Preceding Race Efforts Affect Pacing and Short-Track Speed Skating Performance

Article *in* International journal of sports physiology and performance · January 2018

DOI: 10.1123/ijspp.2017-0637

2 authors:

Marco Konings
University of Essex

Florentina Johanna Hettinga
University of Essex

ORIGINAL INVESTIGATION

Preceding race efforts affect pacing and short-track speed skating performance

Marco J. Konings[1], Florentina J. Hettinga[1]

[1] Sport, Performance and Fatigue Research Unit, School of Sport, Rehabilitation and Exercise Sciences, University of Essex, United Kingdom.

Corresponding Author:

Dr. Florentina J. Hettinga
School of Sport, Rehabilitation and Exercise Sciences
University of Essex
Wivenhoe Park, Colchester CO4 3SQ, United Kingdom
Telephone: +44(0)1206872046
e-mail: fjhett@essex.ac.u

Preferred running title: Preceding races in short-track skating

Word count abstract: 250

Word count text-only: 4005

Number of tables: 2

Number of figures: 2

Abstract

Purpose: To examine whether preceding high-intensity race efforts in a competitive weekend affected pacing behaviour and performance in elite short-track speed skaters. **Methods:** Finishing and intermediate lap times were gathered from 500, 1000 and 1500 m Short Track Speed Skating World Cups during the seasons 2011-2016. The effect of preceding races on pacing behaviour and performance was explored using two studies. *Study I:* the effect of competing in extra races due to the Repechage (Rep) system, leading to an increased number of high-intensity race efforts prior to the subsequent main tournament race, was explored (500m: N=32, 1000m: N=34; 1500m: N=47). *Study II:* the performance of skaters over the tournament days was evaluated (500m: N=129, 1000m: N=54; 1500m: N=114). For both analytic approaches, a two-way repeated measures ANOVA was used to assess differences in pacing and performance within the skater over the races. **Results:** An additional number of preceding high-intensity race efforts due to the Rep system reduced the qualification percentage in the first main tournament race for the next stage of competition in all events (500m: Direct qualification=57.3%, Rep=25.0%; 1000m: Direct=44.2%, Rep=28.3%; 1500m: Direct=27.1%, Rep=18.2%), and led to a decreased pace in the initial two laps of the 500m event. In contrast, Tournament day (Saturday vs Sunday) only affected the pacing behaviour of female skaters during the 1500m event. **Conclusion:** High-intensity race efforts earlier on the day affected pacing and performance of elite skaters, while the effect of high-intensity race efforts from the previous day seem to be only marginal.

Keywords. *Pacing strategy, fatigue, sport performance, decision-making, head-to-head competition*

Introduction

To perform optimally, athletes in various sports are required to continuously make decisions about how and when to invest their limited energy resources over time.[1] This goal-directed regulation of the exercise intensity over an exercise bout is known as 'pacing'.[2] Many studies have suggested that the sensation of fatigue has a crucial impact on the decision-making process regarding exercise regulation and performance.[3–7] Indeed, many theories on pacing regulation emphasize the importance of fatigue sensations and willingness to tolerate discomfort (in anticipation of future rewards) for the regulation of the exercise intensity.[1,8–11]

In this respect, previous laboratory studies indicated that higher levels of muscle fatigue before the start of a race, caused by a pre-fatiguing protocol, affected performance and resulted in a slower initial pace.[12–14] In addition, Skorski et al.[15] revealed that cyclists adopted a more conservative starting pace after an intensive training period. In this sense, it seems that an increased sensation of fatigue prior to the exercise invites athletes to adopt a different behaviour in order to avoid excessive fatigue sensations and ensure task completion during time trial exercise.[1,16]

Nevertheless, how increased fatigue sensations impact on the decision-making process involved in pacing during head-to-head competitive situations is not yet well known, let alone how this is relevant in sports performance practice. In many sports, athletes have to complete several races within a short period of time during their competitions (e.g., stage races, heats), possibly leading to increased fatigue sensations due to the repetitive high intensity efforts that are conducted, before the finals take place. For example, road cyclists compete on 90–100 competition days, comprising 1 day races, 1 week tour races, and 3 week tour races.[17] Similarly, elite short-track speed skaters typically skate multiple races a day for three days in a row during a competition weekend.

To perform optimally in head-to-head competitions, one is required to balance the optimal distribution of the available energy resources against possible tactical (dis)advantages.[18] As a result, each race may not require the use of all available energy stores, and finishing times are irrelevant as long as you finish in front of your opponents.[18,19] Indeed, in sports such as cross-country running,[20] middle-distance running,[21] rowing,[22] track cycling,[23] and short-track speed skating,[19,24] athletes did not adopt the theoretical optimal pacing strategy, most likely due to tactical considerations. As a result, the impact of preceding high-intensity efforts on pacing and performance could likely be more varied compared to what has been reported on time-trial exercise.

