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Before hitting the slopes: athlete and staff perspectives on warm-up and activation in high-performance snowsports

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CB and JS contributed equally.

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ABSTRACT

To explore warm-up and activation (W&A) practices in high-performance snowsports to describe their importance, application and potential improvements based on the perspectives of elite-level athletes and staff members. Qualitative study consisting of semistructured interviews with 13 international elite-level athletes, on-snow coaches, strength and conditioning coaches, sports physiotherapists and sports psychologists from different snowsports and subdisciplines: alpine skiing, freestyle skiing (park and pipe, aerials, moguls) and snowboarding (park and pipe, snowboard cross). The interviews were transcribed verbatim and analysed based on the principles of grounded theory. The main themes raised by the participants were (1) the importance of readiness for sports participation as the motive for W&A, (2) how readiness is reached with a structured W&A routine and (3) the different athlete-specific, task-specific and environmental-specific factors for optimal W&A. Athletes and staff members considered W&A an essential measure to get physically and mentally ready for sports participation. Being ready was described as a key factor for performance and injury prevention. For these athletes, adherence to W&A was the result of a process of experiencing the beneficial effects of W&A and learning from sustaining one or more injuries. Broad implementation of basic physical and mental W&A at the youth level was considered an important measure to increase the overall adoption of W&A as an inherent part of training and competition. At the elite level, W&A is performed to reach athletes' mental and physical readiness for performance enhancement and injury prevention. W&A is acknowledged as a complex and dynamic programme and is typically adapted to sport-specific demands, injury risks, environmental circumstances and individual needs and preferences. Overall, this study provides valuable contextual insights into the complexity of W&A and the factors that need to be considered to make sport-specific recommendations.

INTRODUCTION

Warm-up is widely used to prepare for sports participation. Its temperature-related, metabolic-related, neural-related and psychology-related effects beneficially influence subsequent performance and reduce the risk of acute and overuse lower limb injuries.¹⁻⁴ Sports associations developed sport-specific neuromuscular warm-up

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Warm-up is frequently used to gradually build up to the intensity of subsequent sports activity.
- ⇒ Sport-specific neuromuscular warm-up programmes may enhance performance and prevent injuries due to different short-term and long-term effects.
- ⇒ To date, no evidence-based sport-specific warm-up programme is publicly available for high-performance snowsports.

WHAT THIS STUDY ADDS

- ⇒ This qualitative study provides insights into athlete and staff perspectives on current warm-up and activation (W&A) practices in high-performance snowsports.
- ⇒ The goal of W&A in snowsports is to reach athletes' readiness before on-snow training or competition.
- ⇒ To ensure the practicability, effectiveness and up-take of such a programme, different snowsport-specific aspects must be considered.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ The results of this study provide context that may be used to inform snowsport-specific W&A recommendations.
- ⇒ It may guide and inform implementation efforts on different levels and inform event regulation to ensure athletes' readiness before the on-snow performance.

programmes to enhance performance and prevent injuries.^{4 5} To tailor these kinds of warm-up programmes and increase their applicability and adherence, qualitative research was conducted to get an in-depth understanding of the context and complexity of the respective sports settings.⁵⁻⁷

In high-performance snowsports, specific physical and mental demands are placed on athletes,⁸⁻¹⁰ and dedicated warm-up and activation (W&A) practices may help to prepare for successful and healthy snowsport participation. Snowsport athletes are often exposed to cold weather, and sheltered areas are



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not always close to the training or competition course. Performing a proper W&A may therefore be challenging yet all the more necessary.^{8 11} To be able to describe the importance, application and potential improvements of snowsport-specific W&A, this study aimed to explore the perspectives of elite-level athletes and staff members around current W&A practices in high-performance snowsports.

METHODS

Study design

This study is underpinned by a constructivist interpretative paradigm, considering the value of the subjective experience the findings are cocreated by the researchers and the participants and defined by the researcher's interaction with and interpretation of the data.¹² Considering the exploratory nature of this study and our research paradigm, grounded theory (GT) was chosen to explore and understand the concepts behind the participants' perspectives of W&A.^{13 14} The data collection and analysis reporting follows the Consolidated criteria for Reporting Qualitative research.¹⁵

Participants

We recruited athletes, on-snow coaches, strength and condition (S&C) coaches, sports physiotherapists and sports psychologists from different national high-performance snowsport teams.¹⁶ Potential participants were expected to work or compete at the elite level, where experience and resources were assumed to be highest. Sampling aimed at maximum variation regarding role, country and snowsport disciplines and subdisciplines. During data collection, we also used theoretical sampling to include new participants with different roles, to get different perspectives and a more in-depth understanding of emerging concepts.¹⁶ Personal contacts for recruitment were provided by two researchers (LB and JS) who have been working in competitive snowsports for many years. An invitation was sent via email to 21 potential participants, out of which 5 did not respond at all and 3 refrained from participating. If interested in participation, they signed an informed consent form and arranged an appointment with the researcher responsible for the interviews (LB).

Data collection

Data were collected through online semistructured interviews from June to August 2022. The interviews were video recorded with Microsoft Teams or Zoom (Microsoft Teams, V.1.5.00.14473; Zoom, V.5.11.5 (9788)). All interviews were conducted by the same researcher (LB) in English (n=10) or German (n=3), depending on the participant's first language and preference. LB is fluent in English and German. One researcher (LB) initially developed the interview guide based on the current literature and refined it with the research group (SB, EV, CB

and JS). LB performed two pilot interviews to test the interview guide, after which final updates were added. Interview questions focused on how W&A is defined, why and how it is done, perceived effects and challenges, and needs and suggestions for improvements. The interview guide is presented in online supplemental appendix 1. After 11 interviews, no additional concepts emerged, indicating that saturation had been reached.¹⁷ Two planned additional interviews were performed to confirm saturation. The average interview time was 40 min (range: 24–60).

Data analysis

The audio of the interview recordings was transcribed verbatim. Inductive open coding was performed using MAXQDA (V.22.2.1) as a data management tool. Analysis was undertaken employing principles of GT.^{13 14} Collected data were analysed parallel to data collection to inform subsequent data collection and to increase the level of abstraction.¹⁴ During the coding of every new interview, the coding of previous interviews was compared (constant comparison), and if needed, codes were refined or merged. Transcription and coding were done by LB. Code titles were set in English, while the interviews were coded in the original language. After the coding of the first three interviews, LB and CB revised the coding using the English interviews to ensure a solid coding procedure. CB is fluent in English. Relationships between the codes were analysed by LB and CB. The presented quotes from the German interviews were translated into English by LB and reviewed by JS, who is fluent in German and English. The detailed process of the analysis is presented in [figure 1](#).

