Objectifying tactics: Athlete and race variability in elite short-track speed skating

ORIGINAL INVESTIGATION

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Abstract

Purpose. To objectively capture and understand tactical considerations in a race, we explored whether race-to-race variation of an athlete and the variation of competitors within a race could provide insight into how and when athletes modify their pacing decisions in response to other competitors. ***Methods.*** Lap times of elite 500, 1000 and 1500 m short-track speed skating competitions between 2011–2016 (n=6965 races) were collected. Log-transformed lap and finishing times were analyzed with mixed linear models. To determine within-athlete race-to-race variability, Athlete Identity (between-athlete differences) and the residual (within-athlete race-to-race variation) were added as random effects. To determine race variability, Race identity (between-race differences) and the residual (within-race variation) were added as random effects. Separate analyses were performed for each event. ***Results.*** Within-athlete race-to-race variability of the finishing times increased with the prolonged distance of the event (500 m: CV=1.6%; 1000 m: CV=2.8%; 1500 m: CV=4.1%), mainly due to higher within-athlete race-to-race variability in the initial phase of 1000 m (3.3-6.9%) and 1500 m competitions (8.7-12.2%). During these early stages, within-race variability is relatively low in 1000 m (1.1-1.4%) and 1500 m (1.3-2.8%) competitions. ***Conclusion.*** The present study demonstrated how analyses of athlete and race variability could provide insight into tactical pacing decisions in sports where finishing position is emphasized over time. The high variability of short-track skaters is a result of the decision to alter initial pacing behavior based on the behavior of other competitors in their race, emphasizing the importance of athlete-environment interactions in the context of pacing.

Keywords: Pacing, Decision-making, Interpersonal competition, Performance analysis, Sport

Introduction

To achieve optimal performance, it is essential for athletes to use their available energetic resources efficiently.[1] Therefore athletes are required to decide continuously how and when to invest their available energy in a process that is known as pacing.[2] In this respect, modelling studies have shown to be able to determine which pacing strategy should be adopted to achieve the fastest possible finishing time for an athlete.[3–5] However, the performance of an athlete will always show random variation from competition to competition.[6] It has been estimated that in a time trial setting, an improvement equal to 0.3 of the coefficient of variation (CV) in an athlete's race-to-race performance (i.e. within-athlete race-to-race variability) leads to the smallest worthwhile enhancement in performance.[7,8] On top of this, the variation of an athlete from race to race could also offer interesting insights into an individual's race strategy and to what extent athletes modify their pacing behavior in response to the behavior of other competitors.[9]

For example, in several middle-distance and endurance sport disciplines, finishing times are irrelevant as long as you finish in front of your opponents.[10,11] In these types of sports, athletes may decide to alter their pacing behavior based on drafting possibilities, expectations or actions of any opponents who affect their winning chances, rather than adopting the theoretical most optimal pacing strategy.[10,11] Indeed, athletes have been shown to display different pacing behavior in sports such as cross-country running,[12] middle-distance running,[13] rowing,[14] track cycling,[15] and short-track speed skating[10,16] in comparison with the theoretical most optimal pacing strategy. Athlete-environment interactions appear to be crucial in the context of pacing and within-athlete race-to-race variability might be affected because of tactical considerations. However, up until now tactical decision-making in individual middle-distance and endurance sport disciplines is often evaluated based on what athletes and coaches perceive rather than what actually is happening. In addition, the importance of decision-making aspects and the external environment have only been emphasized recently in the context of pacing.[2,17] As a result, most previous pacing models have not addressed athlete-environment interactions, and most experimental and modelling studies focused solely on time-trial exercise: racing against the clock.[11] Although these time-trial studies provided interesting insights into actual pacing outcomes, it is yet unclear how these outcomes can be generalized to competitive sports where all contenders start at the same time and the winner of the event is the one who passes the finish line first.