In the present study we used competitive data to examine whether preceding high-intensity race efforts in a competitive weekend affects pacing behaviour and performance in elite short-track speed skating. To do this, we employed two different analytical approaches, using the competition structure of short-track speed skating world cups. Firstly, we analysed the effect of preceding high-intensity race efforts within a day on the first main tournament race, by using the repechage system as an 'intervention'. That is, those athletes who had to qualify via this system needed to complete an additional number of races during the day prior to the first main tournament race. Secondly, differences in pacing and performance between days within a competitive weekend were explored. On Sunday, more preceding high-intensity races have been completed than on Saturday, when athletes start relatively fresher. We hypothesized that a higher number of preceding high-intensity race efforts would evoke a more conservative initial pace, possibly resulting in a decreased performance.

Methods

Data acquisition

Finishing and intermediate lap times were gathered for men and women from all 500 m (4.5 laps), 1000 m (9 laps) and 1500 m (13.5 laps) Short Track Speed Skating World Cups during the seasons 2011/12 until 2015/16. In total, 28 indoor short-track speed skating World Cup tournaments were analysed. This resulted in 10483 skating performances for the 500 m, 9889 skating performances for the 1000 m, and 7890 skating performances for the 1500 m 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 automatically recorded the time in which the finish line was reached by each competitor. The International Skating Union (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 tournament, 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. The study was approved by the local ethical committee and was in accordance with the Declaration of Helsinki.

<<< Figure 1 about here >>>

Study I – Repechage effect

Each short-track world cup tournament consisted of qualification stages in which a skater had to qualify for the main tournament. One could proceed to the next stage of the tournament by finishing in first or second position, or as a fastest time qualifier who did not already qualify via their finish position in some stages of the tournament of some world cups. A schematic overview of a typical short-track world cup race weekend can be found in Figure 1. The qualification stages took place in general on Friday, followed by the main tournament days on Saturday and Sunday. The composition of the races in the qualification stages is based on the current World Ranking list per distance, which is used as a seeding list. The main tournament starts with the quarterfinal for the 500 m and 1000 m event, while this is the semi-final for the 1500 m. Most short-track speed skaters qualify for the main tournament directly via the qualification stages. However, there is an alternative way to reach the main tournament for the speed skaters who did not qualify on first hand, the so-called repechage system. All short-track speed skaters who did not qualify directly for the main tournament can compete in this repechage competition. Using a similar system as the qualification stages, a short-track speed skater has to proceed in two or three stages of the repechage competition. Finally, the first one or two finishers in the final stage of the repechage competition are added to the main tournament. These repechage races take place in the morning before the start of the main tournament races later on that day in the afternoon/evening. There was no repechage competition during the World Cups in the Olympic season 2013/14. Therefore, all races performed in this season were excluded from the analysis.

To examine the effect of the extra races involved in the repechage competition on pacing and performance of elite short-track speed skaters during the first main tournament race (i.e. the quarter final race for the 500 and 1000 m event, and the semi-final race for the 1500 m event), skaters who have qualified themselves both directly (control condition) as well as via the repechage system ('intervention') were identified. This led to 32 skaters (17 men, 15 women) for the 500 m event, 34 skaters (16 men, 18 women) for the 1000 m event, and 47 skaters (23 men, 24 women) for the 1500 m event out of the collected database who fulfilled the criterion of qualification via both ways and were included into the analysis. Lap times and finishing times of these speed skaters in their first main tournament race (i.e. the quarter final race for the 500 and 1000 m event, and the semi-final race for the 1500 m event) were retrieved and analysed.

Study I - Statistical analysis

Differences between direct qualification or qualification via the Repechage competition on the pacing and performance of short-track speed skaters in their subsequent first main tournament race were assessed using a two-way repeated measures ANOVA (Qualification x Laps) for each event. Sex was added as between-subject factor. A Greenhouse-Geisser correction was used when sphericity could not be assumed. All analyses were performed using SPSS 19.0, and significance was accepted at $p<0.05$. If appropriate, post-hoc analyses were performed using a Bonferroni correction. Finally, the percentage of short-track speed skaters from both Qualification groups that qualified for the next stage of the tournament (i.e. semi-final for the 500 and 1000 m event; final for the 1500 m event) in the main tournament was determined. Chi-Square tests were used to compare these percentages to the expected qualification percentage in that stage of the tournament. The expected values were set at 50% (typically two out of four competitors qualify for the next stage of the tournament) for the 500 and 1000 m and 33% (two out of six competitors) for the 1500 m.

Study II –Tournament day

During each short-track world cup tournament, except for the world cups in the Olympic season 2013/2014, four individual events were organised per world cup. That is, each individual discipline (500, 1000, 1500 m) was organised at least once, but one of the disciplines was performed twice during the weekend. When the same discipline was organised twice in a weekend, the first one was always on Saturday, and the second one always on Sunday.