Positionality

All authors are trained and experienced in conducting qualitative research. LB is a sports physiotherapist working in elite snowboard park and pipe with experience as a former snowboard athlete. At the time of the interview study, LB was a master's student. SB is an associate professor in injury prevention with expertise in implementation. EV is a sports scientist and epidemiologist and a professor in injury prevention with broad research experience. CB is a sports physiotherapist with experience in elite sports and a postdoctoral researcher. JS is a movement scientist with wide experience as former ski alpine athlete and coach and extensive experience in injury prevention research. Participant recruitment was performed by LB and JS. Their professional involvement in the explored field may have influenced participant sampling. Some of the interview participants were personal contacts of LB and knew about her role in the field and her interest in injury prevention, which may have influenced the way they responded in the interviews. For data analysis, a constructivist interpretative paradigm was used. The analysis results are seen as a construct produced by the interaction of the researcher (LB) and the participants, as well as the researchers'

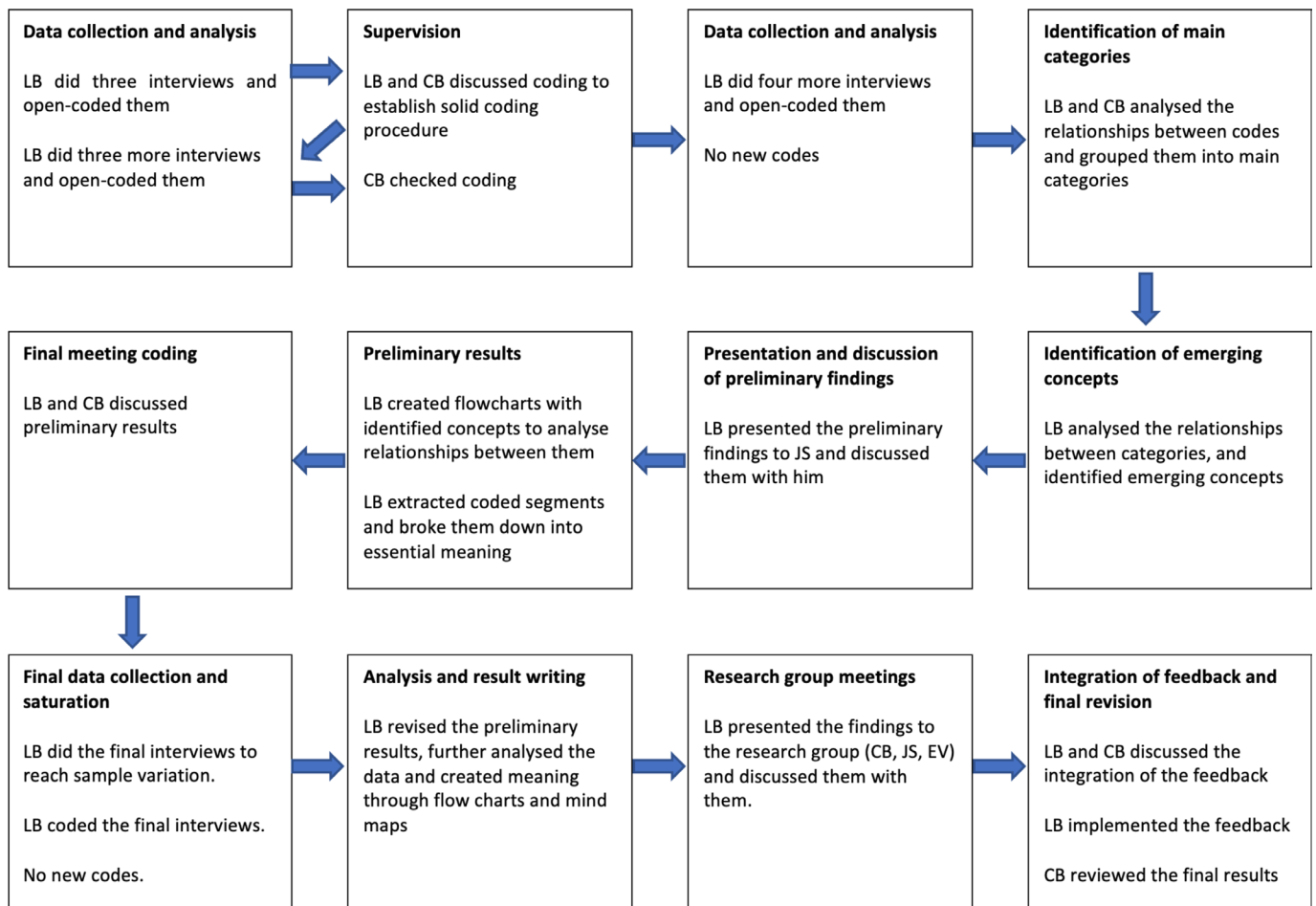


Figure 1 Data analysis flowchart. After three and six interviews, codes and memos were reviewed and discussed with a second researcher (CB). After 10 interviews, LB and CB met to review data collection and analysis, to identify different emerging categories and to discuss further analysis procedures. Subsequently, preliminary results were developed by LB. Related codes were merged into categories, and connections between the categories were defined to identify emerging concepts. Preliminary findings were discussed with another researcher (JS), who was unfamiliar with the collected data. LB analysed the relationship between identified concepts with different flowcharts and mind maps and extracted coded segments to break them down into essential meaning. In a subsequent meeting, CB and LB met to discuss the relationships between concepts and their essential meaning. Another three interviews were conducted and analysed by LB. Preliminary results were reviewed and refined by LB and presented to and discussed with the whole research group (CB, EV and JS). When consensus about the results and the best way of their presentation was found, LB implemented the feedback of the group and discussed the final results with CB.

(LB and CB) interaction with and interpretation of the data.¹² LB being highly involved in the field facilitated the interpretation of the data, while the inclusion of CB as an outsider of snowsports helped to be critical and guarantee that generated findings were clearly derived by data.

RESULTS

In total, 13 interviews were conducted with athletes (n=2, 1 female, 1 male), on-snow coaches (n=3, male), S&C coaches (n=3, male), sports physiotherapists (n=3, 2 female, 1 male) and sports psychologists (n=2, male), competing/working with the national teams of Austria (n=2), Canada (n=2), China (n=1), Finland (n=1), Italy (n=1), Japan (n=1), New Zealand (n=2), Norway (n=1), Switzerland (n=2) and the USA (n=4). The participants

competed/worked at the elite level in different snowsports and subdisciplines (skiing (alpine skiing: n=7; freestyle skiing (park and pipe: n=4, aerials: n=2, moguls: n=1); snowboarding (park and pipe: n=5, snowboard cross: n=1)). Their experience as elite-level athlete/staff ranged from 5 to 35 years (mean 15). Overall, 8 out of 11 staff members were former elite-level snowsport athletes. To guarantee confidentiality, no additional demographic details will be presented.

There was homogeneity among the participants' perspectives despite their variety regarding role, nation and discipline. The main concepts raised were (1) the importance of readiness for sports participation as the motive for W&A, (2) how readiness is reached with a structured W&A routine and (3) the different athlete-specific, task-specific and environmental-specific factors for an

Table 1 Main codes and related quotes on the theme ‘Why—the importance of readiness for sports participation as the motive for W&A’

Codes	Exemplary quotes
Definition	It's the steps that we take to put ourselves in positions to be ready to compete on the snow. (S&C coach 2) It's preparing your whole body and mind for what you're gonna be doing. (Physical therapist 2) [...] doing whatever we think is required to really get the athlete ready and prepared properly for training or competing. (S&C coach 3) Just to kind of get that creative kind of mindset, or that flow state, as we call it here. (S&C coach 2)
Importance of readiness for performance	But my experience was that the better I warmed up, the better I was prepared for training, and the better I was able to maintain the quality of training. (Athlete 1) So, if you wanna get that really good training, you have before to warm-up without the board. (Athlete 2) And certainly, though there's not a lot of research on it, the mental state that athletes have when they leave the starting gate or begin a performance on snow, can often determine how they perform but also their risk of injury. (Sports psychologist 1)
Importance of readiness for injury prevention	They are sports of very, very high risk - very high risk when you're pushing your limits. [...] anything you can do to prepare yourself for what you're going to do - to be 110% prepared - I think would be stupid not to do. (Physical therapist 2) Because in terms of injury, I'm gonna guess - I don't think there's any data on this but... - that often injuries occur when athletes are not properly focused, or when they're emotionally upset or they're tense, or they're distracted. (Sports psychologist 1) Often warm-up an activation and whether the athlete has a good history of warm up and activation is something that can have an impact on the injury or the propensity for them to be injured. (On-snow coach 2)
Importance and cold	And during winter it is often very cold and then they have to stay active, much more active than when it's warm and comfortable. So, when it's cold, you really always have to keep moving or the heat jacket has to be brought down [to the bottom of the course] so you can put it right back on. (On-snow coach 1) The most difficult part is doing warm-up when it's really cold because you want to just stand and grab your arms {folds his arms in front of his chest} and try to get warmer and warmer. (Athlete 2)

optimal W&A. We gained insight into the complexity of W&A and the different factors that need to be considered to make sport-specific W&A recommendations to enhance immediate readiness and contribute to long-term athletes' preparation.