To objectively capture and understand tactical considerations in a race, we will attempt to explore the differences in variability between- and within a race, in addition to within-athlete race-to-race variability. Between-race variability can be defined as the variability caused by the differences in mean pace between races. In contrast, within-race variability would be the variability that is a result of differences between skaters within a race. In this sense, a low variability in lap time within a race would indicate all competitors in that particular race are adopting a similar pace. In contrast, in combination with a high within-athlete race-to-race variability, this would strongly suggest athletes are adjusting their pacing behavior in that lap based on the behavior of their opponents. By using this new approach, it might become possible to distinguish whether the within-athlete race-to-race variability in pacing behavior is mainly caused by random race-to-race variation of an individual's pre-determined race strategy or whether athletes are reacting and interacting with their fellow competitors.

The aim of the present study is to examine the within-athlete race-to-race variability in elite short-track speed skating competitions. Secondly, we will explore the extent of the variability that can be assigned to differences of competitors between- or within a race. We hypothesize to find a high within-athlete race-to-race variability in the beginning and final race stages. However, we expect a relatively low within-race variability and high between-race variability in the initial race stages, indicating that athletes adjusted their own pacing behavior in response to other competitors in the early stages of competition.

Methods

Data acquisition

Finishing and intermediate lap times were gathered for men and women from 500 m (4.5 laps), 1000 m (9 laps) and 1500 m (13.5 laps) Short Track Speed Skating World Cups, the European Championships, World Championships, and the Olympic Games during the seasons 2011/12 until 2015/16. In total, 39 indoor competitions (28 World Cups, 5 European Championships, 5 World Championships, and 1 Olympic Games) were analyzed. Each short-track competition consisted of qualification stages in which a skater had to qualify for the next stage by finishing in first or second position, and the final race where the goal was to win the event. 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 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 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. The study was approved by the local ethical committee and in accordance with the Declaration of Helsinki.

Races involving falls, disqualifications and/or missing values were excluded out of the dataset, whereas falls and/or disqualifications could affect the lap times and positioning of the skater. In addition, outliers, defined as performances with a standardized residual >5.0, were excluded from the dataset.[18] A standardized residual >5.0 means that the performance was far slower than normal for the given skater. This resulted for the 500 m in 10483 of the 11675 skating performances (89.8%), for the 1000 m in 9889 of the 11164 skating performances (88.6%), and for the 1500 m in 7890 of the 9148 skating performances (86.2%) that were examined.

Statistical analysis

The mixed linear modelling procedure in SPSS was used for the analyses of each event. Finishing and lap times were log transformed before modelling, because this approach yields variability as a percent of the mean (CV), which is the natural metric for most measures of athletic performance.[19] Subsequently, within- and between-athlete CV were derived by back transformation into percentages of the residual and subject random effects in the mixed model.

Separate analyses were performed for data from each event. To determine within-athlete race-to-race variability, the fixed effect in the model was Sex and the random effects were Athlete identity (between-athletes differences) and the residual (within-athlete race-to-race variation). To determine within-race variability, the fixed effect in the model was Sex and the random effects were Race identity (between-race differences) and the residual (within-race variation). The dependent variables were the natural log of the lap times and finishing times in an event; As stated above, analysis of this transformed variables yields CV, which are variations in performance expressed as a percent of average performance.[8] Precision of the estimates of CV are shown as 90% confidence limits which represent the limits within which the true value is 90% likely to occur. In addition, we performed separate analyses in regard to the within-athlete race-to-race variability and between-athlete differences for top 10 short-track speed skaters. Top 10 skaters were determined based on the World Cup classification per event per season.

Intra-class correlations coefficients (ICC) were used to determine the predictability of finishing times in elite short track speed skating competitions. The within-athlete ICC (reproducibility of finishing times for athletes) was calculated as the sum of the pure between-athlete variance divided by the sum of the pure between-athlete variance and within-athlete variance. To assess the magnitude of the ICCs, thresholds of 0.14, 0.36, 0.54, 0.69, and 0.83 for low, moderate, high, very high, and extremely high were used.[20,21]

