Abstract

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

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

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

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

Key words: priming; Nordic skiing; preparation; pre competition; transition

Introduction

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

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

Cross-country skiing competitions involve both freestyle (i.e., skate skiing) and classic techniques. Within each technique there are a number of sub-techniques[12] and the choice of sub-technique is determined by skiing speed and terrain.[13] Performance across varying terrains is important in XC skiing and terrain-specific pacing strategies and performance in uphill sections of races are important performance determinants.[13,14] Senior distance competitions generally involve a single race over 10–15 km and last approximately 26–35 min.[12] In comparison, sprint competitions consist of a time trial (prologue) followed by three head-to-head races (for the six most successful athletes), with each race lasting 2–4 min and separated by irregular recovery periods.[15] The multiple rounds within sprint competitions present challenges, whereby an initial WU and subsequent “re-warm-ups” are required. Previous work has indicated that active and passive recovery between simulated sprint rounds have trivial effects on subsequent performance.[16] Due to these differences in competition distance, duration and format, the relative energy system contributions differ for distance and sprint competitions, with greater importance of anaerobic metabolic power during sprint races.[17,18] As such, WU strategies should probably be tailored to the specific demands of the event.[3]

In XC skiing, cold environments negatively affect core and muscle temperatures[19]. Despite the unique challenges involved in the sport, the WU practices of high-performing XC skiers during real-world competition have not been detailed in the literature. It is currently unknown how skiers plan and execute their pre-competition preparation strategies in terms of exercise *durations and intensities or offsetting the negative impacts of the* cold. Similarly, it is unknown whether XC skiers plan and execute different WUs before distance and sprint events. Such information would prove useful for researchers and applied practitioners supporting XC skiers and contribute to improving the ecological validity of future lab-based studies. Therefore, the primary aim of the study was to provide a descriptive analysis of the WU strategies employed before distance and sprint events at a national championship. Our secondary aim was to compare the planned and executed WUs before each event.

Methods

Participants

Twenty-one national- and international-level XC skiers (11 Swedish women; 1 Italian and 9 Swedish men) who completed the distance and sprint competitions at an annual national championship participated in the study (Table 1). A total of 51 women and 122 men entered the distance competition, and 49 women and 99 men entered the sprint competition. Opportunistic sampling was conducted, whereby the coaches and skiers were informed of the study in the weeks leading up to the championship event, and further details were presented at the team-leader meetings prior to the specific competitions. All skiers were invited to participate and those who submitted their planned and executed WU information, responded to the subjective readiness questions, and provided HR data were included. All participating skiers were over 18 years at the time of data collection, and they were fully informed about the risks and benefits of the study before providing written informed consent for their data to be included. The study was approved by the regional ethical review board in Umeå, Sweden (2018-441-32M).

Design

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

*Self-reported warm-up informat*ion

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

Heart rate data

All participants used their own HR monitors and were instructed to start their HR recordings when starting the WU and to end the data collection following their cool down after the competition. They were also instructed to use splits to mark the beginning and end of the WU and transition, allowing the durations and relative exercise intensities to be calculated for these two distinct phases. Peak HR (HR_{peak}) and average HR expressed as a percentage of HR_{peak} (HR_{ave}) were calculated for the WU and transition phases, where HR_{peak} was defined as the 1-s peak value attained on the respective distance and sprint competition days. For the women, HR_{peak} was 183±10 and 177±11 beats·min^{-1} during the distance and sprint competitions, respectively (p=0.036, 3.2%), and for the men was 182±13 and 176±9 (p=0.872, 2.9%).

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

Performance variables

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

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

Statistical analyses

The feelings of readiness and competition finishing position (ordinal data) are presented as median (interquartile range [IQR]), while all other data (interval and ratio) are presented as mean ± *SD* and the alpha level of 0.05 was set *a priori*. All quantitative analyses were conducted using Jamovi 1.2[22] and qualitative analyses were conducted with Nvivo 11.0 (QSR International, Melbourne, Australia). The Shapiro-Wilk test of normality indicated that all interval and ratio data were not-normally distributed ($p < 0.05$).