Why—the importance of readiness for sports participation as the motive for W&A

All participants reported that they include W&A before competition and training to get physically and mentally ready for sports participation (table 1), as one participant stated: “I define warm-up and activation as getting ready, getting ready for training, for competition, for execution. [...] Warm-up and activation is getting your body ready, as well as your mind, your focus, your overall level of readiness.” Being physically ready was described as a state of increased cardiovascular function, neuromuscular control and agility. Mental readiness was portrayed as being in a state of optimal emotional and increased cognitive function (figure 2). They explained that state as having the right mindset, being on or being in the zone or *the flow state*, where body and mind are connected, and one is motivated, positive, highly focused on and confident about the task at hand.

The participants stated that being prepared or ready was crucial for performance enhancement and injury prevention. In their experience, readiness not only facilitates the execution of their sport but also enables peak performance and injury risk management, as one participant explained: “It's a very short period of time that you're actually doing your performance and you need to be 100% ready for that - for the physical demands of that activity - once you go out of the gate or drop in the half pipe to be able to do them as safely as possible and as well as possible.” Having experienced the beneficial effects of readiness was stated as the main reason athletes engage in W&A. This motivation to engage in W&A was

related to more experienced athletes and referred to as something that is achieved through a learning process. Sustaining one or more injuries and what they learnt from this experience was acknowledged as part of this process, or as one participant stated: “Most of our elite athletes know from mistakes, I guess, that if they're not well warmed up, they're not gonna be able to perform as well, and then more likely to get injured.”

The importance of physical readiness

The participants described the different physical effects of W&A as necessary to perform well in training and competition. The ability to generate the power to withstand and react to external forces that act on the body and to stabilise and execute specific movement patterns were acknowledged as effects of elevated muscle temperature and neuromuscular activation. Being agile and able to quickly get into needed positions was described as an important effect of elevated body temperature and mobilisation exercises. The same components of physical readiness were associated with injury risk reduction since injuries were associated with falls and the inability to absorb external forces and stabilise specific positions. Additionally, W&A was thought to reduce the risk of getting injured during falls. One participant stated: “Because a body that is warmed up and activated is less likely to become injured”. The need to be and stay warm and agile within often-experienced cold temperatures was consistently mentioned. In addition, feeling physically ready was described as a fundamental part of mental readiness.

The importance of mental readiness

W&A's different emotional and cognitive effects were stated to be essential for sports execution, as one participant explained: “I think the mindset is the most important thing in our sport.” Different aspects of

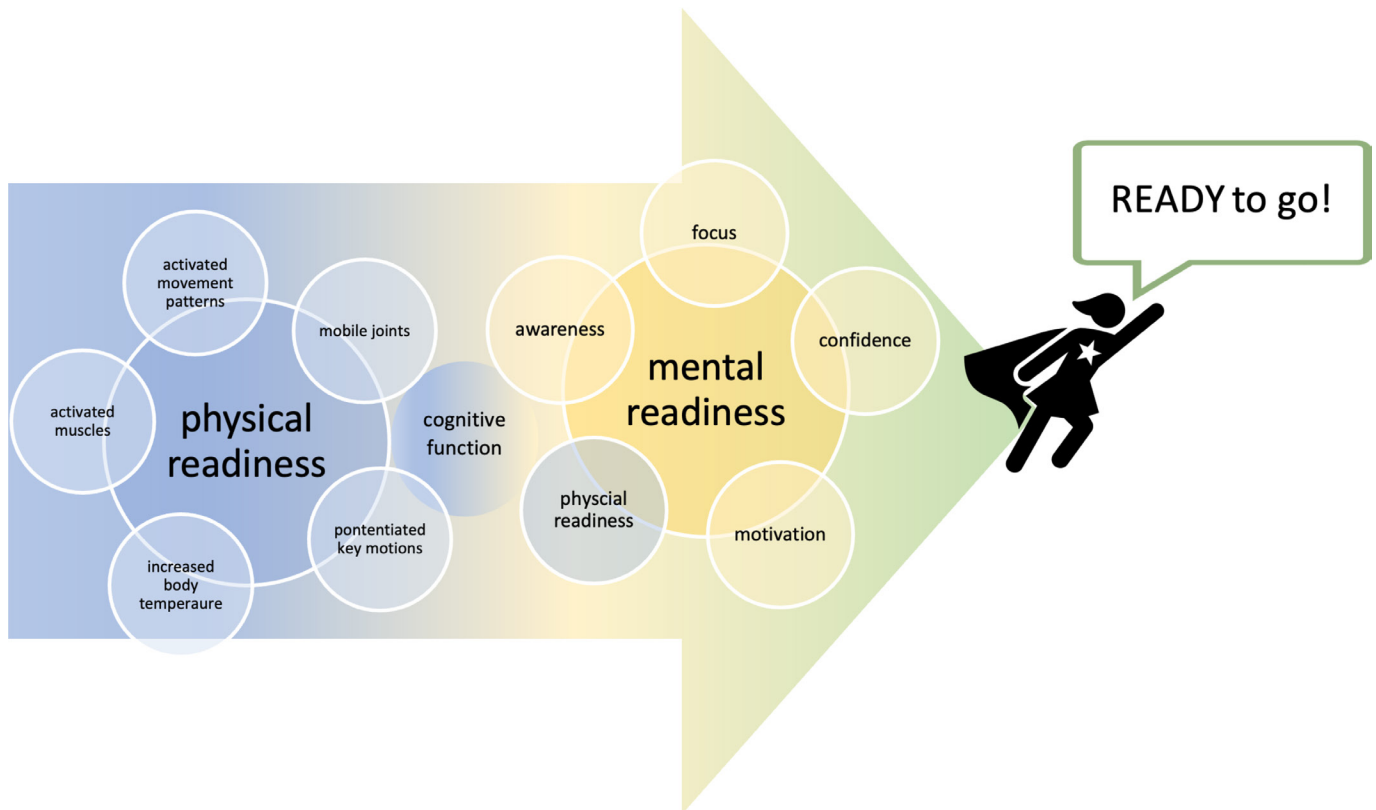


Figure 2 The concept of readiness. Following our data analysis, readiness is a concept that entails physical and mental readiness, which are based on different factors. Cognitive function was described as a connection between the physical and the mental, and physical readiness was said to be an important cornerstone of mental readiness.

increased cognitive function were described to influence performance and injury risk. The participants stated that body and mind need to be connected to recognise and interpret physical conditions, analyse external conditions (snow characteristics, visibility, course setup and material properties) and discern how to adapt their riding to perform as well and safely as possible. They described that they need to be in the right mindset, in a good mood and at the right level of intensity to fully focus on training or competition and that motivation, confidence and a positive attitude allow skill progression and peak performance. The lack of mental readiness, and thus focus, was associated with an increased injury risk due to the high-risk nature of the sport: “Because as you will know, in all the different forms of snowsport, if you're not focused, you're in danger.” Another participant mentioned: “Anyway, if you have a bad mood, everything looks shadow, black, you can't really focus on training, and it gets really dangerous as well”.