****Table 1 near here****

Results

Mean ± SD of the lap times and finish times in seconds of the 500, 1000 and 1500 m event can be found in Table 1. The CV and 90% confidence intervals for the finishing times of the 500 m, 1000 m and 1500 m events are reported in Table 2. Within-athlete race-to-race variability of the finishing times increased with a prolonged distance of the race (500 m: 1.6%; 1000 m: 2.8%; 1500 m: 4.1%). The CV and 90% confidence intervals for all the lap times per event for all athletes can be found in Figure 1. Within-athlete race-to-race variability was high in the initial phase of 1000 m (3.3-6.9%), and in particular 1500 m competitions (8.7-12.2%). At the same time, within-race variability was relatively low in these beginning stages of 1000 m (1.1-1.4%) and 1500 m (1.3-2.8%) competitions. This would indicate that within a race all skaters are adopting a similar initial pace, but the chosen pace varies greatly between races. The CV and 90% confidence intervals for finish times per event for Top 10 athletes can be found in Table 3. The CV and 90% confidence intervals for all the lap times per event for Top 10 athletes can be found in Figure 2. The within-athlete race-to-race variability appeared to be relatively similar for Top 10 skaters compared to all skaters. The between-athlete differences are much smaller between Top 10 skaters compared to all skaters, as you may expect. Sex resulted in a most likely difference in finish time of about 5-6% (±0.5%) in all events.

****Table 2 near here****

****Table 3 near here****

****Figure 1 near here****

****Figure 2 near here****

ICCs for all laps per event can be found in Table 4. The within-athlete predictability for the finish time, expressed as ICC, was extremely high for the 500 m event, high for the 1000 m event, and low for the 1500 m event. During the race within-athlete predictability was high for the first lap of the 500 m event, and very high for the other laps. No to low within-athlete predictability was found for the lap times of the first five laps of the 1000 m event. For the sixth lap and ninth lap of the 1000 m event ICCs were high, while ICCs of the seventh and eight lap were very high. No to low within-athlete predictability was found for the lap times of the first nine laps of the 1500 m event. For the tenth lap a moderate ICC was reported, while high ICCs were found in the final four laps of the 1500 m event.

****Table 4 near here****

Discussion

The present study aimed to examine the race-to-race variation in lap and finishing times of elite short-track speed skaters. Furthermore, we explored whether the within-athlete race-to-race variability in pacing behavior is mainly due to random race-to-race variation of an individual's pre-determined race strategy or athletes are reacting and interacting with their fellow competitors. Our findings showed that the within-athlete race-to-race variability of the finishing times increased with a prolonged distance of the race (500 m: 1.6%; 1000 m: 2.8%; 1500 m: 4.1%). This increase could mainly be attributed to a higher within-athlete race-to-race variability in the initial phase of 1000 m (3.3-6.9%), and in particular 1500 m competitions (8.7-12.2%). At the same time, within-race variability was relatively low in these beginning stages of 1000 m (1.1-1.4%) and 1500 m (1.3-2.8%) competitions. Therefore, our findings strongly suggest that short-track speed skaters adjust their own pacing behavior to other competitors within their race in the early stages of 1000 m and 1500 m competitions. In this sense, as the distance of the event increases, skaters appear to modify their pacing behavior in response to the behavior of other competitors. The importance of the behavior of other competitors impacting on pacing behavior highlights the necessity to incorporate human-environment interactions[2] in our thinking regarding pacing and decision-making in competitive performance.

In comparison with other sports, within-athlete race-to-race variability is relatively high in short-track speed skating. For example, within-athlete race-to-race variability of the finishing times was 0.9-1.1% in elite rowers[20] and 0.8-1.3% elite track cyclists.[6,22] Furthermore, the within-athlete race-to-race variability of long-track speed skaters (0.3-1.3%)[23] is much lower in comparison with the within-athlete race-to-race variability of short-track speed skaters. In addition, the predictability of finishing times is lower in the 1000 m and 1500 m short track events compared to the long track, but similar in the 500 m event. The most likely explanation for these differences is the intrinsic difference in the structure of the competition between long-track and short-track speed skating. Whereas in long-track speed skating the final classification is based on the finishing times of all skaters, in short-track speed skating, a head-to-head competition structure is used in which the skaters have to qualify for the next stage of the competition until the final. In this respect, also the relatively high variability in finishing times between races and the low variability in finishing times of competitors within a race is likely related to this head-to-head competition structure in which completion time is only relevant in relation to other competitors in that particular race.

