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1 **Abstract**

2 **Purpose:** To provide a descriptive analysis of the warm-up
3 (WU) strategies employed by cross-country skiers prior to
4 distance and sprint competitions at a national championship, and
5 to compare the skiers' planned and executed WUs prior to the
6 respective competitions.

7 **Methods:** Twenty-one national- and international-level skiers
8 (11 women, 10 men) submitted WU plans prior to the distance
9 and sprint competitions and after the competitions reported any
10 deviations from the plans. Skiers used personal monitors to
11 record heart rate (HR) during WU, races and cool down.
12 Quantitative statistical analyses were conducted on WU
13 durations, durations in HR-derived intensity zones and WU
14 loads. Qualitative analyses were conducted on skiers' WU plans
15 and their reasons for deviating from the plans.

16 **Results:** Skiers' planned WUs were similar in content and
17 planned time in HR-derived intensity zones for both the distance
18 and sprint competitions. However, 45% of the women and 20%
19 of the men reported that their WU was not carried out as planned,
20 with reasons detailed as being due to incorrect intensities and
21 running out of time. WU activities including skiing across
22 variable terrain, muscle-potentiating exercises and heat
23 maintenance strategies were missing from the skier's planned
24 routines.

25 **Conclusions:** Skiers favored a long, traditional WU approach
26 for both the sprint and distance events, performing less high-
27 intensity and more moderate-intensity exercise during their WUs
28 than planned. Additionally, elements likely relevant to
29 successful performance in XC skiing were missing from WU
30 plans.

31

32 **Key words:** priming; Nordic skiing; preparation; pre
33 competition; transition

34 Introduction

35 Warming up prior to competitive events is considered an
36 effective means of enhancing performance, with increases in
37 muscle temperature, priming of oxygen uptake ($\dot{V}O_2$) kinetics
38 and the neuromuscular system, and enhanced feelings of
39 readiness to perform proposed as effective mechanisms.¹⁻⁴
40 Typically, warm ups (WUs) are structured using the RAMP
41 principle to *raise* the heart rate (HR) and muscle temperature,
42 *activate* the key musculature, *mobilize* the relevant joints, and
43 *potentiate* for the upcoming event.⁵ There is some published
44 guidance on WU strategies, with a comprehensive review of the
45 available literature indicating that active WUs consisting of brief
46 (~15 min) aerobic activity, 4–5 sprints or race-pace efforts and
47 muscular potentiating activities elicit improved performance in
48 certain sports.³ However, there remains a dearth of research on
49 optimal WU strategies for cross-country skiers, who typically
50 compete in cold environments.

51 Owing to the absence of sufficient information on effective WU
52 strategies for specific endurance events,^{2,6,7} many WU practices
53 adopted by athletes and coaches are based on anecdotal
54 experiences and traditions rather than empirical evidence. This
55 is particularly true of XC skiing, where only one peer-reviewed
56 publication has examined different WU approaches prior to
57 competition.⁸ In this study, it was found that a short, specific WU
58 elicited similar physiological responses, perception of effort and
59 subsequent sprint time-trial performance compared to a longer,
60 more traditional approach. This is, in part, consistent with
61 previous research acknowledging the potential for longer-
62 duration WUs to result in fatigue,^{6,8-11} while shorter WUs have
63 been reported to enhance physiological and/or performance
64 measures in rowing⁶ and track cycling.¹¹ While the
65 aforementioned study investigated WU approaches in sprint XC
66 skiing, no research has been conducted to date on WU strategies
67 prior to distance XC skiing.

68 Cross-country skiing competitions involve both freestyle (i.e.,
69 skate skiing) and classic techniques. Within each technique there
70 are a number of sub-techniques¹² and the choice of sub-
71 technique is determined by skiing speed and terrain.¹³
72 Performance across varying terrains is important in XC skiing
73 and terrain-specific pacing strategies and performance in uphill
74 sections of races are important performance determinants.^{13,14}
75 Senior distance competitions generally involve a single race over
76 10–15 km and last approximately 26–35 min.¹² In comparison,
77 sprint competitions consist of a time trial (prologue) followed by
78 three head-to-head races (for the six most successful athletes),
79 with each race lasting 2–4 min and separated by irregular
80 recovery periods.¹⁵ The multiple rounds within sprint