HOW—W&A structure and routine to reach readiness

All participants described following a W&A routine that they could rely on based on their positive experience (table 2). While some athletes perform some activation exercises in the morning at home or in the hotel, a structured W&A of 15–30 min right before the performance, as well as two to three W&A runs on the slope, were seen as the most important measure to achieve readiness

at the time of training or competition runs. Almost all participants emphasised that the structured W&A before the runs on the slope is ideally done somewhere inside, where it can be done in training shoes, as boots, specifically ski boots, hinder proper activation of the feet, ankles and knees. Everyone stated to repeat their W&A or parts of it after waiting times—especially during competitions in disciplines that include more than one competition run. The use of passive warm-up strategies, such as additional clothing, blankets, heat garments, hot beverages and going inside, was also mentioned in every interview.

The physical dimension of W&A

The basic W&A structures described by the participants are based on or resemble the RAMP protocol,¹⁸ which consists of raising the heart rate and body temperature, activating the muscles, mobilising the joints and potentiating sport-specific activities. To address sport and injury specificity, the activation of muscles around the hip, core and knee, as well as neuromuscular activation for good landing patterns were stated to be of particular focus. Knee and especially ACL injury prevention were specifically mentioned. Neck and upper body injury prevention during falls was associated with neck and shoulder activation and mobilisation. The W&A runs on the slope were described as a sport-specific activity to progress into the intensity and skill level of subsequent training or competition, to get used to the snow conditions and material,

Table 2 Main codes and related quotes on the theme 'HOW—the structure and routine to reach readiness'

Codes	Exemplary quotes
Routine	<p>I do the same routine every day. (Athlete 2)</p> <p>We try to do always more or less the same. (On-snow coach 1)</p> <p>And they usually have a set routine or an ideal routine. So again, a lot of comfort and confidence comes from that. That is not only physically related, although you do test yourself: how your body is doing in that moment but also feel, feeling ready to execute. (Sports psychologist 2)</p> <p>You wanna kind of put the quality in your training, so you can repeat that for racing, so the quality also in your warm-up, in the types of activities or skills or strategies that you're utilizing, make them fairly similar to one another. (Sports psychologist 2)</p> <p>Like physically, I don't think it matters. But just to, for like, for the mental part of it and to make the training and competition in the same way, I absolutely think it would be important to always keep the same routine. (Physical therapist 2)</p> <p>What I try to convince athletes of, is that whatever they do in a competition, they first need to do in training. And so, you're developing these habits, these patterns that ensure total preparation, physical and mental. And so, when they get to a competition, this is just what they do, and they go through their routine. (Sports psychologist 1)</p>
Structure	<p>There's a general basis for everyone. [...] 15 minutes is plenty enough time to do a good physical warm-up. [...] The model we work with is the RAMP model - RAMP: Raising the heart rate, activating the muscle groups, mobilizing the joints, potentiating - in terms of the physical preparation, before we hop on snow. (On-snow coach 2)</p> <p>I would say that the majority of the warm-up is the standardized protocol for everybody. [...] We have just a general, aerobic type of warm-up, where they're just doing, you know, five minutes or so of just really general activity to elevate the body temperature and the blood flow and, just get them started that way. And then we'll move into some dynamic flexibility or mobility exercises. Then we'll shift more into a little bit of what we call our activation exercises and movement prep. [...] where we look at different squat patterns and single leg squat patterns, different lunch patterns. And then we start to introduce some impact, some low level plyometrics and quick, quickness exercises. (S&C coach 3)</p> <p>In our more elite groups, we define it as preparing them to jump and land. So, it's more based around getting the muscle temperature raised, getting the muscles, the neural pathways activated, getting the joints mobilized, and then getting the muscles potentiated. (Physical therapist 3)</p>
Re-warm-up	<p>[...] it's minus 20 the whole time. You sit in the lift for 20–30 min before you go the next time. Technically, you should warm up before dropping into the half pipe every time. (Physical therapist 2)</p> <p>We also have a between run kind of leg swing, a few jumps, some torso twist, and then they go. [...] Just because they normally sit right in the tent in between their runs. (S&C coach 2)</p> <p>Each athlete will have their pre-performance routine before their first and their second competition runs because depending on when they're dropping in the start list, they might be waiting. (Coach 2)</p>
Passive warm-up	<p>So, if it's a really cold day, they definitely go with an overcoat that they can leave at the top of the course before they do their run on snow. (S&C coach 3)</p> <p>Then it is optimal if you have a heated coat which covers from the very top to the very bottom [...] so, for preparation it is important, to have the good gear, to have a coat like this, so that the staff can react immediately, having it at hand all the time and then puts it over. (Athlete 1)</p> <p>In extremely cold temperatures, in venues like copper, where the chairlift lap is quite slow and it can be, you know minus 20, minus 25 Celsius, we might lap with the athletes, and we'll go down the halfpipe and have a down jacket for them to put on at the bottom and they wear that down jacket to the top. (On-snow coach 2)</p> <p>First of all, it's about those, about clothing and everything, and also about hydration: that they get enough water or sports drinks. Either it's cold or a little bit warmer. Not warm, but warmer. (S&C coach 1)</p> <p>Or for example in Canada, I remember was super super cold in Stoneham during a slopestyle contest and every lap of training, we stopped at the lodge to warm up a little. (Athlete 2)</p>
Location/proximity	<p>It was important that the time between the warm-up program and the on-snow warm-up was very short. That was the reason why I did not do it in the hotel, but always at the lift, right before I stepped onto the skis. (Athlete 1)</p> <p>The most intense part of warm-up is certainly happening in the starting area or in the mountain lodge, ideally before they do their first turns on slope. (On-snow coach 3)</p> <p>We try to do warm-up as close to the on-snow session as possible. We always start our warm-up off snow. In the day lodge, or whatever facility that we could access, athlete lounge or whatever it is. And the athletes will start in their running shoes. (S&C coach 3)</p> <p>If there is like a place where I can do it inside without the boots, it's better. [...] With the boots is a little bit more, especially if it's cold, it's more difficult. (Athlete 2)</p> <p>For the ski athletes we normally find a spot in the lodge, or I do travel with some rubber flooring in my bag, and will, we'll roll that out if there's no space to warm up in our flats. (S&C coach 2)</p> <p>They have to bring their normal shoes up and, not that they are one hour standing in the gondola with the ski boots. (Physical therapist 1)</p>