The importance of tactical positioning has been highlighted recently in elite short-track speed skating competitions.[10,16] The present study emphasizes once again the impact of interactions with competitors for the outcome of an individual's pacing decisions. That is, elite short-track speed skaters appeared to often decide not to adopt pacing strategies as used in a time trial setting but instead alter their pacing decisions based on the behavior of other competitors in the initial phase of 1000 m and 1500 m competitions. Moreover, if we only look at the Top 10 skaters, the between-athlete differences in lap times are rather low, even in the decisive final segment of the race. This would again emphasize the importance of tactical positioning at the elite level. The present study is the first that showed how analysis of variability in pacing behavior could provide insight into when and to what extent tactical interactions with other competitors are prioritized above pursuing the fastest possible completion time.

Even in laboratory-controlled conditions the behavior of the opponent has been shown to evoke a change in initial pacing behavior and performance.[24] That is, a faster starting opponent was able to evoke a faster initial pace in cyclists compared to a slower starting opponent.[24] Previous research has made several suggestions to explain why athletes may act differently when an opponent is present. For example, an increased motivation,[25] a shift in attentional focus from internal to external aspects,[26] and a change in fatigability[27] have been mentioned. Similarly, observational studies using novel approaches[10,12,15,16,28] demonstrated the importance of what is happening around the exerciser for the outcome of the pacing decisions of the exerciser. All these examples based on experimental and observational data demonstrated that competing against others is different from riding a time-trial. In head-to-head competitions one is required to balance the energetically optimal distribution pace against possible tactical (dis)advantages to perform optimally.

In addition to the invitation to response in terms of pacing that an opponent may provide anyway, there are clear advantages for short track speed skaters in altering their pacing behavior based on their competitors. Short track speed skaters could benefit from the effect of drafting in proximity behind their opponents.[29,30] That is, when positioning oneself closely behind one of the opponents, the effect of drafting could reduce air frictional losses by 23%.[30] Moreover, skating in the beginning stages of short-track races at another position than the leading position could provide the opportunity to better oversee your competitors.[13,15] During their races, short track speed skaters are required to continuously weigh up these benefits and their ultimate goal to pass the finish line in leading position. Clearly the outcome of this balance differs per event. In the 500 m event, the aim to achieve the first position appeared to be favored above saving energy in the beginning phase of the race. In contrast, in the 1000 m and 1500 m events, saving energy in the initial stages to be able to use the remaining energy for the decisive final part of the race appeared to be the commonly used strategy. That is, the initial stages of a race in this event are characterized by a relatively low within-race and high between-race variability, while the decisive final part is characterized by a relatively high within-race and low between-race variability.

In conclusion, the present study provides a novel tool to measure and objectify tactical decision-making in individual middle-distance and endurance sports by using the variation of an athlete from the race to race in combination with the variability in lap times between and within races. As demonstrated in this study, the combination of within-athlete race-to-race variability and between- and within-race variability could provide novel insights into the complex process of decision-making that is involved in pacing behavior and tactical considerations. The relatively high race-to-race variation of the finishing times in elite short-track speed skaters during the 1000 m and 1500 m events could be mainly assigned to the high within-athlete race-to-race variability in the initial laps of the race. It appears that this high variability of the skater is a result of the skater's decision to alter initial pacing behavior based on the behavior of other competitors in that particular race, emphasizing the importance of the behavior of competitors as a determinant for the outcome of an athlete's pacing decisions during competition.

