-track speed skating. *Med Sci Sports Exerc.* 2013;45(1):83-92.
27. Hesford CM, Laing SJ, Cardinale M, Cooper CE. Asymmetry of quadriceps muscle oxygenation during elite short-track speed skating. *Med Sci Sports Exerc.* 2012;44(3):501-508.
28. Menaspà P, Abbiss CR, Martin DT. Performance analysis of a world-class sprinter during cycling grand tours. *Int J Sports Physiol Perform.* 2013;8:336-340.

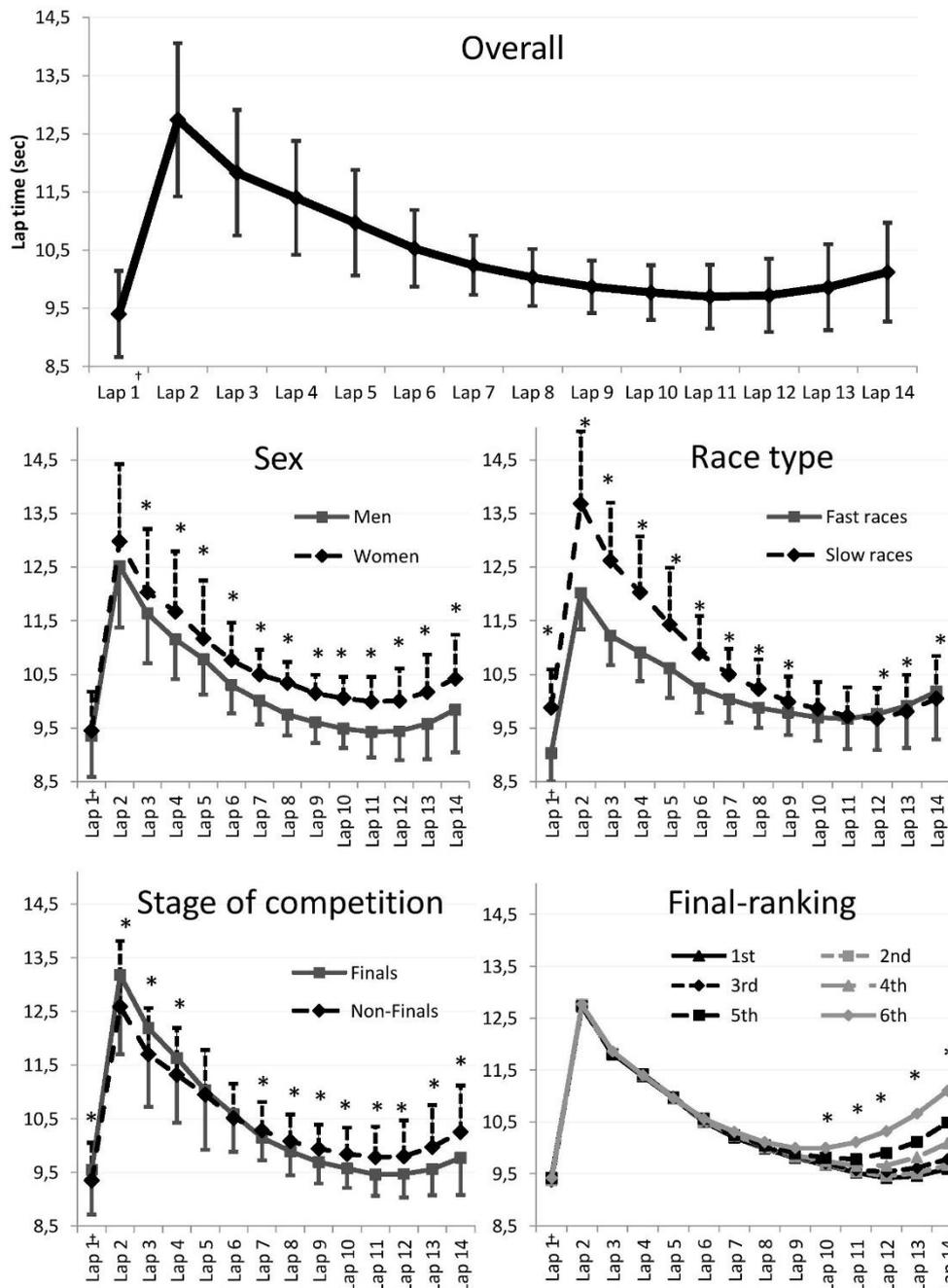
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Figure 1. Mean (SD) lap times throughout the 1500 m short-track speed skating are presented, overall and for each subtype (‘Sex’, ‘Race type’, ‘Final-ranking’, ‘Stage of competition’).