Continued

Table 2 Continued

Codes	Exemplary quotes
Sport specific and injury specific	<p>So, a big thing that we do is a lot of our rotation, anti-rotational core work. (S&C coach 2)</p> <p>So, the specific mostly about hip, knee and core. (S&C coach 1)</p> <p>Jumps were important for me, just to see that I was ready for stabilisation, so, to stabilise the forces acting at landing. (Athlete 1)</p> <p>So, we have a little bit more core in their warm-up because of what we're trying to achieve with their performance. And then they do a basic plyometric jump series. [...]</p> <p>And they finish off with double leg jump, to single leg landing, and really focusing on good landing patterns. (Physical therapist 3)</p> <p>We specifically focus on ACL injury prevention with agility exercises and jumping hop to stop type of exercises. We target the major muscle groups that are more prone to injuries, so we'll include attention to the neck, often in particular. (On-snow coach 2)</p> <p>And then, we, our main focus and injury prevention at that stage was reducing ACL injuries, because they're our biggest time loss injury. And so, we used a lot of various information around ACL prevention programs. (Physical therapist 3)</p> <p>Yes, so I think the whole shoulder area is something that can always be dangerous, especially during falls, because you might want to catch yourself, or something like that. That's why I think we have to stretch well, and the shoulders and all that. (On-snow coach 1)</p>
On-slope	<p>I think, also part of the warm-up needs to be the on snow. Them getting into that state of what they're doing and, doing a few laps as warm-up on skis, in Alpine skiing or in the halfpipe (Physical therapist 2)</p> <p>And then they'll progress through some really low-level skiing, some drills and things like that, and progress up to where they're at their full intensity. (S&C coach 3)</p> <p>We always take two to three just fun labs, do like a mini park, or anything like that. (S&C coach 2)</p>
Mental par	<p>Imagery is used extensively, so obviously in competition, imagery of the competition run, of the features, of them performing. We use, you know, the basic mental skills, self-talk for confidence or to deal with anxiety, relaxation and breathing and mindfulness exercises in terms of centering. (On-snow coach 2)</p> <p>I'm having this mental toolkit that they can use. Breathing - the most powerful. [...] Muscle relaxation [...] Music is a very powerful mental tool. [...] Also, talk to teammates and coaches. If you're talking to somebody you're not in here {points to the head} going like "brrrrrrr" {shows rotating in the head with finger}, like this. (Sports psychologist 1)</p> <p>We try to incorporate in the warm-up an opportunity for the athlete to visualize, mentally prepare for the training or competition. So yeah, we take quite seriously, and we really do try to promote that each athlete is doing that on a regular basis. (S&C coach 3)</p> <p>I think they will have a goal and they have to prepare for that goal, and if they use some time, so like the 20 minutes warm-up when preparing their body, they will prepare their cognitive part as well at the same time. (Physical therapist 1)</p> <p>And it always helped me for example, to know there is someone in case of changes during the day, like changes in the schedule, or weather situations, with whom I could talk about it and with whom I could make a plan for the changes, let's say. So, it also was important, so I wouldn't feel alone somehow. (Athlete 1)</p> <p>But mostly about talking; getting back to what they should think about and everything and then. But it's, yeah mostly about my kind of - what do you call that? What's that in English? - It's about taking care. (S&C coach 1)</p> <p>And then the race day itself, when it goes at the inspection, where the athletes pass by the coach, the conversations or the choice of words is designed in a way that, to give them simply the assurance, so they get into this tunnel, this focus. This is the only thing we can do more or less. That means, we can only try to create an environment where everything works, where they can trust us, where they feel comfortable. (On-snow coach 3)</p>

and to mentally prepare and focus on performance. A participant described, “The first few runs, we’re gonna be activating. So, we’re gonna be switching on. We’re gonna be, you know, it’s part of trying to reduce injury risk, connecting the mind and the body and also checking in on snow conditions as well, and the environmental factors. [...] So, we have a bit of a staged sort of build-up through the park. [...] and that’s activating the body and the mind as we go.”

The mental dimension of W&A

In addition to a reliable routine to get physically ready and the activation of cognitive function during the W&A runs on the slope, the participants stated that they used different measures to reach a state where they feel mentally ready to perform. Breathing, visualisation, self-talk, posture, listening to music and mindfulness exercises were said to be used either during the physical warm-up routine or immediately after. Talking to staff members or other athletes was mentioned as a strategy to deal with anxiety and distracting thoughts and to reach an emotional state where the athlete feels comfortable and supported.

For whom, by whom, when and where—different needs, possibilities and circumstances call for W&A adaptation, dynamic planning and flexibility

Although all participants mentioned similar basic W&A structures and components, W&A was presented as a dynamic construct that needs to be adapted to different athlete-specific, task-specific and environment-specific factors to serve the purpose of reaching readiness (table 3 and figure 3).

Athlete-centred adaptations—individualised W&A

All the interviewed athletes and staff members emphasised that the W&A or parts of it should be individualised, as how to reach readiness differs from athlete to athlete. Individualisation of W&A was described as a process where athletes determine what helps them best through trial and error. Physical therapists, S&C coaches, coaches and sports psychologists support them by making suggestions based on the athlete’s injury history, psychological disposition, personal preferences and movement insufficiencies revealed in biomechanical tests or during the on-snow performance. Or as one participant quoted: “I think it’s important to also let them have their, like address their individual needs. That it’s not a forced thing that everybody needs to do the same way. That they figure out their own warm-up routine that they like. [...] And you’re there, if they need help, you help them. They have an issue with their shoulder, you bring some bands or give them bands and show them what they can do in addition.” And another one stated: “As a coaching team, we’ll sort of work with the athletes on some sort of general advice options and they’ll experiment a little bit and they’ll fine-tune their own individual recipe.” Good communication with the athlete and other staff members

was stated to be essential to determine if an athlete’s W&A needed to be adapted at a specific point during the season. Furthermore, good communication and interaction with the team were said to help the staff adapt to individual needs and to create a safe environment where the athletes could fully focus on their performance, as one participant described: “I think it just comes down to body language and it comes down to talking with them on the chair and you get a feel for where their head space is at, where their confidence is at and you know if they’re engaged and focused and you know if they’re distracted or nervous or you know, and that’s your art as a coach: to be aware of those things and adjust accordingly.”

External factors that call for dynamic planning and flexibility

Schedules, the time needed to use the (chair-)lift and the proximity of mountain lodges and competition or training venues were reported to influence the planning of the timing and the location of W&A. The demands of training or competition regarding discipline, skill level and skill characteristics determine which aspects of the W&A need to be emphasised. In addition, due to the possible occurrence of abrupt changes, such as weather conditions or holds on the competition or training course, they need to be prepared to swiftly adapt W&A to reach readiness within a different timeframe or in suboptimal conditions. Such factors impact the need for re-warm-up and passive warm-up strategies. All participants talked about how they plan W&A in advance to ensure enough time for W&A, time for re-warm-up and the availability of passive warm-up measures, as one participant described: “For example, when they’re preparing for their run, they are just in their race suits and then there’s something on the course that’s a, it’s a delay, and they have to wait. So that will interrupt the whole process. And in that time, they cannot do, they’re in their - of course they are in their race boots. Umm, we will get out of the skies and then try to keep them warm with long clothes, that’s an important thing.” They mentioned that they always look out for a sheltered area close to the competition or training venue, where they can do their W&A. The local proximity to the mountain lodges was presented as a challenge in training and competition. Some participants mentioned that it makes a big difference and facilitates their W&A if a dedicated warm-up area close to the competition venue is made available by the event organisation. A participant stated: “It was always very important for me to know in advance when I had to start my warm-up program to be ready for the competition. Just to have a schedule ready to ensure there will be no stress or not enough time for something.” And another one described: “I find that really helpful when in some competitions there is the warm-up area. So that at the drop-in, they put something to warm up, maybe a bicycle or even a little tent so you can warm up inside. That’s really helpful and makes the difference, I guess for me. So, you can stay warm, you can be ready faster.”