Practical applications

Previous studies that examined the within-athlete race-to-race variability often mainly attempted to provide coaches, athletes and practitioners with a guideline for measuring the effectiveness of an intervention, in which an improvement equal to 0.3 of the CV in within-athlete race-to-race variability is commonly accepted as the smallest worthwhile enhancement in performance.[7,8]. We recognize and emphasize the importance of a guideline to determine whether an intervention of any kind actually leads to an quantifiable and worthwhile improvement in performance. However, we would like to note that in middle-distance and endurance sport disciplines with a strong interaction of tactical nature between the competitors this particular way of determining the smallest worthwhile enhancements has its limitations. That is, the smallest worthwhile enhancement of the finishing time in the 1500 m short-track speed skating event would be 1.80 seconds. This is so large because the variability in finish times is very large, mainly related to tactical decisions in the beginning stages of the race. At first sight, this improvement could be achieved by just adopting a pacing strategy aimed at completing the event as fast as possible. However, in terms of performance quantified using finishing position, this strategy is likely to have a detrimental effect. Yet there might be alternative ways in which it is still possible to determine a smallest worthwhile enhancement. For example, we could use the lap with the lowest within-athlete race-to-race variability, in which athletes tend to follow their own strategy and are not too much influenced by the actions of the opponents. Interestingly, for both the 1000 m as well as the 1500 m, this lap corresponds to the lap in which short track speed skaters in general achieve their fastest lap time. Using this approach, the smallest worthwhile enhancement for the 1000 m would be 0.08 s in lap 7, and 0.09 s in lap 11 for the 1500 m.

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References

1. Foster C, De Koning JJ, Hettinga FJ, et al. Pattern of energy expenditure during simulated competition. *Med Sci Sports Exerc*. 2003;35(5):826-831.

2. 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.

3. Hettinga FJ, De Koning JJ, Schmidt L, Wind N, Macintosh BR, Foster C. Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *Br J Sports Med*. 2011;45(1):30-35.

4. De Koning JJ, Foster C, Lucía A, Bobbert MF, Hettinga FJ, Porcari JP. Using modeling 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.

5. 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.

6. Paton CD, Hopkins WG. Variation in performance of elite cyclists from race to race. *Eur J Sport Sci*. 2006;6(1):25-31.

7. Malcata RM, Hopkins WG. Variability of competitive performance of elite athletes: a systematic review. *Sport Med*. 2014;44(12):1763-1774.

8. Hopkins WG, Hawley JA, Burke LM. Design and analysis of research on sport performance enhancement. *Med Sci Sports Exerc*. 1999;31(3):472-485.

9. Micklewright D, Kegerreis S, Raglin J, Hettinga FJ. Will the Conscious–Subconscious Pacing Quagmire Help Elucidate the Mechanisms of Self-Paced Exercise? New Opportunities in Dual Process Theory and Process Tracing Methods. *Sport Med*. 2016:1-9. doi:10.1007/s40279-016-0642-6.

10. 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.

11. 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.

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

13. 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.

14. 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.

15. 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.

16. 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.

17. 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. *Sport Med*. 2014;44(2):147-158.

18. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3-13. doi:10.1249/MSS.0b013e31818cb278.

19. Hopkins WG. Log transformation for better fits. *A New View Stat*. 2000. http://www.sportsci.org/resource/stats/logtrans.html. Accessed August 25, 2016.

20. Smith TB, Hopkins WG. Variability and predictability of finals times of elite rowers. *Med Sci Sports Exerc*. 2011;43(11):2155-2160.

21. Spencer M, Losnegard T, Hallén J, Hopkins WG. Variability and predictability of performance times of elite cross-country skiers. *Int J Sports Physiol Perform*. 2014;9(1):5-11.

22. Flyger N. Variability in competitive performance of elite track cyclists. *ISBS-Conference Proc Arch*. 2009;1(2):27-40. https://ojs.ub.uni-konstanz.de/cpa/article/view/3441.

23. Noordhof DA, Mulder RCM, De Koning JJ, Hopkins WG. Race Factors Affecting Performance Times in Elite Long-Track Speed Skating. *Int J Sports Physiol Perform*. 2016;11(4):535-542. doi:10.1123/ijspp.2015-0171.

24. Konings MJ, Schoenmakers PP, Walker A, Hettinga FJ. The behavior of an opponent alters pacing decisions in 4-km cycling time trials. *Physiol Behav*. 2016;158(1):1-5.

25. McCormick A, Meijen C, Marcora SM. Psychological Determinants of Whole-Body Endurance Performance. *Sport Med*. 2015;45(7):997-1015. doi:10.1007/s40279-015-0319-6.