*Significant main effect for the subtype in that particular lap ($p < 0.05$)

† Lap 1 is only the lap time for the first ½ lap

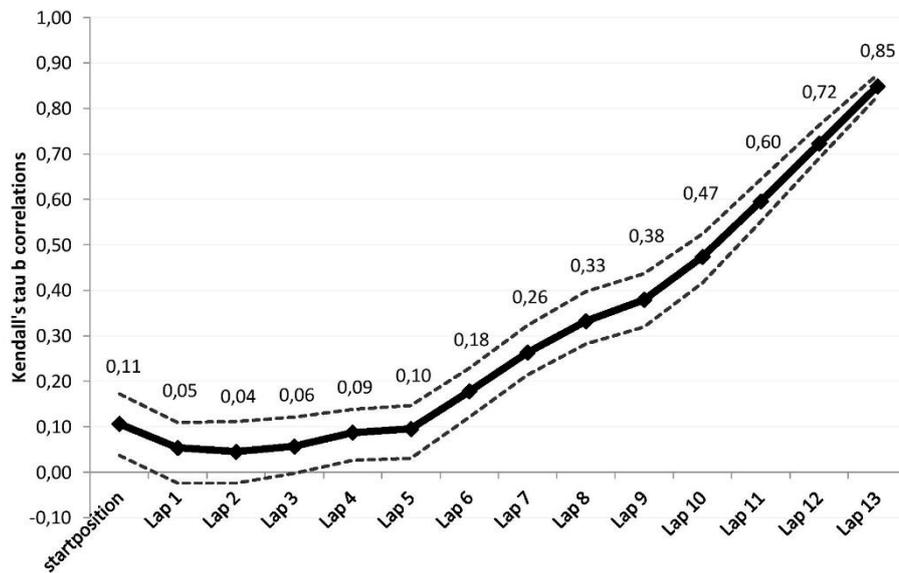
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Figure 2. Kendall’s tau b correlations are presented (solid line): the intermediate lap rankings throughout the race are correlated with the final-ranking. The 95% confidence intervals are given (dotted lines; N=85 races).



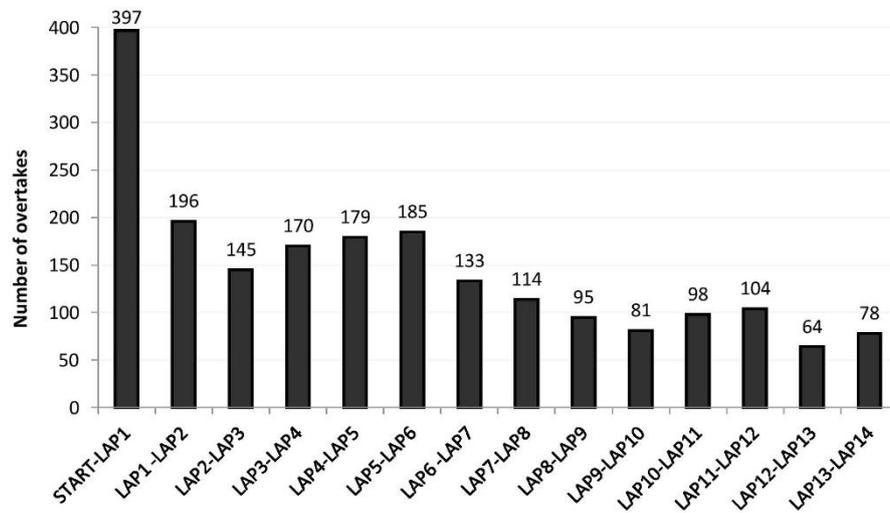
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Figure 3. The total number of changes in position is presented per lap for all analysed 1500 m short-track races (N=85 races).



