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

3
4 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

89 **Introduction**

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

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

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

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

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141 **Methods**

142 *Data acquisition*

143 Finishing and intermediate lap times were gathered for men and women from 500 m
144 (4.5 laps), 1000 m (9 laps) and 1500 m (13.5 laps) Short Track Speed Skating World Cups, the
145 European Championships, World Championships, and the Olympic Games during the seasons
146 2011/12 until 2015/16. In total, 39 indoor competitions (28 World Cups, 5 European
147 Championships, 5 World Championships, and 1 Olympic Games) were analyzed. Each short-
148 track competition consisted of qualification stages in which a skater had to qualify for the next
149 stage by finishing in first or second position, and the final race where the goal was to win the
150 event. Lap times were measured using electronic time-measuring systems based on optical
151 detectors that started automatically by the firing of a starting-gun and that recorded
152 automatically the time in which the finish line was reached by each competitor. The
153 International Skating Union (ISU) demands that lap times are recorded with the accuracy of at
154 least a hundredth of a second. Therefore, for every automatic timekeeping system a certificate
155 stating the reliability and accuracy of the system had to be presented to the referee before the
156 competition, ensuring that all systems recorded with the accuracy of at least a hundredth of a
157 second. No written consent was given by participants as all data used are publicly available at
158 the ISU website (<http://www.sportresult.com/federations/ISU/ShortTrack/>) and no
159 interventions occurred during the data collection. The study was approved by the local ethical
160 committee and in accordance with the Declaration of Helsinki.

161 Races involving falls, disqualifications and/or missing values were excluded out of the
162 dataset, whereas falls and/or disqualifications could affect the lap times and positioning of the
163 skater. In addition, outliers, defined as performances with a standardized residual >5.0 , were
164 excluded from the dataset.¹⁸ A standardized residual >5.0 means that the performance was far
165 slower than normal for the given skater. This resulted for the 500 m in 10483 of the 11675
166 skating performances (89.8%), for the 1000 m in 9889 of the 11164 skating performances
167 (88.6%), and for the 1500 m in 7890 of the 9148 skating performances (86.2%) that were
168 examined.

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170 *Statistical analysis*

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

176 Separate analyses were performed for data from each event. To determine within-athlete race-
177 to-race variability, the fixed effect in the model was Sex and the random effects were Athlete
178 identity (between-athletes differences) and the residual (within-athlete race-to-race variation).
179 To determine within-race variability, the fixed effect in the model was Sex and the random
180 effects were Race identity (between-race differences) and the residual (within-race variation).
181 The dependent variables were the natural log of the lap times and finishing times in an event;
182 As stated above, analysis of this transformed variables yields CV, which are variations in
183 performance expressed as a percent of average performance.⁸ Precision of the estimates of CV
184 are shown as 90% confidence limits which represent the limits within which the true value is
185 90% likely to occur. In addition, we performed separate analyses in regard to the within-athlete
186 race-to-race variability and between-athlete differences for top 10 short-track speed skaters.
187 Top 10 skaters were determined based on the World Cup classification per event per season.

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

194

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

196

197 **Results**

198 Mean \pm SD of the lap times and finish times in seconds of the 500, 1000 and 1500 m
199 event can be found in Table 1. The CV and 90% confidence intervals for the finishing times of
200 the 500 m, 1000 m and 1500 m events are reported in Table 2. Within-athlete race-to-race
201 variability of the finishing times increased with a prolonged distance of the race (500 m: 1.6%;
202 1000 m: 2.8%; 1500 m: 4.1%). The CV and 90% confidence intervals for all the lap times per
203 event for all athletes can be found in Figure 1. Within-athlete race-to-race variability was high
204 in the initial phase of 1000 m (3.3-6.9%), and in particular 1500 m competitions (8.7-12.2%).
205 At the same time, within-race variability was relatively low in these beginning stages of 1000
206 m (1.1-1.4%) and 1500 m (1.3-2.8%) competitions. This would indicate that within a race all
207 skaters are adopting a similar initial pace, but the chosen pace varies greatly between races. The
208 CV and 90% confidence intervals for finish times per event for Top 10 athletes can be found in
209 Table 3. The CV and 90% confidence intervals for all the lap times per event for Top 10 athletes
210 can be found in Figure 2. The within-athlete race-to-race variability appeared to be relatively
211 similar for Top 10 skaters compared to all skaters. The between-athlete differences are much
212 smaller between Top 10 skaters compared to all skaters, as you may expect. Sex resulted in a
213 most likely difference in finish time of about 5-6% ($\pm 0.5\%$) in all events.