To examine the effect of the tournament day on pacing and performance of elite short-track speed skaters during the main tournament, skaters who competed in the main tournament for the same event on both days were identified. This led to 129 skaters (65 men, 64 women) for the 500 m event, 54 skaters (27 men, 27 women) for the 1000 m event, and 114 skaters (57 men, 57 women) for the 1500 m event out of the collected database who fulfilled the criterion and were included into the analysis. Lap times and finishing times of these speed skaters on both days were retrieved and analysed. In addition, the final stage of the tournament achieved by the short-track speed skater was noted.

Study II - Statistical analysis

Differences in pacing and performance between tournament days were assessed using a two-way repeated measures ANOVA (Day x Laps) for each event. Sex and the final stage of competition achieved by the short-track speed skater on Saturday were added as between-subject factors. A Greenhouse-Geisser correction was used when sphericity could not be assumed. All analyses were performed using SPSS 19.0, and significance was accepted at $p<0.05$. If appropriate, post-hoc analyses were performed using a Bonferroni correction.

Results

<<< Table 1 about here >>>

Study I – Repechage effect

Mean (± SD) lap times and finishing times for direct qualification and qualification via repechage are shown in Table 1. Moreover, mean world cup ranking for all skaters per condition per event can be found in Table 1. No differences were found between the conditions in the 500 m ($p=0.331$), 1000 m ($p=0.814$), or 1500 m event ($p=0.238$). In addition, the average number of races prior to the analysed race on the same day per condition and the qualification percentage for the next stage of competition per condition after the analysed race are provided in Table 1. Main effects for Qualification ($F=4.89$; $p=0.035$), Laps ($F=2972.7$; $p<0.001$), and Sex ($F=437.2$; $p<0.001$) were found for the 500 m event. An interaction effect was revealed for

Qualification x Laps (F=3.49; p=0.024), indicating differences in pacing between direct and repechage qualification. No interaction effects were found for Qualification x Sex (F=0.23; p=0.633), Laps x Sex (F=1.10; p=0.353), or Qualification x Sex x Laps (F=1.13; p=0.339). Post-hoc analysis revealed that short-track speed skaters were slower in the initial two laps of the 500 m when they qualified via the repechage compared to when they qualified directly for the quarterfinals.

Main effects for Laps (F=4093.8; p<0.001) and Sex (F=385.8; p<0.001), but not for Qualification (F=0.270; p=0.607) were reported for the 1000 m event. No interaction effects were found for Qualification x Laps (F=0.940; p=0.422), Qualification x Sex (F=0.402; p=0.531), Laps x Sex (F=1.88; p=0.151), or Qualification x Sex x Laps (F=0.476; p=0.693) in the 1000 m event.

Main effects for Laps (F=342.3; p<0.001) and Sex (F=108.0; p<0.001), but not for Qualification (F=0.09; p=0.766) were reported for the 1500 m event. No interaction effects were found for Qualification x Laps (F=0.974; p=0.412), Qualification x Sex (F=2.71; p=0.107), Laps x Sex (F=2.06; p=0.130), or Qualification x Sex x Laps (F=1.53; p=0.205) in the 1500 m event. The percentage of all short-track speed skaters from both Qualification groups that qualified for the next stage of the tournament (i.e. semi-final for the 500 and 1000 m event; final for the 1500 m event) in the main tournament can be found in Table 1 for all events. The chi-square tests revealed a reduction in the percentage of short-track speed skaters that qualified for the next stage of the tournament in relation to what could be expected for all events after qualification via the repechage system (500 m: p=0.007; 1000 m: p=0.024; 1500 m: p=0.024), but not after direct qualification (500 m: p=0.597; 1000 m: p=0.608; 1500 m: p=0.255).

<<< Table 2 about here >>>

Study II –Tournament day

Mean (± SD) lap times and finishing times for Saturday and Sunday races are shown in Table 2. Main effects for Laps (F=4148.9; p<0.001), Sex (F=405.6; p<0.001), and End stage (F=7.01; p=0.001), but not for Day (F=2.11; p=0.149), were found for the 500 m event. An interaction effect was reported for Laps x Sex (F=10.40; p<0.001), indicating differences in pacing between Sex. That is, female short-track speed skaters appear to slow down more than their male counterparts in the final two laps, independent of tournament day. No effect was found for Day x Laps (F=1.017; p=0.388), Day x Sex (F=0.509; p=0.477), Day x End stage (F=0.108; p=0.898), Day x Laps x Sex (F=0.369; p=0.786), or Day x Laps x End stage (F=1.129; p=0.344).

Main effects for Laps (F=899.5; p<0.001) and Sex (F=42.97; p<0.001), but not for Day (F=0.072; p=0.789) or End stage (F=0.477; p=0.623), were revealed for the 1000 m event. Interaction effects were reported for Day x Sex (F=5.879; p=0.019), Day x Laps x Sex (F=3.729; p=0.022), and Day x Laps x Sex x End stage (F=3.556; p=0.006), indicating pacing and performance over the days differs between men and women. However, post-hoc analysis revealed no differences in pacing between days for men or women. Similarly, no performance effects between days were found, although there seems to be a tendency towards a faster performance for female short-track speed skaters on Saturday (Finish time = 93.06 ± 1.58s) compared to Sunday (Finish time = 93.66 ± 2.09s; p=0.057). No effect was found for Day x Laps (F=0.992; p=0.383), Day x End stage (F=0.383; p=0.684), Laps x Sex (F=1.487; p=0.229), Day x Laps x End stage (F=0.632; p=0.663).