81 competitions present challenges, whereby an initial WU and
82 subsequent “re-warm-ups” are required. Previous work has
83 indicated that active and passive recovery between simulated
84 sprint rounds have trivial effects on subsequent performance.¹⁶
85 Due to these differences in competition distance, duration and
86 format, the relative energy system contributions differ for
87 distance and sprint competitions, with greater importance of
88 anaerobic metabolic power during sprint races.^{17,18} As such, WU
89 strategies should probably be tailored to the specific demands of
90 the event.³

91 In XC skiing, cold environments negatively affect core and
92 muscle temperatures¹⁹. Despite the unique challenges involved
93 in the sport, the WU practices of high-performing XC skiers
94 during real-world competition have not been detailed in the
95 literature. It is currently unknown how skiers plan and execute
96 their pre-competition preparation strategies in terms of exercise
97 *durations and intensities or offsetting the negative impacts of the*
98 *cold*. Similarly, it is unknown whether XC skiers plan and
99 execute different WUs before distance and sprint events. Such
100 information would prove useful for researchers and applied
101 practitioners supporting XC skiers and contribute to improving
102 the ecological validity of future lab-based studies. Therefore, the
103 primary aim of the study was to provide a descriptive analysis of
104 the WU strategies employed before distance and sprint events at
105 a national championship. Our secondary aim was to compare the
106 planned and executed WUs before each event.

107 **Methods**

108 *Participants*

109 Twenty-one national- and international-level XC skiers (11
110 Swedish women; 1 Italian and 9 Swedish men) who completed
111 the distance and sprint competitions at an annual national
112 championship participated in the study (Table 1). A total of 51
113 women and 122 men entered the distance competition, and 49
114 women and 99 men entered the sprint competition. Opportunistic
115 sampling was conducted, whereby the coaches and skiers were
116 informed of the study in the weeks leading up to the
117 championship event, and further details were presented at the
118 team-leader meetings prior to the specific competitions. All
119 skiers were invited to participate and those who submitted their
120 planned and executed WU information, responded to the
121 subjective readiness questions, and provided HR data were
122 included. All participating skiers were over 18 years at the time
123 of data collection, and they were fully informed about the risks
124 and benefits of the study before providing written informed
125 consent for their data to be included. The study was approved by

126 the regional ethical review board in Umeå, Sweden (2018-441-
127 32M).

128 *Design*

129 This was an observational study and data included skiers'
130 qualitative descriptions of planned WUs and whether the WUs
131 were carried out as planned, HR data during WU and in the phase
132 between the WU ending and the race beginning (i.e., the passive
133 phase before the race start, hereafter referred to as the
134 “transition”) and subjective ratings of physical and
135 psychological readiness following WU. The distance and sprint
136 competitions were performed on two consecutive days, with the
137 distance competition involving 10 and 15 km of classic skiing
138 for the women and men, respectively, and the sprint competition
139 performed using the skating technique over a 1.4-km course for
140 both sexes. The sprint competition involved up to four races in a
141 knockout format: a prologue, and if successful, a quarterfinal,
142 semifinal, and final. All sprint competition data used for analyses
143 were taken from the WU activities performed before the
144 prologue and the prologue race-performance data.

145 *Self-reported warm-up information*

146 All participants submitted detailed written WU plans on arrival
147 at the race venue prior to commencing the distance and sprint
148 competitions and any deviations from the plans were reported
149 after the respective competitions. Physical and psychological
150 subjective feelings of readiness were rated after completing the
151 distance and sprint competitions using a 1–5 Likert scale in
152 response to the questions: “I felt physically ready after the warm-
153 up” and “I felt psychologically ready after the warm-up”, with 1
154 representing “not at all” and 5 representing “completely”. After
155 completing the sprint and distance competitions skiers were
156 asked “Did the warm-up work as planned”, to which they replied
157 either yes or no. If no, the skiers were asked the open-ended
158 question: “Why did the warm-up not work as planned” and gave
159 their responses in writing (all terms have been translated from
160 Swedish and agreed upon by at least two bilingual co-authors).