Table 3 For whom, by whom, when and where—different needs, possibilities and circumstances call for adaptation, planning and flexibility

Codes	Exemplary quotes
Athlete dependant adaptations – individualisation of W&A	<p>Which kind of exercises we choose, I think it doesn't matter that much, as long as we get all the systems, all the aspects of skiing active and working properly. The harder part, I think, is where's the athlete at, at starting moment - and at the beginning of this warm-up? Where is he and for what he has to prepare? What does he have to do to get there? (Physical therapist 1)</p> <p>The elite athletes have their own routine, so they will write their warm-up and then it will be viewed by myself and their coach and the S&C, and we'll tweak it or add suggestions. (Physical therapist 3)</p> <p>I'd say it's very individual and I think it's important to keep it like that, that it's not something that one shoe fits all. (Physical therapist 2)</p> <p>For example, there's a portion of our warm-up that we usually try to incorporate some of the athlete's specific corrective exercises or if they have a specific set of activation type exercises that are appropriate for their injury history or you know specific areas of weakness, so that section, that group of exercises is individualized. (S&C coach 3)</p> <p>The majority of our athletes, they have access to a mental performance coach or mental performance consultant. And they have their individualized mental training program and their kind of mental readiness program. (S&C coach 3)</p> <p>They developed their own individual pre-performance routine that's got a physical component and a mental component that's geared towards what they need depending on you know, are they generally an anxious competitor that suffers from competitive anxiety or are they generally a calm athlete that needs a little bit of arousal. [...] It's fine-tuned with the help from a sports psychologist. (On-snow coach 2)</p> <p>And some have a specific need in the competitions that they need to do kind of this routine, that they need to do this exercise because that's what they do when they do well, for example. (Physical therapist 1)</p> <p>I think it comes down to trust and knowing the athlete and that's why it's important there's a strong coach athlete relationship. [...] Some athletes take longer to build up to their max, and you need to allow that time. [...] So, if you think your athlete is not ready. [...] You might take them for an extra run. It might be more, you know, it might be less about the physicality, but more about the mental. You know, it might be more to build confidence than actually have any physical impact, but it's a combination of those two things being ready as mind and body. (On-snow coach 2)</p>
External factors/planning	<p>It is important for us, of course, to give them this room; that is to arrange the time schedule for training or competition days in a way that they can do it (warm-up and activation) the way they need to. (On-snow coach 3)</p> <p>Often times, depending on the location, it's sometimes more challenging to do it right beforehand. Sometimes there's a gondola ride or a chair lift or whatever, that kind of interrupts the timing of things. I guess in a perfect world, we would have dedicated space for warm-up, very close to the venue [...] If we want to do this really well, it would be nice to have kind of a combined effort, I suppose, between organizing committee and ski team to make the best, most optimal environment for the athlete to do this in. (S&C coach 3)</p> <p>And we always looked in advance, where I could do that [warm-up & activation]. (Athlete 1)</p> <p>So, in competition, we have to get into our riding quicker depending on the phase. [...] Depending on the venue and the lap time will dictate how many runs we have. And that will dictate a little bit how fast we build into our work, I guess, or build towards our actual desired competition run. (On-snow coach 2)</p> <p>So, we'll generally kind of, you know, gear the first few runs of the session while we're activating towards what is the content of the session. (On-snow coach 2)</p>
External factors that call for flexibility	<p>I often talk about the ideal warm-up and activation because ideal is desirable, it's preferred, but the reality is often different, so then it's a matter of about how can you adapt from the ideal routine into making choices, making things shorter and doing different because of the situation that just requires a bit of a different approach, whether it's time or whether it's kind of the physical environment that doesn't allow for certain activities, then you have to kind of maybe do something different or maybe skip a part of your warm-up routine altogether, because it's not possible and be ok with that. (Sports psychologist 2)</p> <p>And of course, we tried to shorten the time frame of the athletes being outside and standing in the cold. That means keeping the distances short, time structure, maybe planning everything a bit tighter so that you don't have to wait too long at the start until a training run starts. (On-snow coach 3)</p> <p>Situations sometimes change last minute and so ensuring athletes can kind of, you know, have got a real quick warm-up their sleeve if they need to. [...] You know, we've got to still have that agility, flexibility, ability to adapt. (On-snow coach 2)</p>
Resources	<p>And I think that in the younger ages, younger athletes, I think there is a lot of things to do because in the, in my business the athletes have a lot of experience, there are experienced trainers, more experienced physical therapists maybe – or at least a physical therapist. And in the younger, youth teams there are a lot of volunteers and no physical therapist, and there is no data collection. (Physical therapist 1)</p> <p>So, our development group is much more focused on the injury prevention, because they're not getting the same amount of conditioning work off-snow in the gym. So that's more developed around the likes of a FIFA11 plus. (Physical therapist 3)</p> <p>And at the lower levels they don't have that much experience yet, they haven't experienced as much, so I think we try to do everything the same way with everyone. And with the older ones there are differences. Not everyone always responds to the same thing, and I think it makes sense if everyone knows exactly what they really need and then does it. (On-snow coach 1)</p>

Continued

Table 3 Continued

Codes	Exemplary quotes
W&A and youth athletes/compliance	<p>And I don't know if there's a way to get young athletes to do it, except for forcing them, because unfortunately you don't really understand the benefit until it's kind of too late. Or you go through the one or two injury cycles and then you start to have to do it. I wish there was a way to, to make athletes understand the importance of it before they get to this stage, but it's tough because before you, before you feel pain and have a lot of issues it's really hard to spend 15 to 20 min doing some weird exercises instead of just jumping in the halfridge and having fun. (Physical therapist 2)</p> <p>As a young athlete, you simply underestimated the fact that you always cool down and that this is actually a risk in training. And then with injuries you are forced to take it more seriously and that it can also influence performance. (Athlete 1)</p> <p>They now feel like, they understand how much better they feel after properly preparing before they get into the training course, whereas before I guess, they didn't really know how beneficial it was and so they didn't really see the value, but now they definitely understand it. They see the value and their absolutely ready to include that into their routines. (S&C coach 3)</p>
W&A and youth athletes/adapt to their needs	<p>We define it in our development group as movement skills. So, it's a little bit of mainly neuromuscular conditioning work, coordination and balance, and less focus on the activation. So, we define it as them doing, 15 to 20 min every day before they ski, to get neuromuscular patterning through. (Physical therapist 3)</p> <p>And I think it also provides a great opportunity just to continue to educate athletes on movement skill and different forms of exercise and mobility. You know, we kind of forget that 15-, 20- or 30-minute warm-up is actually just a little mini training session, and the athlete is benefiting from all those movements. (S&C coach 3)</p> <p>We've seen that in instances that coaches put those movements, the athletes haven't become competent in yet, it actually is detrimental to on-snow training, because they're going in already with faulty movement patterns [...] Just meet them where they're at currently, and then design that warm-up based on that. (S&C coach 2)</p> <p>I believe that raising awareness is one of the biggest tasks of any athlete, is that you kind of know that you can listen to your body, that you can listen to yourself, that you can understand yourself or you can understand yourself in the environment. That awareness is really helpful because then you start noticing what works, what's ideal, what is not. (Sports psychologist 2)</p> <p>Because whether I work with world cuppers or 11-year-old young racers, the same basic ideas are, I address, but with the world cuppers it's very personalized. (Sport psychologist 1)</p>
Role of the coach/introduce young athletes	<p>It [warm-up or activation] needs to be promoted, but it also needs to be exemplified. [...] But yes, to be an example in professionalism is certainly a big point. (On-snow coach 3)</p> <p>And for coaches to remember that that is very important to not rush the athletes to jump in the pipe or jump in the course, even though they might show up late. [...] And I think it's also a culture that once someone starts doing it, everybody else follows. (Physical therapist 2)</p> <p>When I meet the kids here in my hometown and I go snowboarding with them, we take always ten to 15 minutes to do a little warm-up before we start. So, I try to push the kids doing it and maybe do not like a really routine workout stuff, but some game or something more funny. To just realize that it's important to get into the warm-up and then start the day. (Athlete 2)</p> <p>Things like imagery and routines, those are two mental tools that every young athlete can do, and it's not complicated. It doesn't take a lot of time. But it does take a matter of commitment from the programs and the coaches to educate the kids about it and find the time to do them. (Sport psychologist 1)</p> <p>I think now in the national team, everyone knows, why they do it [warm-up and activation] and I think they feel better when they have done it. With the development team, or with the younger ones, it is needed that the junior coach is also there and makes sure that they really do it properly. (On-snow coach 1)</p> <p>And there are probably some coaches at the club and provincial levels at the development sort of grassroots levels that maybe don't incorporate warm up as much as they should. (S&C coach 3)</p>
Role of the coach/coach education	<p>I think the coach engagement is really, really important. And the coaches knowing the why, you know why the warm-up is happening and that link not only to injury prevention, but also to performance is really important for a coach. (Physical therapist 3)</p> <p>And so, where a lot of education and involvement of the program, whether a national team or a junior team is very important. Where the program educates the coaches and encourages coaches to communicate, to listen to the athlete's needs, to be responsive to emotions. Because an athlete is supposed to be tough, right? No emotions. Well, that's clearly, that's not what the emotions play such a huge role. (Sports psychologist 1)</p>
W&A, warm-up and activation.	