Main effects for Laps (F=370.5; p<0.001) and Sex (F=85.04; p<0.001), but not for End stage (F=1.433; p=0.234), were revealed for the 1500 m event. The main effect for Day was non-significant (F=3.885; p=0.051). Interaction effects were found for Day x Laps (F=4.027;

p=0.011) and Day x Laps x Sex (F=3.468; p=0.021), indicating a difference in pacing between days and pacing over the days differs between men and women (see Table 2 and Figure 2). No interaction effect was found for Day x Sex (F=1.163; p=0.283), Day x End stage (F=3.353; p=0.070), Laps x Sex (F=1.302; p=0.273), or Day x Laps x End stage (F=0.934; p=0.415).

<<< Figure 2 about here >>>

Discussion

This study showed that overall performance time seems largely robust to different conditions but that progression is affected and pacing profiles in some places. An additional number of preceding high-intensity race efforts due to the Repechage system led to a slower initial pace in the following quarterfinal of the 500 m event. Moreover, qualification to the main tournament via the repechage system, compared to when these same skaters qualified directly for the main tournament, led to a reduction in the percentage of skaters that qualified in the subsequent quarterfinal race (500 and 1000 m event) or semi-final race (1500 m event) for the subsequent stage of the tournament (i.e. semi-final for the 500 m and 1000 m event; final for the 1500 m event) in the main tournament for all events (See Table 1). In contrast, the tournament day did not evoke any differences in pacing or performance for male short-track speed skaters, indicating there is enough time to recover from the high-intensity race efforts one day prior. However, some minor differences in the chosen pacing behaviour and performance were found for female short-track speed skaters during the 1500m event, indicating a faster initial pace and slower finishing pace on Sunday compared to Saturday.

Previous research has indicated that increased sensations of fatigue prior to the exercise invites athletes to adopt a different behaviour in order to avoid excessive fatigue sensations and ensure task completion during time trial exercise.[1,16] As there does not exist any evidence to support any single factor as being directly responsible for the onset of the sensation of fatigue,[9,25] it is suggested that a number of different afferent inputs, together with other non-sensory inputs such as psychological and motivational factors, are integrated in brain structures and the ensemble leads to the development of the sensation of fatigue which arises directly from these integrative brain structures.[9] In this respect, sensations of fatigue have been shown indeed to be essential in the regulation of exercise intensity during time trial exercise.[1,4,8–10] Nevertheless, how the repetitive high intensity efforts that are conducted in head-to-head competitions such as short-track speed skating, possibly leading to increased fatigue sensations was yet unclear.

Our findings indicate that the efforts required to utilize the second chance provided by the repechage system in short-track speed skating could have a detrimental effect on the performance of skaters in the subsequent first main tournament race. For example, the start has been reported as crucial for the outcome of the race in the 500 m event.[24,26,27] In this sense, the slower initial pace as found in the first main tournament race after skating the additional races of the repechage could impair the performance of the skater, and gives the skater a disadvantage compared to other competitors that did not had to skate these extra races. Interestingly, skating in the repechage competition several hours before the main tournament did not led to a change in pacing during the first main tournament race of the more tactical 1000 and 1500 m events. The lack of an effect in pacing could likely be related to the relatively slow, tactical start of most 1000 and 1500 m races.[19,24] That is, the typically slower tactical start in the 1000 and 1500 m event may affect the inducement of and recovery from fatigue sensations and physiological consequences compared to faster starting 500 m event. Nevertheless, in terms of performance it still appears that the percentage of skaters that qualified in the first main tournament race for the next stage of competition in the main tournament did reduce significantly when they had competed in the repechage competition.

Intuitively, one may argue that the group qualified via the repechage system is of a qualitatively lower level of performance. However, we would like to emphasize that the groups we compared both consist of the exact same skaters, as only skaters were included into the analysis if they have qualified for the main tournament via both the repechage system as well as via direct qualification. Nevertheless, even when using the same individuals as self-control, one may still argue that these individuals were in a weaker performance state when they qualified via repechage route than when they qualified directly. In this respect, an analysis of the world cup ranking of the skaters indicated that there was no difference in their world cup ranking when qualification was achieved directly or via the repechage route (see Table 1). This lack of a difference supports the assumption that the skaters were of a similar performance level in both conditions. It indicates as well that the skaters had on average an equal opportunity to achieve direct qualification in both conditions during the qualification stages, as the world cup ranking list was used as a seeding list for the qualification stages of a tournament. In addition, we would like to point out that qualification via the repechage route is a rather challenging task as there are only few available places for qualification via the repechage route (i.e. on average only 2 out of 38 repechage contenders for the 500 m, 2 out of 35 contenders for the 1000 m, and 3 out of 28 contenders for the 1500 m qualify for the main tournament via the repechage route). As a result, in order to establish qualification via the repechage system, a skater is required to perform well in 2-3 subsequent races. An alternative explanation might be that due to the extra races of the repechage competition, the ability to overtake others in that decisive final part of the race is affected rather than the average pace. This would once again emphasize the importance of tactical positioning in head-to-head structured competition in general,[18,20,21,23,28] and in short-track speed skating in particular.[19,24,29]