161 *Heart rate data*

162 All participants used their own HR monitors and were instructed
163 to start their HR recordings when starting the WU and to end the
164 data collection following their cool down after the competition.
165 They were also instructed to use splits to mark the beginning and
166 end of the WU and transition, allowing the durations and relative
167 exercise intensities to be calculated for these two distinct phases.
168 Peak HR (HR_{peak}) and average HR expressed as a percentage of
169 HR_{peak} (HR_{ave}) were calculated for the WU and transition phases,

170 where HR_{peak} was defined as the 1-s peak value attained on the
171 respective distance and sprint competition days. For the women,
172 HR_{peak} was 183 ± 10 and 177 ± 11 $\text{beats} \cdot \text{min}^{-1}$ during the distance
173 and sprint competitions, respectively ($p=0.036$, 3.2%), and for
174 the men was 182 ± 13 and 176 ± 9 ($p=0.872$, 2.9%).

175 For the self-reported WU descriptions, athletes used the Swedish
176 Ski Association's four intensity zones,²⁰ which are defined as
177 A1: 60–74%, A2: 75–84%, A3: 85–95% and A3+: >95% of
178 HR_{peak} .

179 *Performance variables*

180 The distance competitions began at 1030 h and 1140 h and the
181 sprint prologues began at 1600 h and 1620 h for the women and
182 men, respectively. The weather conditions on the days of the
183 distance and sprint competitions, were temperature, -1 to 0°C
184 and 0–1°C; snow conditions, old granular snow and fresh snow;
185 humidity, 80 to 82% and 82 to 85%; barometric pressure, 767
186 and 764 mmHg; wind speed and direction, 10.0–10.9 $\text{km} \cdot \text{h}^{-1}$
187 south-westerly and 13.0–13.1 $\text{km} \cdot \text{h}^{-1}$ southerly.

188 Performance was expressed in three ways for both the distance
189 and sprint competitions: attained FIS points, finishing position,
190 and race time. Long-term performance was defined by pre-
191 competition FIS distance and sprint points using the FIS points
192 lists from the time immediately preceding the championship
193 event (retrieved from fis-ski.com on 18/11/2019). The
194 calculation of FIS points has been described elsewhere.²¹

195 *Statistical analyses*

196 The feelings of readiness and competition finishing position
197 (ordinal data) are presented as median (interquartile range
198 [IQR]), while all other data (interval and ratio) are presented as
199 mean \pm *SD* and the alpha level of 0.05 was set *a priori*. All
200 quantitative analyses were conducted using Jamovi 1.2²² and
201 qualitative analyses were conducted with Nvivo 11.0 (QSR
202 International, Melbourne, Australia). The Shapiro-Wilk test of
203 normality indicated that all interval and ratio data were not-
204 normally distributed ($p < 0.05$).

205 Mann-Whitney U tests were employed to analyze sex differences
206 in pre-competition FIS points, as well as absolute and relative
207 performance variables during the distance and sprint
208 competitions. Wilcoxon rank tests were used to analyze
209 differences between distance and sprint competitions for
210 subjective feelings of physical, psychological, and overall
211 readiness following the WU, as well as for WU and transition
212 characteristics. Wilcoxon rank tests were also used to compare

213 skiers' planned and executed times spent in HR zones A1–A3+
214 prior to the distance and sprint competitions. Standardized effect
215 size (Hedge's g) analyses were used to interpret the magnitude
216 of any differences (in interval and ratio data) between sexes, race
217 distance, and planned and executed WU in the aforementioned
218 variables with thresholds set at: $g < 0.2$, trivial effect; $g \geq 0.2$, small
219 effect; $g \geq 0.5$, medium effect; $g \geq 0.8$, large effect.²³

220 Qualitative data, including skiers' descriptions of their planned
221 WUs prior to competition and responses to the open-ended
222 question: "Why did the warm-up not work as planned", were
223 content analyzed according to the methods described by
224 Patton.²⁴ Higher-order themes were identified via inductive
225 content analysis of the skiers' individual responses. Higher-
226 order themes refer to features of the skiers' responses that could
227 be categorized and contained information relevant to the
228 descriptions of the planned WU or why the WU did not work as
229 planned. When higher-order themes were identified, a deductive
230 analysis was used to confirm that all raw data themes were
231 represented. Select raw data representing the skiers' responses
232 are presented as examples of qualitative responses that
233 constituted higher-order themes, with select raw data
234 representing single example responses from individual skiers.