26. Williams EL, Jones HS, Sparks SA, Marchant DC, Midgley AW, McNaughton LR. Competitor presence reduces internal attentional focus and improves 16.1km cycling time trial performance. *J Sci Med Sport*. 2015;18(4):486-491.

27. Konings MJ, Parkinson J, Micklewright D, Zijdewind I, Hettinga FJ. Willingness to tolerate higher levels of peripheral fatigue might explain the performance improvement when riding against opponents. In: *Book of Abstract European College of Sport Sciences*. Vienna; 2016.

28. Hanley B. Pacing, packing and sex-based differences in Olympic and IAAF World Championship marathons. *J Sports Sci*. 2016;34(17):1675-1681. doi:10.1080/02640414.2015.1132841.

29. Rundell K. Effects of drafting during short-track speed skating. *Med Sci Sports Exerc*. 1996;28(6):765-771.

30. Van Ingen Schenau GJ. The influence of air friction in speed skating. *J Biomech*. 1982;15(6):449-458.

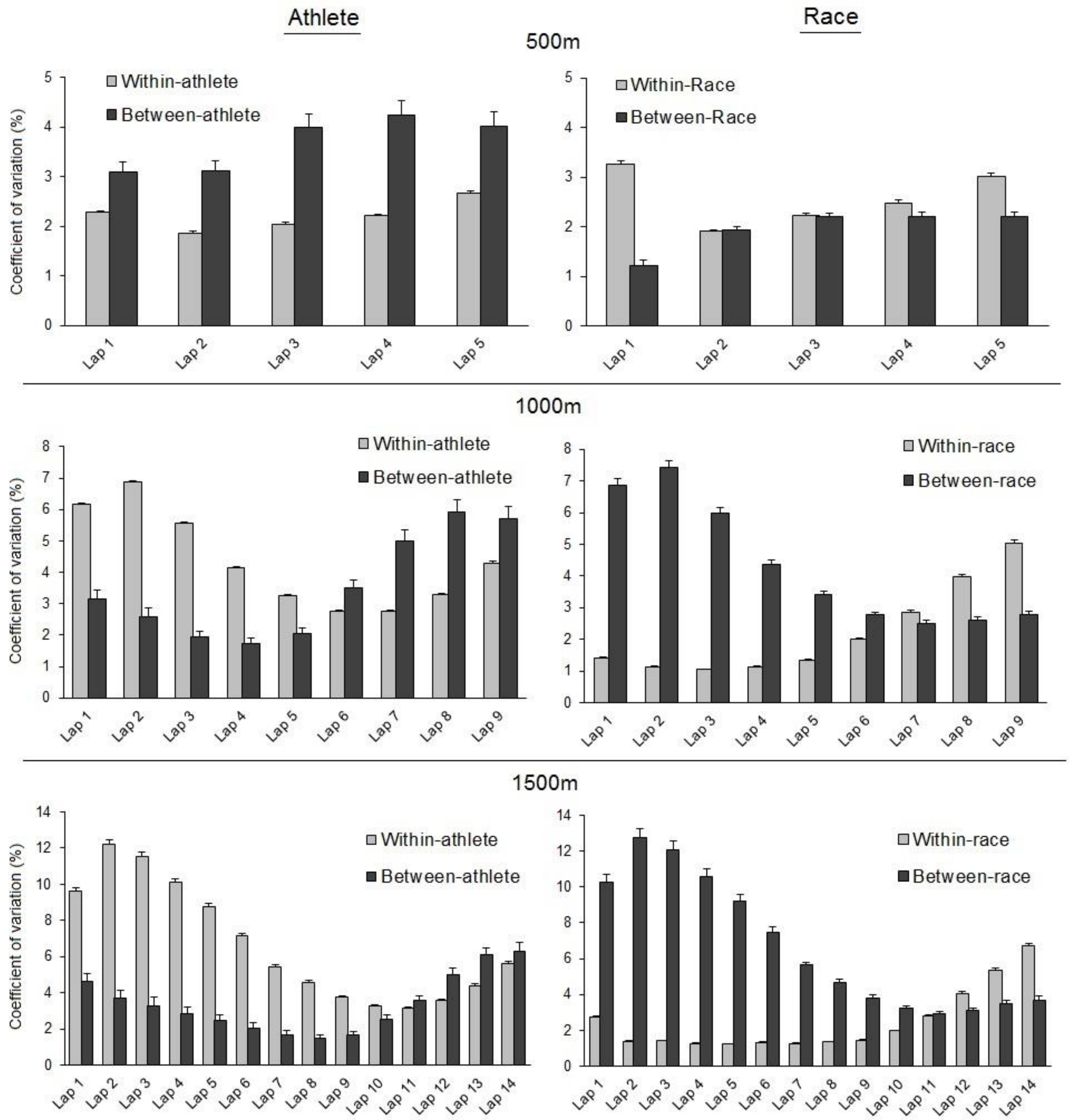

Figure 1. Within-athlete race-to-race variability and within-race variability in lap times expressed as coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m competitions.