When comparing Sunday races to Saturday races, short-track speed skaters did not seem to make any major adjustments in their pacing behaviour. This would suggest that for elite short-track speed skaters, one day provides sufficient time to recover from the high-intensity efforts of the day before, and the consequential actual and experienced physiological impact. The only difference in pacing between days was found for the women's 1500 m event. Surprisingly, the female 1500 m skaters adopted a faster initial pace on Sunday races in comparison to Saturday races. Possibly, differences in overtaking behaviour may be related to this sex difference. Female 1500 m skaters have been shown to overtake less frequently in the decisive final stages of a race compared to their male counterparts.[30] Alternatively, the slower initial pace on Saturday races might be anticipation of the efforts required in upcoming races later on the day, or the day after.

As shown in Konings et al.[31], several external cues have been revealed to impact the chosen pacing behaviour of elite short-track speed skaters. We attempted to control for or minimise the effects of these variables in our analysis within reasonable limits. For example, only races in similar stages of competition were analysed. Moreover, proceeding to the next stage of the tournament as a fastest time qualifier was not possible in any of our included races. Furthermore, we would like to emphasise again that both groups in both analytical approaches consist of the exact same pool of subjects, using a within-subject analysis.

Practical applications

Our findings indicate that the additional high-intensity efforts required in the repechage competition prior to the first main tournament race could negatively impact the performance of elite short-track speed skaters. In this perspective, a possible way to provide for all contenders a fair and equal opportunity could be to complete the repechage races on the same day as the qualification races (typically the Friday; see Figure 1), rather than on the tournament day itself as happens currently. That is, our findings indicate that there is sufficient time from one day to the other to recover from the efforts of the day before. Completing the repechage races on Friday would then provide sufficient recovery time and level playing field for all contenders in the main tournament.

Conclusions

The regulation of the exercise intensity involves a complex decision-making process based on a complex interplay between external stimuli and interoceptive information such as the (perceived) level of fatigue.[8] As demonstrated in this study, completion of 2-3 additional races on the same race day negatively affected the performance of elite short-track speed skaters during all events and altered pacing behaviour in the 500 m event. At the same time, it appears that races completed on the day before do not have a major impact on pacing and performance in elite short-track speed skating competitions. In this perspective, a reschedule in the planning of the repechage races during the tournament weekend is advised to level playing field for all contenders during the main tournament.

Acknowledgements

The results of the current study do not constitute endorsement of the product by the authors or the journal. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Edwards AM, Polman RC. Pacing and awareness: brain regulation of physical activity. *Sport Med*. 2013;43(11):1057-1064.
2. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. *Sport Med*. 2008;38(3):239-252.
3. Enoka RM, Duchateau J. Translating Fatigue to Human Performance. *Med Sci Sports Exerc*. 2016;48(11):2228-2238. doi:10.1249/MSS.0000000000000929.
4. Marcora SM. Do we really need a central governor to explain brain regulation of exercise performance? *Eur J Appl Physiol*. 2008;104(5):929-931.
5. Swart J, Lamberts RP, Lambert MI, et al. Exercising with reserve: exercise regulation by perceived exertion in relation to duration of exercise and knowledge of endpoint. *Br J Sports Med*. 2009;43:775-782.
6. Roelands B, De Koning JJ, Foster C, Hettinga FJ, Meeusen R. Neurophysiological determinants of theoretical concepts and mechanisms involved in pacing. *Sport Med*. 2013;43(5):301-311.
7. Konings MJ, Parkinson J, Zijdewind I, Hettinga FJ. Racing an opponent alters pacing, performance and muscle force decline, but not RPE. *Int J Sports Physiol Perform*. 2017:Epub ahead of print. doi:10.1123/ijspp.2017-0220.
8. Smits BL, 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. *Sport Med*. 2014;44(6):763-775.
9. St. Clair Gibson A, Baden DA, Lambert MI, et al. The conscious perception of the sensation of fatigue. *Sport Med*. 2003;33(3):167-176. doi:10.2165/00007256-200333030-00001.
10. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *Br J Sports Med*. 2009;43(6):392-400.
11. Marcora SM, Staiano W. The limit to exercise tolerance in humans: mind over muscle? *Eur J Appl Physiol*. 2010;109:763–770.
12. Amann M, Dempsey JA. Locomotor muscle fatigue modifies central motor drive in healthy humans and imposes a limitation to exercise performance. *J Physiol*. 2008;586(1):161-173.
13. Correia-Oliveira CR, Santos RA, Silva-Cavalcante MD, et al. Prior low- or high-intensity exercise alters pacing strategy, energy system contribution and performance during a 4-km cycling time trial. *PLoS One*. 2014;9(10):e110320.
14. De Morree HM, Marcora SM. Effects of isolated locomotor muscle fatigue on pacing and time trial performance. *Eur J Appl Physiol*. 2013;113(9):2371-2380.
15. Skorski S, Hammes D, Schwindling S, et al. Effects of training-induced fatigue on pacing patterns in 40-km cycling time trials. *Med Sci Sports Exerc*. 2015;47(3):593-600.
16. Noakes TD. Time to move beyond a brainless exercise physiology: the evidence for

