PRACTICAL IMPLEMENTATION OF STRENGTH TRAINING TO IMPROVE THE PERFORMANCE OF WORLD-CLASS CROSS-COUNTRY SKIERS

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Commentary
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Abstract:

Current scientific evidence suggests that sport-specific heavy strength training could be successfully included in elite endurance athletes' training program. In fact, positive effects of short-term interventions, without any negative side-effects, have been shown repeatedly. However, there is a lack of long-term studies investigating the concurrent development of strength and endurance capacities, and there is a limited understanding of the mechanisms underlying the complex mix of strength and endurance training in the daily training plan of elite endurance athletes. In this context, cross-country skiers have shown a unique ability to build up and sustain a relatively large and strong muscle mass whilst, at the same time, having developed some of the highest maximal oxygen uptakes ever measured in humans. Accordingly, this study explores and discusses how world-class cross-country skiers implement strength training in their long-term endurance training schedule. The presented examples provide support to the scientific evidence from short-term studies, with heavy strength training being included approximately two times per week to build up strength in the preparation period and once per week to maintain strength in the competition period. Furthermore, individualized, movement-specific strength programs aiming to improve skiing technique, exercise economy/efficiency and to delay fatigue is employed. However, the systematic use of core/stabilization exercises by the best skiers has lack of scientific support, which is also the case for the placement of strength sessions within the weekly training puzzle, the order of strength exercises during a session, as well as the influence of mental abilities and technical execution during strength sessions.

Key words: *Endurance performance, exercise economy/efficiency, heavy strength training, maximal oxygen uptake, maximum strength*

Introduction

The requirements of strength for endurance performance in sport depend on the competition duration and format, as well as on the exercise mode employed in a given sport. Indeed, endurance training is an essential stimulus for endurance athletes and they do traditionally not prioritize high volumes of strength training (i.e., training aimed to increase muscles' ability to generate maximum force). However, short-term intervention studies in a variety of sports have shown that aerobic capacity and endurance performance can be enhanced through the implementation of strength training, mainly due to improved exercise economy/efficiency and delayed onset of fatigue (Ronnestad & Mujika, 2014).

The current evidence suggests that sport-specific heavy strength training could be successfully included in elite endurance athletes' training program, both to build up strength in the preparation period and to maintain strength in the competition period (Ronnestad & Mujika, 2014). Positive effects of short-term strength training on work economy/efficiency and on delayed fatigue, without any negative side-effects, have been shown repeatedly (Mujika, Ronnestad, & Martin, 2016). In contrast, strength-training gains seem to be negatively influenced by large amounts of endurance training due to molecular interference (Hawley, 2009). Another important question is whether the effects of an intensive period of strength training would be maintained in subsequent periods without or with less strength training. Research shows that only a small part of strength gained during an intervention is maintained after 8-12 weeks without strength training, which is accompanied by a relatively rapid reduction in muscle cross-sectional area and peak power output (Ronnestad, Hansen, Hollan, Spencer, & Ellefsen, 2016). This is highly interesting in relation with the periodization of strength training over the annual training cycle. Thus, in the long-term periodization of strength training for endurance athletes, "maintenance training" seems to be required (Ronnestad, Hansen, & Raastad, 2010). However, in order to avoid overtraining, implementation of strength training will lead to reduced amount of other types of training in highly trained athletes with already full training schedules.

Since the majority of experimental training interventions lasted only 8-12 weeks (Beattie, Kenny, Lyons, & Carson, 2014), caution is advisable when long-term effects are considered. Hence, much of what we know about neurological and structural adaptations induced by strength training derives from short-term interventions, and often in relatively untrained or inexperienced subjects. Consequently, there is lack of long-term studies investigating the concurrent development of strength and endurance capacities of athletes. Furthermore, there is a limited understanding of the mechanisms underlying the complex mix of strength and endurance training puzzled together in a daily training plan of elite endurance athletes. For example, rowers and cross-country (XC) skiers have built up and sustain a relatively large and strong muscle mass whilst, at the same time, having developed the highest maximal oxygen uptakes ever measured in humans (Haugen, Paulsen, Seiler, & Sandbakk, 2017). The reality is that science has probably not caught up with the sophistication of modern training and recovery techniques used by the best athletes. Hence, understanding how strength training is successfully implemented in an endurance-training regime in such athletes would provide a framework for generating new hypotheses in this area. Accordingly, this study will explore and discuss world-class XC skiers' implementation of strength training in their long-term endurance training schedule.

Requirements of strength in XC skiing

Cross-country skiing involves relatively long lasting competitions across varying terrain employing whole-body exertion while gearing between the different sub-techniques of the classical and/or skating styles (Holmberg, 2015; Sandbakk & Holmberg, 2017). Indeed, XC skiers need a well-developed endurance capacity and the best XC skier exhibited some of the highest reported maximal oxygen uptake values to date (Haugen, et al., 2017). At the same time, a high level of strength and power is needed to produce and transfer forces efficiently in the various skiing techniques and especially in the many competitions decided in a finish-sprint. These demands are exemplified by the abilities of male skiers with 85 mL min^{-1} kg^{-1} of maximal aerobic power who, at the same time, are able to produce peak double poling forces as high as 430 N within 0.05 seconds, as well as forces greater than 1600 N during leg push-offs when skating (Stoggl & Holmberg, 2016; Stoggl, Muller, Ainegren, & Holmberg, 2011). Similar demands are present for women, although women possess relatively lower upper- than lower-body strength and endurance capacities than men. Accordingly, XC skiers need to design their training to concurrently improve their aerobic endurance capacity and their upper- and lower-body strength and power.