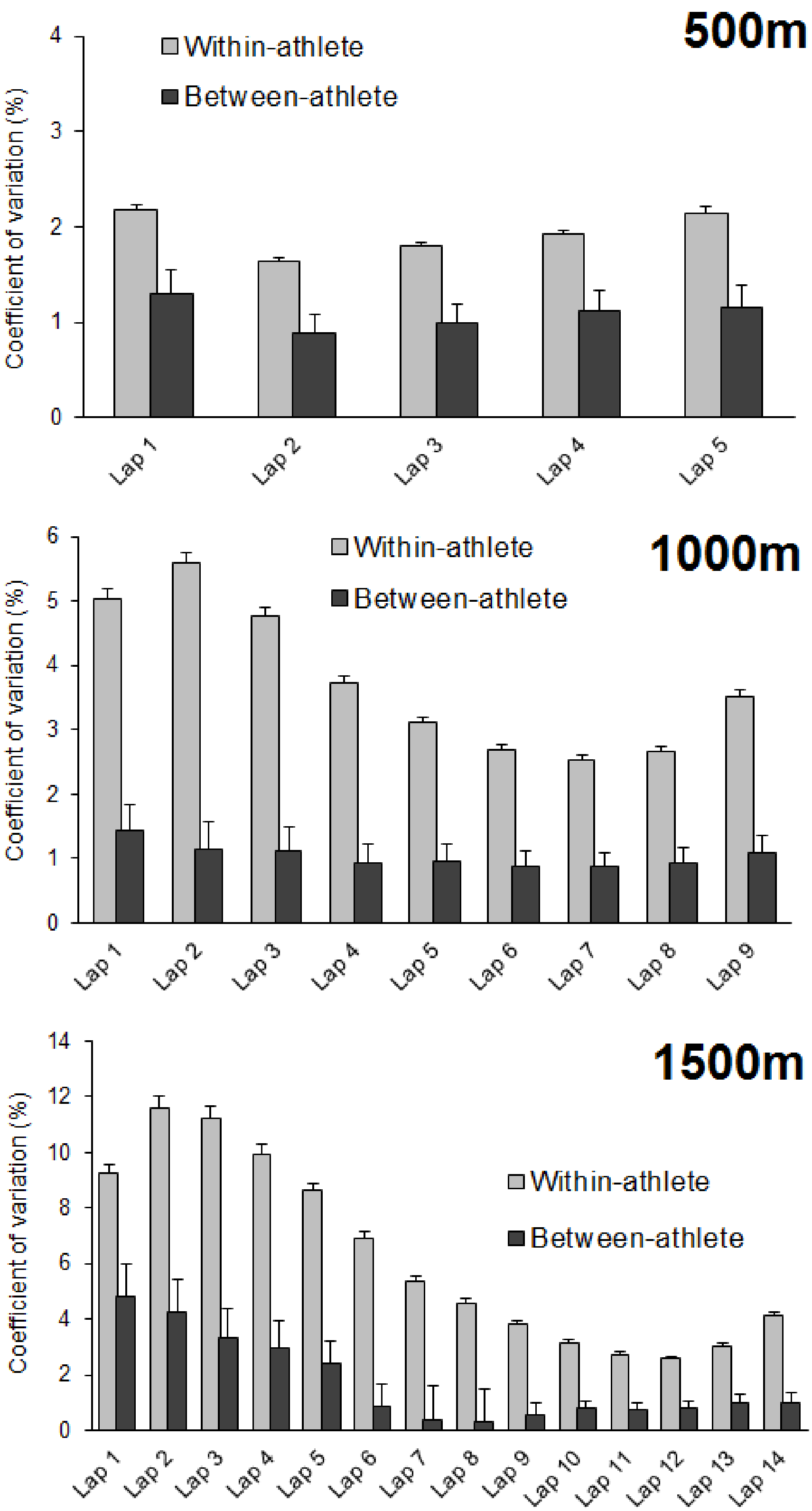

Figure 2. Within-athlete race-to-race variability for Top 10 skaters in lap times expressed as coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m competitions.

Table 1. Mean ± SD of the lap times and finish times in seconds of the 500, 1000 and 1500 m event

	500m	**1000m**	**1500m**
Lap 1	7.32 ± 0.34	13.68 ± 0.98	9.71 ± 1.02
Lap 2	9.32 ± 0.37	10.40 ± 0.80	13.17 ± 1.67
Lap 3	8.87 ± 0.38	10.04 ± 0.65	12.15 ± 1.48
Lap 4	9.01 ± 0.40	9.81 ± 0.51	11.61 ± 1.27
Lap 5	9.26 ± 0.43	9.65 ± 0.46	11.13 ± 1.09
Lap 6		9.51 ± 0.45	10.67 ± 0.87
Lap 7		9.46 ± 0.48	10.30 ± 0.66
Lap 8		9.53 ± 0.56	10.06 ± 0.57
Lap 9		9.76 ± 0.65	9.87 ± 0.49
Lap 10			9.73 ± 0.47
Lap 11			9.62 ± 0.48
Lap 12			9.62 ± 0.57
Lap 13			9.75 ± 0.69
Lap 14			10.04 ± 0.83
Finish time	43.78 ± 1.78	91.85 ± 4.10	147.43 ± 7.97

Table 2. Within-athlete variability and within-race variability in finishing times expressed as coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m competitions.

	Athlete			Race		
	Fixed	Random		Fixed	Random	