complex regulation of human exercise performance. *Appl Physiol Nutr Metab*. 2011;36(1):23-35.

17. Abbiss CR, Laursen PB. Models to Explain Fatigue during Prolonged Endurance Cycling. *Sport Med*. 2005;35(10):865-898. doi:10.2165/00007256-200535100-00004.

18. Hettinga FJ, Konings MJ, Pepping G-J. The science of racing against opponents: Affordance competition and the regulation of exercise intensity in head-to-head competition. *Front Physiol*. 2017;8:118. doi:10.3389/fphys.2017.00118.

19. Konings MJ, Noorbergen OS, Parry D, Hettinga FJ. Pacing behaviour and tactical positioning in 1500 m short-track speed skating. *Int J Sports Physiol Perform*. 2016;11(1):122-129. doi:10.1123/ijspp.2015-0137.

20. Hanley B. Senior men's pacing profiles at the IAAF World Cross Country Championships. *J Sports Sci*. 2014;32(11):1060-1065.

21. 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.

22. Edwards AM, Guy JH, Hettinga FJ. Oxford and Cambridge Boat Race: Performance, Pacing and Tactics Between 1890 and 2014. *Sport Med*. 2016;46(10):1553-1562. doi:10.1007/s40279-016-0524-y.

23. Moffatt J, Scarf P, Passfield L, McHale IG, Zhang K. To lead or not to lead: analysis of the sprint in track cycling. *J Quant Anal Sport*. 2014;10(2):161-172. doi:10.1515/jqas-2013-0112.

24. Noorbergen OS, Konings MJ, Elferink-Gemser MT, Micklewright D, Hettinga FJ. Pacing and tactical positioning in 500 and 1000m short-track speed skating. *Int J Sports Physiol Perform*. 2016;11(6):742-748. doi:10.1123/ijspp.2015-0384.

25. Micklewright D, St Clair Gibson A, Gladwell V, Al Salman A. Development and Validity of the Rating-of-Fatigue Scale. *Sport Med*. 2017:1-19. doi:10.1007/s40279-017-0711-5.

26. Haug W, Drinkwater E, Mitchell L, Chapman D. The relationship between start performance and race outcome in elite 500m short track speed skating. *Int J Sports Physiol Perform*. 2015;Feb 24. Ep. doi:10.1123/ijspp.2014-0504.

27. 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 Sports Sci*. 2006;24(12):1239-1246.

28. Jones AM, Whipp B. Bioenergetic constraints on tactical decision making in middle distance running. *Br J Sports Med*. 2002;36:102-104.

29. Konings MJ, Hettinga FJ. Objectifying tactics: Athlete and race variability in elite short-track speed skating. *Int J Sports Physiol Perform*. 2017. doi:10.1123/ijspp.2016-0779.

30. Al M, Konings MJ, De Jong R, Hettinga FJ. Overtaking behaviour in elite and sub-elite 1500m short track speed skaters. In: *Book of Abstract European College of Sport Sciences*. Vienna; 2016.

31. Konings MJ, Hettinga FJ. The impact of different competitive environments on pacing

and performance. *Int J Sports Physiol Perform*. 2017:Epub ahead of print. doi:10.1123/ijspp.2017-0407.

Table 1. Mean ± SD of the lap times and finishing times in seconds for the short-track speed skaters when qualified directly or qualified via the repechage system for all events. Moreover, mean world cup ranking of the skaters at the time of the event per condition, the average number of races on the same day prior to the analysed race per condition, and the percentage of short-track speed skaters that qualified for the next stage of the tournament after short-track speed skaters did or did not ride the Repechage are presented.