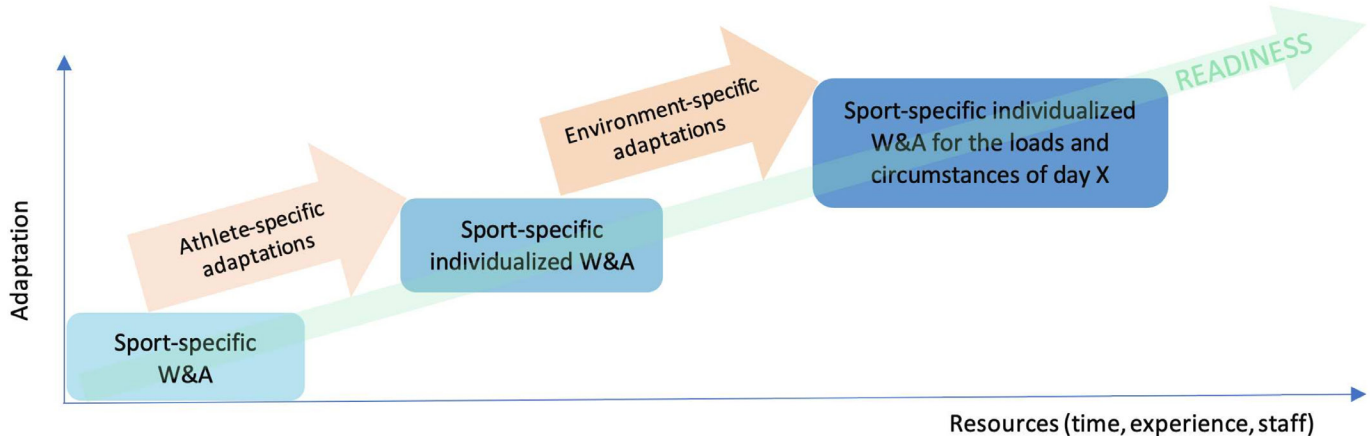


Figure 3 Adaptation of warm-up and activation (W&A) depends on resources. The different adaptations of W&A and their correlation to available resources. While elite athletes benefit from the whole spectrum of adaptations, youth athletes with limited resources may be supported with a basic sport-specific W&A that helps them get into the routine of W&A and sets the baseline for further adaptations.

Available resources influence adaptation and implementation

Most participants stated that broad implementation of W&A was not being reached, primarily but not only in pre-elite-level athletes and that younger athletes did not yet have an individualised W&A routine. This was mainly attributed to limited resources at the pre-elite levels, such as the number and experience of support staff, and the fact that younger athletes often have not yet experienced the benefits of proper W&A for performance enhancement or injury prevention, as they have not yet experienced any injuries. Broad implementation of W&A at a young age was thought to lead to improved application and better-prepared athletes at all levels, or as one participant put it: “I think if we start earlier, then we don't have to worry so much about compliance at the national or World Cup level.”

Adaptation of W&A to the possibilities and needs of younger athletes

To address the challenge of limited available staff, they suggested using general basic group programmes that may serve as a baseline structure that helps younger athletes get into a W&A routine, experience its effects on performance and initiate the learning process of determining what they need to get ready for their sport. As these athletes have not yet reached the physical training level of elite athletes and do not have as much off-snow conditioning training, it was suggested that their W&A should respect their age, training and career stage and support long-term sport-specific conditioning and movement skill acquisition. A participant explained: “We're definitely creating some benefit for their training session that day for proper preparation. But the long-term effect of just repeated mobility work and, you know, squat pattern and single leg squat pattern and quickness and plyo [plyometrics], you know, it just adds up, and I think it's good for these young athletes to do more of that.” In addition to having a routine, imagery and awareness of

the body and the environment were mentioned as basic mental measures that can be done in the group as well.

The coach's role was described as being key in the implementation of W&A and in the resulting effect on the long-term development of the athletes. Or, as a participant explained: “The more the coaching staff at those club and provincial levels can incorporate the warm-up, I think the better the athlete is gonna be.” It was seen as essential that coaches be educated on the importance of W&A, its effects on performance and injury occurrence, and on the different factors that need to be considered when planning W&A.

DISCUSSION

This qualitative interview study in elite high-performance snowsports described the perspectives of athletes, on-snow coaches, S&C coaches, sports physiotherapists and sports psychologists regarding the importance of W&A and factors that influence W&A. The results of this study show that W&A is, despite so far limited snowsport-specific scientific evidence, an inherent part of on-snow training and competition, which is used to reach physical and mental readiness to enhance performance and reduce the risk of getting injured. The participants described that W&A is adapted to athlete-specific, task-specific and environment-specific factors and that adherence to W&A was better in athletes with more experience. It was suggested that W&A needs to be promoted and facilitated at all levels to increase adherence and support athlete readiness.

Experiencing the immediate effects of W&A leads to adherence

The elite-level athletes and staff members in our study stated that in their experience, W&A is being done because it enhances on-snow performance and decreases the risk of getting injured. Realising these direct effects of W&A is what makes athletes adhere to it. This realisation

was described as a learning process that involves experiencing the effects of W&A and often sustaining one or more injuries. Previous studies have indicated that less experienced athletes take less responsibility for preventative strategies and that injuries teach athletes to better understand the relevance of risk reduction programmes.^{19–21} The participants in our study presented the effects of W&A on performance and risk reduction as something tangible. Not directly perceiving the effects of prevention measures is known to be a barrier to adopting them.²² The reported direct experience of W&A effectiveness in our study should be seen as a chance for its implementation,⁷ and implementation efforts may focus on exposing athletes from early on to W&A to help them experience its effects.