Annual training of XC skiers

The major component of an elite XC skier's training is endurance, and 85-90% of the 750-950 hours of annual training is normally endurance training (Sandbakk & Holmberg, 2017). In the best skiers, this include approximately 80% of the total training time spent in low-intensity, 4-5% in moderate- and 5-8% in high-intensity endurance training. The remaining 10% of the total training time is dedicated to strength and/or speed training. In practice, this includes approximately 75 strength-training sessions per year (i.e., 10-15% of the total sessions), normally distributed as two sessions per week in the 6-month preparation period (May to October) and one weekly session in the competitive season. Although there are limited scientific findings on long-term effects of concurrent strength and endurance training, practical experience allow us to hypothesize that, for athletes who perform extensive endurance training, additional strength training would help to develop and/or maintain muscle mass and power. Furthermore, this seems to be particularly important in the upper-body that is less stimulated through other training modes, and in women who often need to put extra emphasis on strength and endurance training of the upper-body (Hegge, Myhre, Welde, Holmberg, & Sandbakk, 2015; Sandbakk, Solli, & Holmberg, 2017).

Strength training in elite XC skiers

Our best XC skiers combine heavy strength training, aiming to increase maximum strength and power in the ski-specific muscles, with submaximal exercises mainly focusing on core stability, motor control and injury prevention. These two types of training are regarded complementary and in XC skiers they are often included in the same session. In addition, speed training and jumps/plyometrics in the ski-specific movements are done 2-3 times per week throughout the whole year and are elements of the programming puzzle with a comprehensive strength/power component. In the following sections, I will focus mainly on heavy strength training aiming to develop XC skiing performance and aerobic capacity through increased maximum strength. However, the transfer effects of strength/

power to enhanced aerobic capacity and endurance performance needs to be evaluated together with the abovementioned components.

Training to improve strength

The preparation phase for a XC skier includes an initial period where strength is progressively built up, from May to August. After the first couple of weeks have assured familiarization and learning of a proper technique, the load of the weights are added until the point where athletes struggle to maintain a good technique and fully clear lifts in the planned number of repetitions. Hopefully, the athlete will gradually be able to lift heavier weights throughout this period and can thereby increase the load of each lift week-by-week. Monitoring the load of lifts is also a good way to track progress of the training, although increased strength should not negatively influence the development of endurance and coaches and athletes need to assure that strength improvements can be transferred to better technique and higher skiing speed. In Table 1, you can see how strength training is included in the daily puzzle of a typical training week for a successful XC skier in the preparation period, whereas Table 2 illustrates a typical strength session. From my own personal experience, I recommend to compose the training plan in a way that ensures a "fresh" and well-fueled musculature during the strength sessions in this period. In addition, a specific focus on technical execution is of particular importance to optimize the development during this period and thereby provide a physical and technical foundation for further progress in the following period.

This is followed by a second period, from August to October, where the strength training programme is maintained relatively similar, with only some minor modifications in the exercises to make the movements more ski-specific and the execution more explosive. Since athletes are then familiarized with the exercises, it costs less to perform the sessions and reduced recovery times are feasible. Hence, a greater focus can be placed on optimizing the key endurance sessions performed in this period. While many high-level athletes do not get

Table 1. Typical training weeks for a world-class cross-country skier during the preparation and competition periods

Day	Preparation phase	Competition period
Monday	a.m.: 6 x 5 min HIT, uphill running with poles	a.m.: 2 h LIT, classical skiing on easy terrain
	p.m.: 1.5 h LIT, classical roller skiing with double poling on easy terrain	p.m.: 1.5 h LIT, ski skating skiing on easy terrain
Tuesday	a.m.: **strength training#**	a.m.: Warm-up + **strength training#**
	p.m.: 1.5 h, LIT roller ski skating on easy/moderate terrain	p.m.: 1.5 h LIT, classical skiing on easy terrain
Wednesday	a.m.: 2.5 h LIT, classical roller skiing on varied terrain	a.m.: 4 x 6 min HIT*, classical skiing and skating on varied terrain with included 10-second attacks or sprints
	p.m.: 1.5 h LIT, running on hilly terrain with a soft surface	p.m.: 0.5 h LIT, running on treadmill
Thursday	a.m.: 50-min continuous MIT/HIT*, roller ski skating on a roller ski track, followed by **10 x 12 s sprints**	a.m.: travel
	p.m.: 1 h LIT, roller ski classic on easy terrain	p.m.: 1 h LIT, skating on moderate terrain including 5 x 10 s sprints
Friday	a.m.: rest	a.m.: 45 min LIT followed by 10-15min continuous MIT/HIT in competition track*. Classical skiing
	p.m.: **10 x 10 maximal jumps + strength training#**	p.m.: 20 min running + **20 min of stabilization/core exercises**
Saturday	a.m.: 5 x 8 min HIT*, roller ski classic on a roller ski track	MO: morning jog 30 min, strides and jumps a.m.: 15 km classic competition*
	p.m.: 60 min LIT, easy cycling	p.m.: easy skiing 45 min, stretching/massage
Sunday	a.m.: 3.5 h LIT, running on terrain of moderate incline with a soft surface	a.m.: 30 km skiathlon competition*
	p.m.: rest	p.m.: travel