	Sex	Within-athlete	Between-athlete	Sex	Within-race	Between-race
500m	5.6 ± 0.6	1.64 x/÷ 1.01	3.71 x/÷ 1.07	6.0 ± 0.2	2.11 x/÷ 1.02	1.89 x/÷ 1.03
1000m	5.2 ± 0.5	2.80 x/÷ 1.01	3.05 x/÷ 1.07	5.6 ± 0.3	1.63 x/÷ 1.02	3.24 x/÷ 1.03
1500m	5.9 ± 0.5	4.07 x/÷ 1.02	2.38 x/÷ 1.09	5.8 ± 0.4	1.42 x/÷ 1.02	4.46 x/÷ 1.04

Table 3. Within-athlete variability for Top 10 skaters in finishing times expressed as coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m competitions

	Athlete – Top 10		
	Fixed	Random	
	Sex	Within-athlete	Between-athlete
500m	6.2 ± 0.5	1.37 x/÷ 1.03	0.89 x/÷ 1.26
1000m	5.9 ± 0.5	2.42 x/÷ 1.03	0.75 x/÷ 1.27
1500m	6.0 ± 0.8	4.17 x/÷ 1.03	1.30 x/÷ 1.30

Table 4. Within-athlete predictability expressed as intra-class correlation coefficients of each event for all athletes

	500 m	1000 m	1500 m
Lap 1	0.65	0.21	0.19
Lap 2	0.73	0.13	0.09
Lap 3	0.79	0.11	0.08
Lap 4	0.78	0.15	0.08
Lap 5	0.69	0.29	0.08
Lap 6	-	0.61	0.08
Lap 7	-	0.76	0.09
Lap 8	-	0.76	0.10
Lap 9	-	0.63	0.16
Lap 10	-	-	0.38
Lap 11	-	-	0.56
Lap 12	-	-	0.66
Lap 13	-	-	0.65
Lap 14	-	-	0.56
Finish time	0.83	0.54	0.26