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Table 1. Mean (\pm SD) finishing times in sec for overall performance are presented, subdivided into the subtypes ‘sex’, ‘final ranking’, ‘race type’ and ‘stage of competition’ (with N = number of short-track athletes).

Subtype	Sub-category (No. of races)	Finishing Times
Overall	(N=510)	146.18 \pm 6.50
Sex*	Men (N=264)	142.89 \pm 4.98
	Women (N=246)	149.71 \pm 6.08
Final ranking*	1st (N=85)	144.52 \pm 6.17
	2nd (N=85)	144.75 \pm 6.15
	3rd (N=85)	145.09 \pm 6.15
	4th (N=85)	145.96 \pm 6.17
	5th (N=85)	147.20 \pm 6.25
	6th (N=85)	149.57 \pm 6.83
Race Type*	Fast (N=288)	142.95 \pm 4.90
	Slow (N=222)	150.37 \pm 5.91
Stage of Competition	Final (N=132)	145.70 \pm 6.55
	Non-final (N=378)	146.35 \pm 6.49

A significant main effect for the items presented per subtype is marked with an * (P<0.05)

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Table 2. Mean lap times of the winners throughout the race are presented in the first row. In the subsequent rows, mean differences between lap times of the winners compared to the competitors at other final-rankings are shown. For example: in lap 11, the race winner was on average 0.3 sec faster than the 5th final-ranked short-track speed skater.

	Lap 1	Lap 2	Lap 3	Lap 4	Lap 5	Lap 6	Lap 7	Lap 8	Lap 9	Lap 10†	Lap 11†	Lap 12†	Lap 13†	Lap 14†
Mean lap times (sec) of 1st final-ranked athlete:	9,5	12,7	11,8	11,4	11,0	10,5	10,2	10,0	9,8	9,7	9,5	9,4	9,5	9,6
Difference in lap time (sec) with 1st final-ranked athlete:														
2nd	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	+0,1	+0,1
3rd	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	+0,1	+0,1	+0,2	+0,2
4th	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	+0,1	+0,1	+0,1	+0,1	+0,2*	+0,4*	+0,5*
5th	0,0	0,0	0,0	0,0	0,0	0,0	+0,1	+0,1	-0,1	-0,1	+0,3*	+0,5*	+0,7*	+0,9*
6th	0,0	0,0	0,0	0,0	0,0	0,0	+0,1	+0,1	+0,2	+0,3*	+0,6*	+0,9*	+1,2*	+1,5*

† Significant main effect in Univariate tests between lap times between for ‘final ranking’ (P<0.05)

* Significant post-hoc effect in lap times for 1st final-ranked athlete compared to 2nd, 3rd, 4th, 5th, and 6th (P<0.05),

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Table 3. How do the winners of the race position themselves? For every lap it has been calculated which percentage of the future heat winners skated at each intermediate ranking. For example: in lap 13, 75% of the race winners were already skating in first position, while none of the winners skated in 4th, 5th or 6th position.

	Start	Lap 1	Lap 2	Lap 3	Lap 4	Lap 5	Lap 6	Lap 7	Lap 8	Lap 9	Lap 10	Lap 11	Lap 12	Lap 13	Finish
1st	20%	16%	13%	12%	14%	19%	21%	32%	34%	41%	47%	56%	66%	75%	100%
2nd	24%	12%	16%	16%	19%	19%	18%	15%	22%	21%	22%	19%	22%	19%	0%
3rd	13%	14%	21%	19%	15%	12%	13%	14%	11%	9%	11%	13%	5%	6%	0%
4th	18%	20%	15%	16%	22%	21%	21%	21%	18%	13%	12%	6%	6%	0%	0%
5th	14%	16%	14%	18%	13%	13%	14%	7%	6%	6%	7%	6%	1%	0%	0%
6th	12%	21%	20%	19%	16%	16%	13%	11%	9%	9%	1%	0%	0%	0%	0%