	500 m (N=32)		**1000 m** (N=34)		**1500 m** (N=47)	
	Direct	**Repechage**	**Direct**	**Repechage**	**Direct**	**Repechage**
Lap 1	7.26 ± 0.32[*]	7.38 ± 0.27	13.24 ± 0.44	13.34 ± 0.55	9.65 ± 0.73	9.70 ± 0.75
Lap 2	9.17 ± 0.31[*]	9.24 ± 0.35	10.02 ± 0.30	10.09 ± 0.39	13.15 ± 1.29	13.17 ± 1.10
Lap 3	8.70 ± 0.30	8.75 ± 0.33	9.78 ± 0.36	9.78 ± 0.39	12.10 ± 1.01	11.95 ± 0.94
Lap 4	8.85 ± 0.31	8.88 ± 0.37	9.66 ± 0.35	9.65 ± 0.37	11.45 ± 0.80	11.37 ± 0.88
Lap 5	9.11 ± 0.31	9.10 ± 0.34	9.56 ± 0.35	9.52 ± 0.39	10.90 ± 0.72	10.85 ± 0.71
Lap 6			9.46 ± 0.34	9.48 ± 0.39	10.46 ± 0.64	10.39 ± 0.59
Lap 7			9.45 ± 0.40	9.44 ± 0.38	10.10 ± 0.51	10.08 ± 0.52
Lap 8			9.51 ± 0.37	9.54 ± 0.36	9.87 ± 0.42	9.90 ± 0.44
Lap 9			9.77 ± 0.37	9.74 ± 0.36	9.77 ± 0.40	9.79 ± 0.40
Lap 10					9.63 ± 0.31	9.65 ± 0.36
Lap 11					9.53 ± 0.31	9.59 ± 0.37
Lap 12					9.52 ± 0.34	9.59 ± 0.39
Lap 13					9.64 ± 0.38	9.72 ± 0.45
Lap 14					9.92 ± 0.45	10.11 ± 0.67
Finish time	43.00±1.53[*]	43.26±1.58	90.44±2.89	90.58±2.91	145.69±6.59	145.85±5.75
World cup ranking	17 ± 9	19 ± 10	27 ± 12	28 ± 13	24 ± 9	26 ± 11
Prior no. of races	0 ± 0	2.5 ± 0.5	0 ± 0	2.5 ± 0.5	0 ± 0	1.7 ± 0.5
Qualified next stage	57.3%	25.0% [†]	44.2%	28.3% [†]	27.1%	18.2% [†]

[*]Significant difference compared to repechage qualification ($P<0.05$)

[†]Significant difference compared to expected qualification rate for next stage (50.0% for 500 and 1000 m and 33.3% for 1500 m, respectively)

Table 2. Mean ± SD of the lap times and finishing times in seconds for the short-track speed skaters on the Saturday and Sunday races for all events.

	500 m (N=129)		**1000 m** (N=54)		**1500 m** (N=114)	
	Saturday	**Sunday**	**Saturday**	**Sunday**	**Saturday**	**Sunday**
Lap 1	7.23 ± 0.29	7.23 ± 0.29	13.51 ± 0.58	13.65 ± 0.74	9.90 ± 1.18	9.86 ± 0.94
Lap 2	9.22 ± 0.29	9.25 ± 0.30	10.24 ± 0.52	10.32 ± 0.55	13.59 ± 1.61	13.24 ± 1.23
Lap 3	8.75 ± 0.32	8.80 ± 0.32	9.91 ± 0.45	9.93 ± 0.45	12.45±1.44*	12.12 ± 0.06
Lap 4	8.93 ± 0.33	8.94 ± 0.35	9.70 ± 0.31	9.65 ± 0.39	11.74±1.17*	11.44 ± 0.80
Lap 5	9.17 ± 0.35	9.19 ± 0.36	9.58 ± 0.35	9.65 ± 0.39	11.08±0.87*	10.89 ± 0.65
Lap 6			9.48 ± 0.35	9.49 ± 0.40	10.71±0.70*	10.49 ± 0.56
Lap 7			9.47 ± 0.36	9.40 ± 0.35	10.28 ± 0.65	10.18 ± 0.52
Lap 8			9.46 ± 0.37	9.45 ± 0.35	10.01 ± 0.53	9.96 ± 0.39
Lap 9			9.70 ± 0.42	9.62 ± 0.43	9.86 ± 0.48	9.82 ± 0.42
Lap 10					9.62 ± 0.34	9.70 ± 0.38
Lap 11					9.52 ± 0.34	9.60 ± 0.41
Lap 12					9.47 ± 0.35*	9.55 ± 0.38
Lap 13					9.61 ± 0.39	9.68 ± 0.47
Lap 14					9.85 ± 0.46	9.95 ± 0.59
Finish time	43.30±1.46	43.43±1.49	91.04±2.70	91.13±3.16	147.69±7.45	146.48±5.63

*Significant difference between days ($p<0.05$)

Figure 1. Schematic overview of a typical short-track world cup race weekend.