Understanding sport-specific readiness to know what is needed to be ready

The participants associated elevated body and muscle temperature with increasing the ability to produce power and decreasing the risk of getting injured. They focused their W&A on the kinetics of correct single-leg landing biomechanics, which was described as a key skill for performance and injury prevention. ACL injury prevention was specifically mentioned in that context. Enhanced agility and mobility have also been mentioned as a desired effect of W&A. Increased muscle temperature is known to enhance performance through increased muscle metabolism, muscle fibre conduction velocity and power output, and dynamic mobility exercises can improve subsequent explosive strength and agility.^{1 23} Current snowsport research has shown that single-leg balance and correct landing biomechanics are essential for performance and injury prevention.^{24 25} While the knee is the most injured body part in snowsports, with ACL ruptures as the most common type of injury,^{11 26 27} it has been suggested that increased muscle temperature and the resulting increase in muscle activation may be preventative, as ACL injuries occur during the first 50 ms of early impact.^{25 27 28} As cold ambient temperatures are known to significantly decrease muscle temperature and the rate of force development,²⁹ a combination of active and passive methods is recommended for athletes performing at subzero temperatures.^{1 8 30}

In our study, reaching a state of mental readiness, involving the regulation of emotions and the activation of cognitive aspects, was seen as key for performance and a necessity due to the high-risk nature of the sport. There is evidence that the ability to regulate emotional states allows athletes to raise self-confidence and maintain focusing abilities and that mental states, such as peak performance, flow and being in the zone, are associated with exceptional performance and a possible injury risk reduction in high-risk situations.^{31–33} In addition, worse cognitive function was associated with biomechanical patterns linked to ACL loading and/or injury risk during cognitively challenging movements.³⁴ Snowsport athletes are exposed to high emotional and cognitive demands

due to high speeds, various environmental stimuli and a high risk of injury, in addition to the emotional load that comes with competitive sports.^{10 33} Previous studies on snowsports reported that athletes use mental exercises before training and competition runs to achieve desired emotional states and to activate cognitive processes.^{33 35} They found that a successful race depends on the athlete's mental readiness and that poor mental skills and poor individual risk management are perceived as potential athlete-related injury risk factors.^{27 33 36} Training programmes that focus on cognitive and mental skills have been recommended for all snowsport athletes.^{33 35 37}

The importance and complexity of achieving readiness for snowsports should be promoted on all levels. Athletes, coaches and other support staff should be educated about what readiness for high-performance snowsports entails and how it can be reached.

Baseline athlete condition defines W&A: the need for structure and flexible adaptation

According to the results of the present study, elite-level athletes have their own individualised W&A routine, which is continuously adapted based on current conditions, personal preferences, psychological disposition and injury history. This is in line with previous research,^{20 21 33 38} and seems specifically important since previous injuries and physical/motor deficits, such as a low rapid hamstrings-to-quadriceps ratio, as well as incorrect landing kinematics specifically in female and previously injured athletes, are known as risk factors for injuries.^{27 31 39} Since limited staff resources do not allow individualisation of W&A at the youth level and the adherence of youth athletes to W&A is perceived as unsatisfactory, basic group W&A programmes were suggested as measures to help these athletes get into a W&A routine. To support long-term development, these programmes should include general conditioning, skill rehearsal and basic mental measures. Previous studies have found that warm-up programmes that address neuromuscular conditioning and jump-landing biomechanics improve performance and reduce acute and overload injuries.^{3 4} Additionally, it is known that general physical fitness correlates with performance in youth ski athletes,⁴⁰ and minimal conditioning has been suggested to impact injury risk.³⁶ Implementing a ski-specific neuromuscular programme has been shown to reduce acute and overload injuries in U16 alpine skiing athletes, while severe acute injuries could not be reduced.⁴¹ This may plausibly be attributed to the high speeds and forces in ski alpine, which are also seen in freestyle skiing and snowboarding. The inclusion of basic mental W&A measures at the youth level to train risk awareness and proper focus may be a valuable attempt to decrease the occurrence of high-risk situations and lead to an overall reduction in injuries. In a study with youth soccer players, the inclusion of a basic 5 min mental warm-up routine improved mental readiness.² Basic, ready-to-use programmes that consider environmental factors and baseline requirements of the

different snowsport disciplines and the different needs of different athlete populations may be used to facilitate adoption in less experienced athletes and improve the long-term physical and mental development of athletes at all levels. According to the previously mentioned importance of mental readiness care must be taken that these ready-to-use programmes include basic mental skill training.

Achieving readiness in suboptimal circumstances

The participants in this study mentioned that different factors could increase the importance of W&A, such as extremely cold temperatures and the absence of a sheltered area close to the training or competition course. In addition to providing a location where athletes can perform their W&A, a supportive environment created by the (staff) team was mentioned to support athlete readiness. Previous studies described the challenges of on-snow competitions, such as competition holds, the environment and logistics and that athletes are mostly expected to perform in gusty winds, heavy snow, whiteout conditions and on icy surfaces, as there are no cold competition thresholds.^{8 30 35} This requires high physical and mental effort, which should be considered in the athletes' mental and physical training.³³ It must be considered that handling difficult situations requires practice and experience. Athletes should be trained in finding strategies to tailor their W&A routine according to different circumstances. Specific considerations should be made to support athletes at the youth level, where the same challenges need to be encountered with limited support staff, limited resources and limited experience. To increase athlete readiness, event organisation and staff teams should know the athletes' needs before and between runs and create optimal supportive conditions for W&A.

Methodological considerations

To increase the credibility of the presented findings, various sources were used (ie, athletes, on-snow coaches, S&C coaches, sports physiotherapists and sports psychologists). The number of participating athletes was relatively small compared with the number of staff members. However, most staff members had a history of being elite snowsport athletes and also shared their perspectives as former athletes. With 10 male and 3 female participants, the distribution of gender was unequal; however, it represents the reality in snowsports, especially regarding staff members. Dependability was accomplished by creating an audit trail with memos and mindmaps to record the development and interpretation of the findings, which were reported to and discussed with two other authors (JS and EV) who were not directly involved in the analysis and interpretation of the data.

CONCLUSION

W&A is being performed to reach readiness for successful and safe sports participation. Readiness involves physical

and mental aspects, and a proper W&A routine should therefore involve physical and mental parts. W&A is a dynamic concept adapted to sport-specific performance and prevention demands, environmental circumstances, and individual needs and preferences. Education about the concept of readiness, snowsport-specific W&A recommendations and dedicated W&A areas at snowsport events may support and facilitate athletes' readiness at all performance levels. To provide additional support at the youth level, basic and predefined snowsport-specific W&A programmes that target long-term athlete development should be implemented and may provide the fundament for individualised W&A routines along the career pathway.

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Contributors LB, SB and JS conceptualised and designed the study. CB and EV revised the study design. LB and JS recruited the participants. LB collected the data and, supervised by CB, processed, analysed and interpreted it (coding, memo writing, categorising, concept finding and essential meaning extraction). LB, SB, JS and EV finalised the interpretation of the data (review of main concepts and essential meaning, defining implications). LB drafted the current manuscript; all authors revised it critically, approved the final version of the manuscript and agreed to be accountable for all aspects of the work. LB is the responsible author for the overall content as the guarantor and accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. CB and JS shared last authorship.

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