235 **Results**

236 *Descriptive characteristics and competition performance*

237 Descriptive characteristics, pre-competition FIS distance and
238 sprint points and distance and sprint national championship
239 performance data are presented in Table 1, together with
240 between-sex comparisons.

241 TABLE 1 ABOUT HERE

242 *Planned versus executed warm ups*

243 Skiers performed significantly less high-intensity (A3/A3+) and
244 more moderate-intensity (A2) exercise during their WUs than
245 planned (Table 2).

246 TABLE 2 ABOUT HERE

247 Content analyses of the skiers' self-reported planned WUs for
248 the distance and sprint competitions, including higher-order
249 themes and representative raw data, are presented in Tables 3
250 and 4. Five of the 11 female skiers reported that their WU was
251 not carried out as planned during either the distance race (four
252 women) and/or the sprint race (three women). By contrast, only
253 two of the 10 male skiers reported that their WU was not carried

254 out as planned during either the distance race (one man) or the
255 sprint race (one man). A content analysis of the skiers' responses
256 as to why their WU was not carried out as planned, including
257 higher-order themes and representative raw data, is presented in
258 Table 5.

259 TABLES 3, 4, AND 5 ABOUT HERE

260 *Distance versus sprint warm ups*

261 Warm-up durations (min:s) were similar between distance and
262 sprint competitions for both women (41:38±18:59 vs.
263 32:38±11:57, $p=0.469$) and men (33:00±15:33 vs. 35:40±14:35,
264 $p>0.999$). HR_{ave} was also similar prior to the distance and sprint
265 competitions for women (78.7±7.2% vs. 83.2±8.0%, $p>0.999$)
266 and men (79.1±6.8% vs. 77.2±6.1%, $p=0.156$). Relative
267 intensity distributions were similar between distance and sprint
268 competitions (Figure 1).

269 FIGURE 1 ABOUT HERE

270 HR_{ave} during the transition period was 4.0%-points lower prior
271 to the distance than sprint competition in women (66.5±1.7% vs.
272 70.5±5.6%, $p=0.031$). Men's HR_{ave} during the transition period
273 was similar prior to distance and sprint competitions
274 (71.8±10.5% vs. 68.6±8.5%, $p=0.813$). Transition durations
275 (min:s) were similar prior to distance and sprint competitions for
276 both women (18:38±5:33 vs. 13:27±5:34, $p=0.176$) and men
277 (14:30±3:24 vs. 13:12 ± 4:06, $p>0.999$).

278 *Physical and psychological readiness*

279 Feelings of physical and psychological readiness following WU
280 were not different prior to the distance or sprint competitions for
281 the women or men. Physical readiness prior to the distance and
282 sprint competitions, respectively, was 4.0 [1.5] and 4.0 [1.0] for
283 the women ($p=0.429$) and 4.0 [0.0] and 4.0 [1.0] for the men
284 ($p=0.890$). Psychological readiness prior to the distance and
285 sprint competitions, respectively, was 3.5 [1.0] and 4.0 [2.0] for
286 the women ($p=0.386$) and 4.0 [0.0] and 4.0 [0.0] for the men (p
287 = 0.766).

288 **Discussion**

289 This is the first study to detail the WU practices of national- and
290 international-level XC skiers in real-world competitive race
291 scenarios. The main findings have shown that skiers planned and
292 executed similar WUs prior to both distance and sprint
293 competitions, and generally favored a long, traditional WU
294 approach. Planned and executed WUs differed in terms of time

295 spent in intensity zones, with all skiers spending more time than
296 planned in A2 prior to both distance and sprint competitions.
297 Coupled to this, the male skiers spent less time than planned in
298 A3 prior to the sprint competition and all skiers spent notably
299 less time than planned in the highest intensity domain of A3+
300 prior to both competitions. Based on the qualitative analyses of
301 the skiers' reported WU plans, it is possible to identify WU
302 activities potentially relevant to successful XC skiing
303 performance that were omitted from the routines, such as skiing
304 over a range of exercise intensities muscle-potentiating
305 exercises, and considerations around heat maintenance during
306 the transition period.