Mann-Whitney U tests were employed to analyze sex differences in pre-competition FIS points, as well as absolute and relative performance variables during the distance and sprint competitions. Wilcoxon rank tests were used to analyze differences between distance and sprint competitions for subjective feelings of physical, psychological, and overall readiness following the WU, as well as for WU and transition characteristics. Wilcoxon rank tests were also used to compare skiers' planned and executed times spent in HR zones A1–A3+ prior to the distance and sprint competitions. Standardized effect size (Hedge's *g*) analyses were used to interpret the magnitude of any differences (in interval and ratio data) between sexes, race distance, and planned and executed WU in the aforementioned variables with thresholds set at: $g<0.2$, trivial effect; $g\geq0.2$, small effect; $g\geq0.5$, medium effect; $g\geq0.8$, large effect.[23]

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

Results

Descriptive characteristics and competition performance

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

TABLE 1 ABOUT HERE

Planned versus executed warm ups

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

TABLE 2 ABOUT HERE

Content analyses of the skiers' self-reported planned WUs for the distance and sprint competitions, including higher-order themes and representative raw data, are presented in Tables 3 and 4. Five of the 11 female skiers reported that their WU was not carried out as planned during either the distance race (four women) and/or the sprint race (three women). By contrast, only two of the 10 male skiers reported that their WU was not carried out as planned during either the distance race (one man) or the sprint race (one man). A content analysis of the skiers' responses as to why their WU was not carried out as planned, including higher-order themes and representative raw data, is presented in Table 5.

TABLES 3, 4, AND 5 ABOUT HERE

Distance versus sprint warm ups

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

FIGURE 1 ABOUT HERE

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

Physical and psychological readiness

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

Discussion

This is the first study to detail the WU practices of national- and international-level XC skiers in real-world competitive race scenarios. The main findings have shown that skiers planned and executed similar WUs prior to both distance and sprint competitions, and generally favored a long, traditional WU approach. Planned and executed WUs differed in terms of time spent in intensity zones, with all skiers spending more time than planned in A2 prior to both distance and sprint competitions. Coupled to this, the male skiers spent less time than planned in A3 prior to the sprint competition and all skiers spent notably less time than planned in the highest intensity domain of A3+ prior to both competitions. Based on the qualitative analyses of the skiers' reported WU plans, it is possible to identify WU activities potentially relevant to successful XC skiing performance that were omitted from the routines, such as skiing over a range of exercise intensities muscle-potentiating exercises, and considerations around heat maintenance during the transition period.

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

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

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

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

Muscle activation and priming of the upper- and lower-body musculature did not form part of the skiers’ WU strategies, despite recent work indicating that brief (10-s) high-intensity sprints within a WU may elicit potentiating effects on both $\dot{V}O_2$ kinetics and neuromuscular qualities.[9] In fact, only five of the 21 skiers (three women, two men) planned any type of muscle-activation exercises (e.g., countermovement jumps or exercises using external resistance, such as bands). Prior to both the distance and sprint events, 11 skiers (eight women, three men) planned “high-intensity skiing”, with individual descriptions including “short sprints” and “sprints on skis”. Skiers may have planned short-duration sprints and high-intensity skiing as a proxy for specific muscle-activation activities. A review on post-activation potentiation in endurance sports has indicated that potentiating activities within the WU that are specific to the subsequent event are likely beneficial for performance in shorter endurance events.[27] Therefore, activation and muscular priming activities may warrant inclusion in skiers' WUs, particularly prior to sprint competitions.

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

Mean transition durations of ~16 (6–25) min were observed in the present study. Lengthy transition periods (>15 min) have been identified as disrupting the WU process by elite swimming coaches[28] and in elite snowboard athletes.[29] Moreover, only 4 of the 21 skiers (two women, two men) planned to change clothes as part of their WU strategy. Not changing into dry, thermal, or heated garments in cold environmental conditions following a WU and during long transition periods may result in peripheral vasoconstriction and lowering of muscular temperature.[19] Passive heating strategies, such as heated or thermal garments, may allow skiers to better maintain their core and muscle temperature.[1] A recent study has shown that wearing a lower-body heated garment following active WU improves performance and perceptual measures in alpine skiers in sub-zero temperatures, when compared to active or passive WU strategies alone.[30] Cross-country skiers' practices related to the transition period could therefore be improved. Currently, there is no research on the influence of passive heating strategies in XC skiing and this could be an impactful avenue for future research.

Practical Applications

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

Conclusions

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

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Figure legend

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