214

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

216

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

218

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

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

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Discussion

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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 interactions² in our thinking regarding pacing and decision-making in competitive performance.

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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 rowers²⁰ 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

264 competition until the final. In this respect, also the relatively high variability in finishing times
265 between races and the low variability in finishing times of competitors within a race is likely
266 related to this head-to-head competition structure in which completion time is only relevant in
267 relation to other competitors in that particular race.

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

280 Even in laboratory-controlled conditions the behavior of the opponent has been shown
281 to evoke a change in initial pacing behavior and performance.²⁴ That is, a faster starting
282 opponent was able to evoke a faster initial pace in cyclists compared to a slower starting
283 opponent.²⁴ Previous research has made several suggestions to explain why athletes may act
284 differently when an opponent is present. For example, an increased motivation,²⁵ a shift in
285 attentional focus from internal to external aspects,²⁶ and a change in fatigability²⁷ have been
286 mentioned. Similarly, observational studies using novel approaches^{10,12,15,16,28} demonstrated the
287 importance of what is happening around the exerciser for the outcome of the pacing decisions
288 of the exerciser. All these examples based on experimental and observational data demonstrated
289 that competing against others is different from riding a time-trial. In head-to-head competitions
290 one is required to balance the energetically optimal distribution pace against possible tactical
291 (dis)advantages to perform optimally.

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

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

321

322 **Practical applications**

323 Previous studies that examined the within-athlete race-to-race variability often mainly
324 attempted to provide coaches, athletes and practitioners with a guideline for measuring the
325 effectiveness of an intervention, in which an improvement equal to 0.3 of the CV in within-
326 athlete race-to-race variability is commonly accepted as the smallest worthwhile enhancement
327 in performance.^{7,8} We recognize and emphasize the importance of a guideline to determine
328 whether an intervention of any kind actually leads to an quantifiable and worthwhile
329 improvement in performance. However, we would like to note that in middle-distance and
330 endurance sport disciplines with a strong interaction of tactical nature between the competitors
331 this particular way of determining the smallest worthwhile enhancements has its limitations.
332 That is, the smallest worthwhile enhancement of the finishing time in the 1500 m short-track
333 speed skating event would be 1.80 seconds. This is so large because the variability in finish
334 times is very large, mainly related to tactical decisions in the beginning stages of the race. At
335 first sight, this improvement could be achieved by just adopting a pacing strategy aimed at
336 completing the event as fast as possible. However, in terms of performance quantified using
337 finishing position, this strategy is likely to have a detrimental effect. Yet there might be
338 alternative ways in which it is still possible to determine a smallest worthwhile enhancement.
339 For example, we could use the lap with the lowest within-athlete race-to-race variability, in
340 which athletes tend to follow their own strategy and are not too much influenced by the actions
341 of the opponents. Interestingly, for both the 1000 m as well as the 1500 m, this lap corresponds
342 to the lap in which short track speed skaters in general achieve their fastest lap time. Using this
343 approach, the smallest worthwhile enhancement for the 1000 m would be 0.08 s in lap 7, and
344 0.09 s in lap 11 for the 1500 m.