307 Content analysis of the skiers' planned WUs identified 14 and
308 12 higher-order themes for the distance and sprint competitions.
309 One theme present for the sprint competition was "Same warm
310 up as the distance race" (three skiers) and six other skiers
311 detailed the same planned WU for the distance and sprint
312 competitions, although they did not explicitly state that the same
313 WU was planned. The higher-order theme "Skiing at A1–A2
314 intensity" was most frequently detailed within both the distance
315 and sprint WU plans, and a similar number of skiers planned
316 "high intensity" and "threshold skiing" prior to both the distance
317 and sprint competitions. The similarities in the skiers' planned
318 WUs for the distance and sprint competitions is further reflected
319 in the HR data, with relative durations in HR-derived intensity
320 zones being similar between the distance and sprint WU. As
321 such, it can be concluded that skiers performed very similar WUs
322 prior to the two types of event.

323 The similarities in the planned and executed WUs during the
324 distance and sprint competitions is perhaps surprising. As
325 previously stated, the formats and durations are notably different
326 between distance and sprint competitions.¹² As such, it is
327 possible that using the same WU strategies prior to the two
328 different events would be sub-optimal. It has been proposed that
329 sprint-type competitions are more sensitive to the effects of a
330 WU than longer races, particularly with respect to fatigue
331 induced by a longer, traditional WU.³ As sprint competitions
332 involve multiple rounds, the accumulation of excessive fatigue
333 induced by longer WUs may negatively influence performance
334 in the latter rounds. Only one study has investigated the effects
335 of passive vs. active recovery between heats and it was observed
336 that both had negligible effects on subsequent performance.¹⁶ It
337 is worth noting that while the skiers in the current study naturally
338 had different preferences, they were all-rounders competing in
339 both distance and sprint events. This may at least partly explain
340 the similarities in WU methods employed.

341 The mean durations and intensity distributions of the WUs prior
342 to the distance and sprint competitions observed in the present
343 study constitute a long, traditional WU for endurance sports.^{1,8}
344 In XC skiing, a short, specific WU consisting of eight
345 incremental 100-m efforts starting at ~60% (~20.5 s) and ending
346 at ~95% (~14.5 s) of maximal speed, can elicit similar
347 physiological responses, perception of effort, and subsequent
348 sprint time-trial performance as a long, traditional WU.⁸ Since a
349 short, specific WU involves less risk of fatigue and depletion of
350 glycogen stores, it might be a preferable option during a sprint
351 XC skiing competition.

352 In XC skiing races, skiers may employ variable, terrain-specific
353 pacing strategies¹⁴ and more successful skiers perform better
354 than their lower-performing counterparts in uphill sections of
355 races.¹³ In addition, uphill terrain can increase workloads to
356 supramaximal intensities of up to 160% of $\dot{V}O_2$ peak.^{14,25}
357 Moreover the choice of sub-technique is determined by skiing
358 speed and terrain.¹³ One skier, however, deliberately planned to
359 ski across different terrain within their two WUs. Interestingly,
360 this skier won both the sprint prologue and the sprint final and
361 finished third in the distance competition. She also had the third
362 lowest pre-competition FIS distance and sprint points (and thus
363 the third highest performance ranking) of all skiers. While this
364 skier's success is almost certainly not entirely attributable to
365 incorporating terrain- and sub-technique-specific preparation
366 into her competition WUs, it appears that most skiers did not
367 account for different terrains or sub-techniques within their WU
368 plans. Due to the importance of performance on uphill sections,
369 and the documented importance of enhancing VO_2 kinetics
370 through priming exercise,²⁶ skiers should be aware of the course
371 profile and energy demands prior to planning and executing their
372 WU. Further research should investigate the impact of skiing
373 over variable terrains and inclines within a WU and the
374 subsequent effects on physiological responses and performance
375 under controlled experimental conditions.