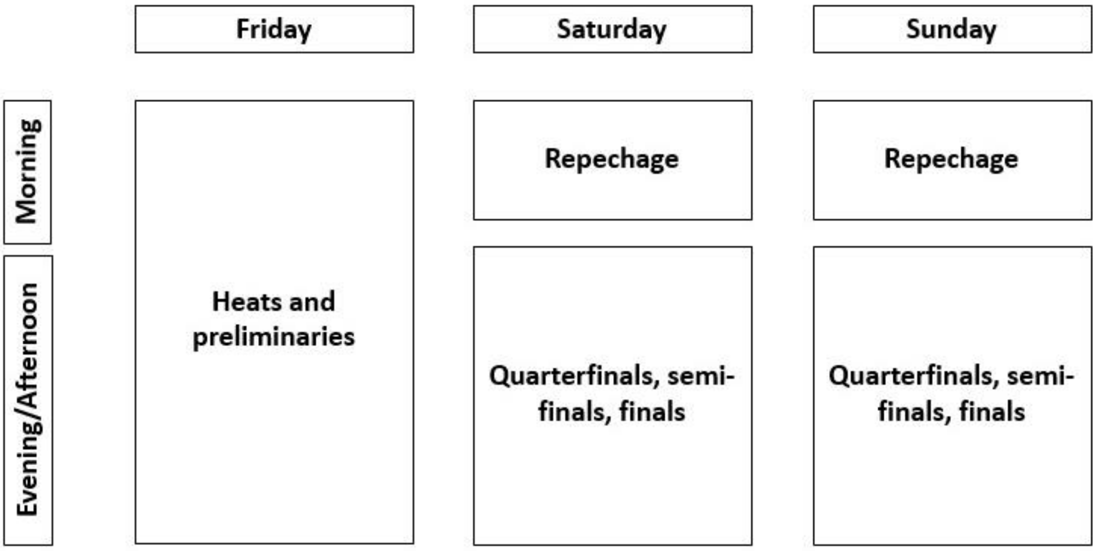
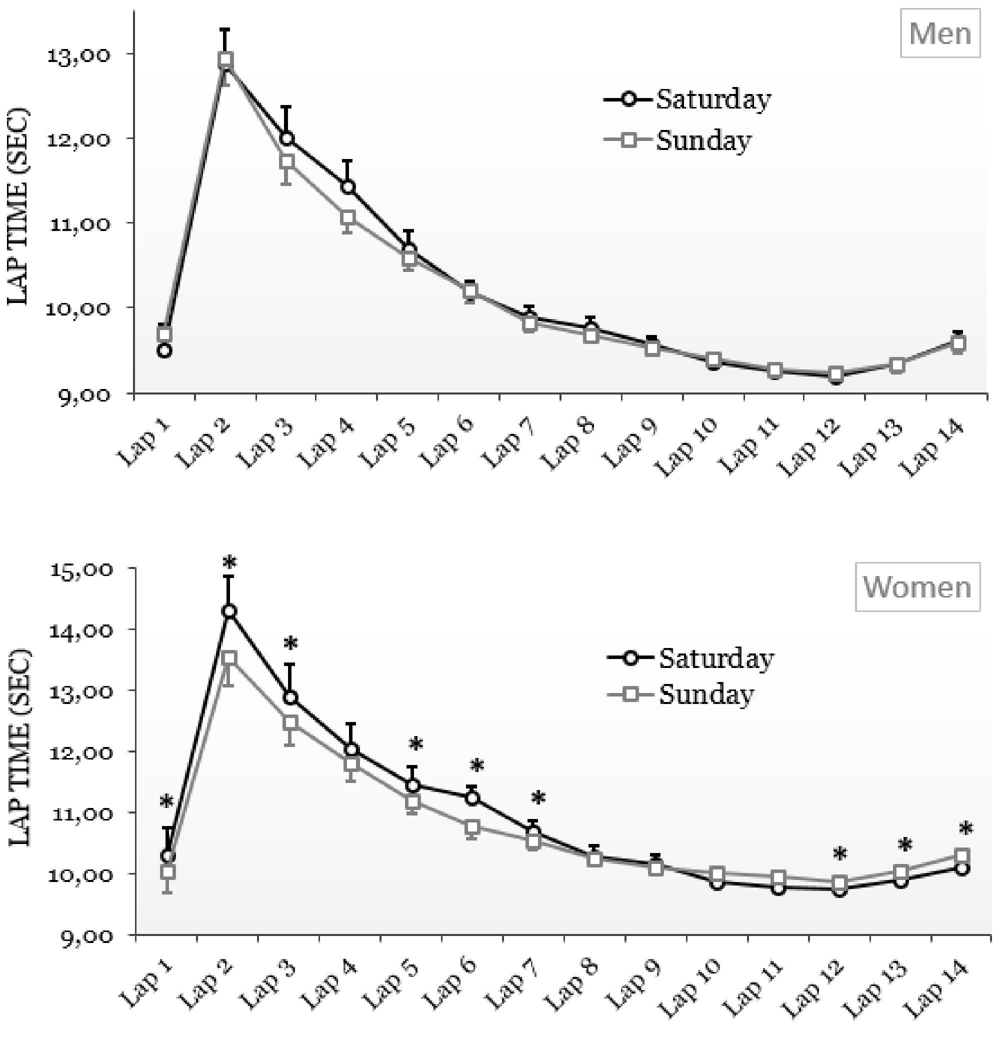


Figure 2. Mean (±95% CI) lap times per day for the 1500 m event for male (N=57) and female short-track speed skaters (N=57).



* Significant difference in lap time between days ($p<0.05$)