345

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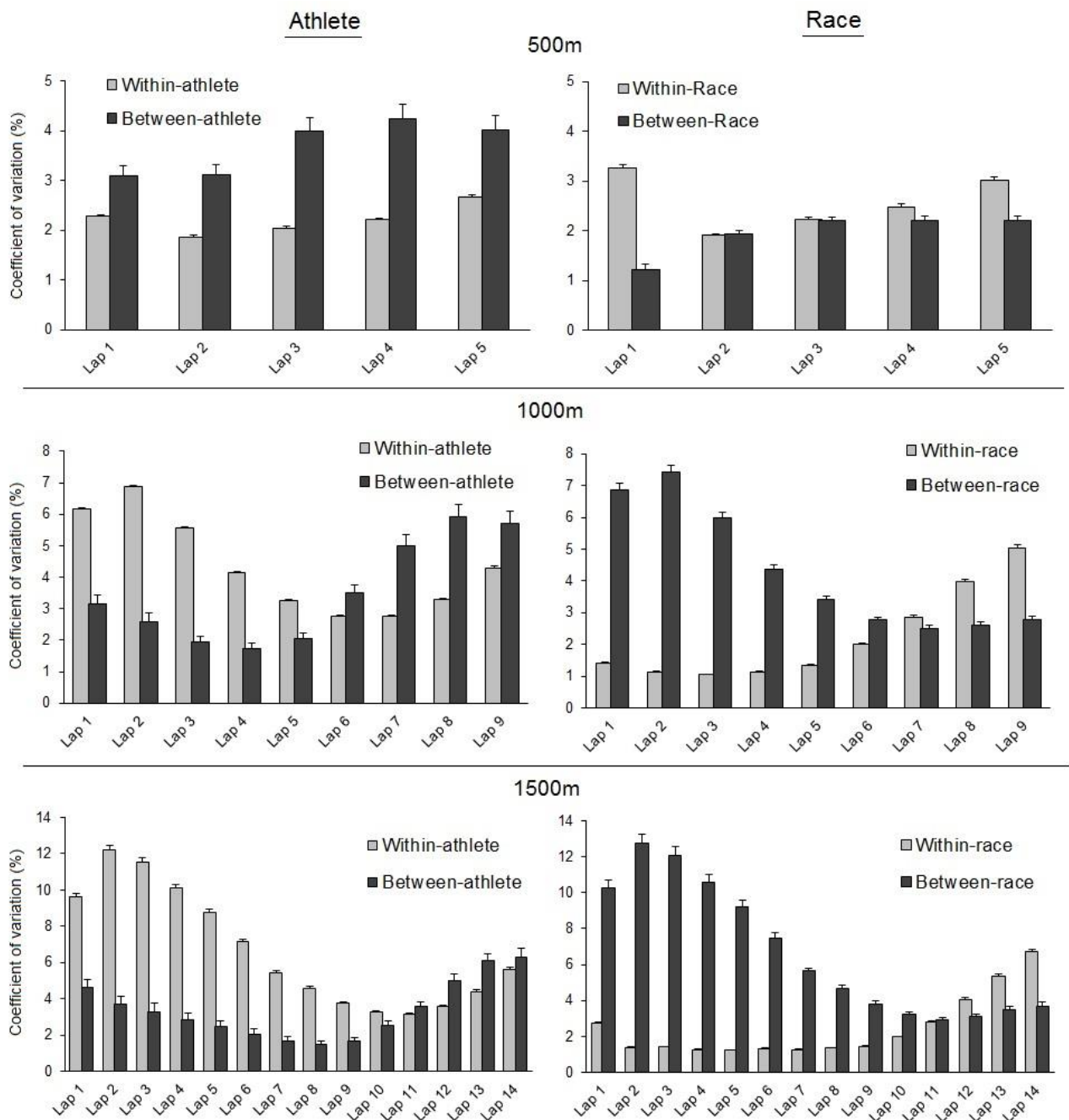
347 The results of the current study do not constitute endorsement of the product by the authors or
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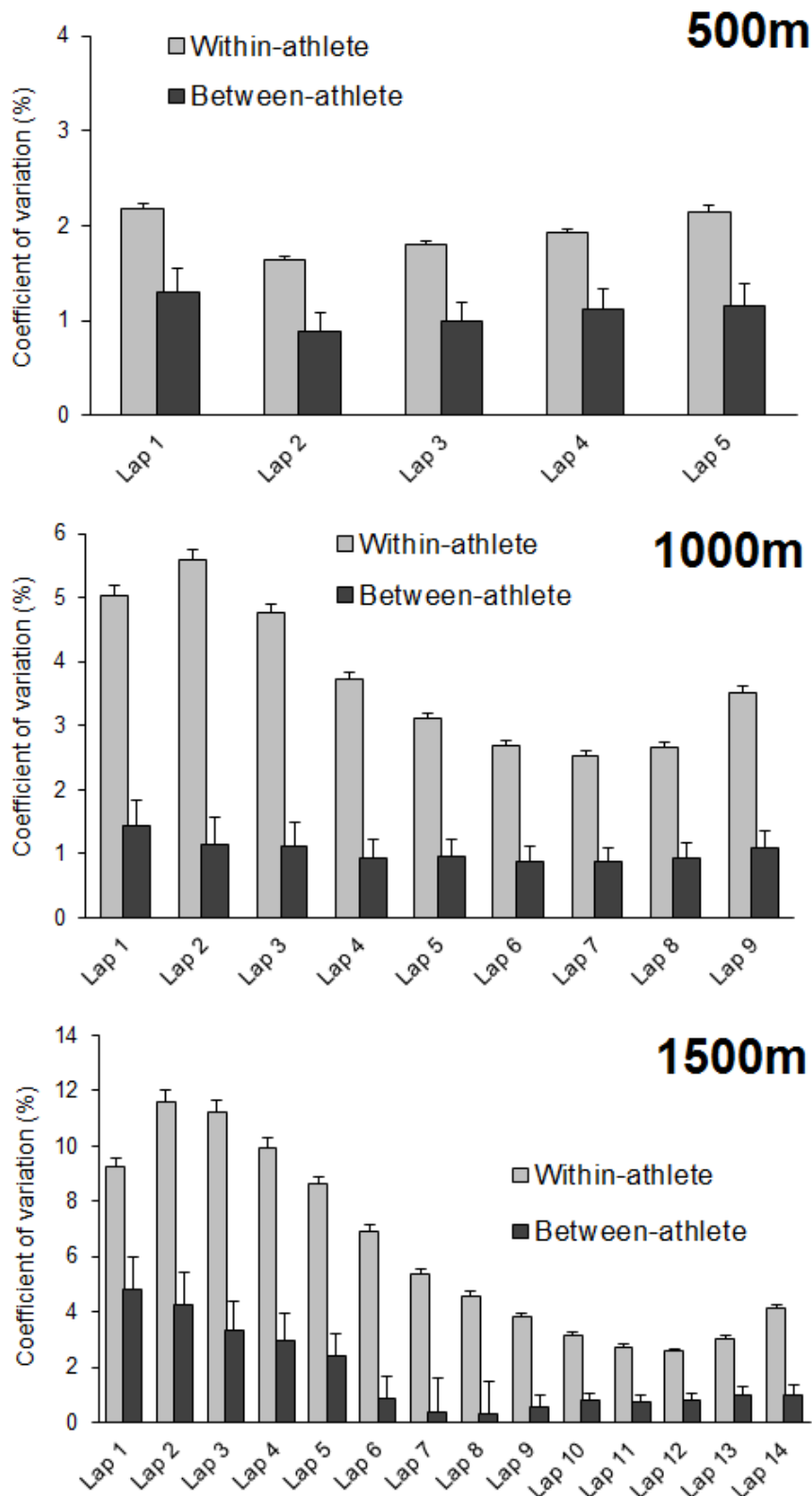
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Figure 1. Within-athlete race-to-race variability and within-race variability in lap times expressed as coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m competitions.



440
 441 **Figure 2.** Within-athlete race-to-race variability for Top 10 skaters in lap times expressed as
 442 coefficients of variation (CV) and the 90% confidence limits in 500 m, 1000 m and 1500 m
 443 competitions.

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

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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

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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/÷ 1.03
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

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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

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