376 Muscle activation and priming of the upper- and lower-body
377 musculature did not form part of the skiers' WU strategies,
378 despite recent work indicating that brief (10-s) high-intensity
379 sprints within a WU may elicit potentiating effects on both $\dot{V}O_2$
380 kinetics and neuromuscular qualities.⁹ In fact, only five of the 21
381 skiers (three women, two men) planned any type of muscle-
382 activation exercises (e.g., countermovement jumps or exercises
383 using external resistance, such as bands). Prior to both the
384 distance and sprint events, 11 skiers (eight women, three men)
385 planned "high-intensity skiing", with individual descriptions
386 including "short sprints" and "sprints on skis". Skiers may have
387 planned short-duration sprints and high-intensity skiing as a

388 proxy for specific muscle-activation activities. A review on post-
389 activation potentiation in endurance sports has indicated that
390 potentiating activities within the WU that are specific to the
391 subsequent event are likely beneficial for performance in shorter
392 endurance events.²⁷ Therefore, activation and muscular priming
393 activities may warrant inclusion in skiers' WUs, particularly
394 prior to sprint competitions.

395 Within the WU prior to the sprint competition, female and male
396 skiers spent less time than planned within the highest intensity
397 zone of A3+ (>95% HR_{peak}), indicating that they accumulated a
398 sub-optimal volume of high-intensity work before the sprint
399 competition. Moreover, only three skiers (two women, one man)
400 planned any time in the highest intensity domain of A3+ before
401 the distance competition and only five (two women, three men)
402 before the sprint competition. The limited time planned and
403 executed at A3+ intensities before the sprint competition is
404 perhaps surprising, since intermittent periods of high-intensity
405 work within a WU can benefit $\dot{V}O_2$ kinetics.^{9,26} Therefore, skiers
406 may be unaware of the potential positive effects of incorporating
407 high-intensity intermittent work into their WU routines.
408 Furthermore, the large inter-individual variation in total WU
409 durations and planned and executed times in intensity zones may
410 indicate a lack of standardization of WU practices. As such, the
411 skiers examined here could benefit from education on WU
412 practices.

413 Mean transition durations of ~16 (6–25) min were observed in
414 the present study. Lengthy transition periods (>15 min) have
415 been identified as disrupting the WU process by elite swimming
416 coaches²⁸ and in elite snowboard athletes.²⁹ Moreover, only 4 of
417 the 21 skiers (two women, two men) planned to change clothes
418 as part of their WU strategy. Not changing into dry, thermal, or
419 heated garments in cold environmental conditions following a
420 WU and during long transition periods may result in peripheral
421 vasoconstriction and lowering of muscular temperature.¹⁹
422 Passive heating strategies, such as heated or thermal garments,
423 may allow skiers to better maintain their core and muscle
424 temperature.¹ A recent study has shown that wearing a lower-
425 body heated garment following active WU improves
426 performance and perceptual measures in alpine skiers in sub-
427 zero temperatures, when compared to active or passive WU
428 strategies alone.³⁰ Cross-country skiers' practices related to the
429 transition period could therefore be improved. Currently, there is
430 no research on the influence of passive heating strategies in XC
431 skiing and this could be an impactful avenue for future research.

432 **Practical Applications**

433 Key pre-race preparation elements, such as skiing over a range
434 of exercise intensities and terrains (thereby provoking the use of
435 different sub-techniques), incorporating muscle-potentiating
436 activities and heat maintenance strategies during the transition
437 period were missing from XC skiers WU plans. We therefore
438 recommend that coaches and applied practitioners work with XC
439 skiers to further educate them about the benefits of including
440 these common pre-race preparation strategies as part of their
441 WU. Moreover, given that many skiers executed a similar WU
442 in both the distance and sprint competitions, further research is
443 required to determine how changes in WU duration and exercise-
444 intensity distributions may affect subsequent performance in
445 these two different events.

446 **Conclusions**

447 Skiers favored a long, traditional WU approach for both the
448 sprint and distance events, performing less high-intensity and
449 more moderate-intensity exercise during their WUs than
450 planned. Additionally, elements likely relevant to successful
451 performance in XC skiing were missing from WU plans.

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592 **Figure legend**

593 **Figure 1.** Percentage of the total time spent by the female and
594 male skiers in the four different heart rate zones (A1-A3+) prior
595 to the distance and sprint competitions.