Note. LIT = low-intensity training: blood lactate concentration < 2.5 mmol/L, heart rate < 80% HRmax; MIT = moderate-intensity training: blood lactate concentration 2.5-4.0 mmol/L, heart rate 80-90% HRmax; HIT = high-intensity training: blood lactate concentration >4.0 mmol/L, heart rate > 90% HRmax.

* Competitions and HIT sessions routinely included approximately 30-45 min of LIT, followed by 10-15 min of MIT/HIT. Cool-down involves 15 min of LIT.

Strength sessions typically consisted of a 30-minute warm-up (running/cycling at LIT), followed by 20-45 min maximal movement-specific strength exercises and 20-45 min of more general core/stabilization exercises (see Tables 2 and 3 for details).

Table 2. Example of a strength training session for a world-class cross-country skier during the preparation period with the goal of concurrently develop strength and endurance

Activity	Duration	Series and reps	Intensity
General warm-up: easy running	20-30 min		Low intensity – first 15 min at 70% HR_{max}, thereafter at 75-80% HR_{max}
Mobility	5-10 min		Slow, dynamic movements
Part 1: Core/stabilization exercises			
Mat exercises: hollow sit, ab roller, back raise	10 min	3 tasks x 3 x 30/15 s work/rest ratio	Slow and controlled movement
Sling: superman	5 min	1 task x 3 x 30/30 s work/rest ratio	Controlled movement with 3 sec hold
Medicine ball: front throw, side throw and throw down	15 min	3 tasks x 3 x 30/45 s work/rest ratio	Controlled, accelerated movement
Skating simulation: with and without control jump	10 min	2 tasks x 3 x 20/40 s work/rest-ratio	Controlled, accelerated movement
Part 2: Maximal strength training*			
Step-up with weights	5 min	2x10 (5 left and 5 right foot), at 25% of 1RM	Controlled movement, high velocity
Hang power cleans	8 min	3x4 reps at 70-80% of 1RM	Maximal mobilization, high intended velocity
Lying bench-pull	8 min	3x6-8 reps at 60-80% of 1RM	Controlled, accelerated movement
Pull-over	8 min	3x5-6 reps at 70-80% of 1RM	Maximal mobilization, high intended velocity
Seated pull-down	8 min	3x4-5 reps at 80-90% of 1RM	Maximal mobilization, high intended velocity
Standing double poling	5 min	2x6 reps at 60-70% of 1RM	Maximal mobilization, explosive movement
Recovery: easy running/cycling	10 min		Low-intensity: 60-70% HR_{max}

*Each exercise includes one warm-up set with low weight; recovery between sets 2 min.

large improvement in strength in this period, the hypothesis is that strength maintenance through two high-quality weekly sessions with high quality is important to transfer the effects of strength to endurance performance and that a longer "strength period" will facilitate better maintenance of strength in the following competition period. Still, my opinion is that strength sessions' quality is more important than their quantity during this period, regarding both the number of sessions and the number of exercises and series within each session.

The two strength sessions included in Table 1 are from different time points of the training program. On Tuesday, a strength training session with relatively heavy loads and low number of repetitions is done in the morning, with a low-intensity training planned both in the evening before and in the following afternoon. The reason for this is that an easy session after the high-intensity session on Monday morning would allow the athlete to be physically and mentally prepared for the strength session. Furthermore, it seems like light loads in the subsequent sessions facilitate good recovery and strength adaptations, thereby reducing a negative inference from endurance training on strength-training adaptations. The second strength session is placed on Friday afternoon, and follows an easy evening session on Thursday and rest or an easy morning jog Friday morning. After a warm-up and some jumps, this session will be more focused on explosiveness compared to the Tuesday session (i.e., slightly lower loads and higher velocities of movement execution). The same exercises are mainly used, but one or two tasks are sometimes modified to enhance explosiveness. The session is placed in the afternoon since explosive movements training quality seems to be better in the afternoon (athletes feel being more fresh and awake, can jump higher and lift faster, etc.) and the session facilities an optimal muscle tension for the subsequent high-intensity session on Saturday morning, which is a key session of the week. However, although this is a general pattern, some athletes might respond different than others which coaches and athletes must be aware of when making individual plans.

The information provided above on this topic is purely descriptive and current advises are mainly based on not yet systematized personal experiences. However, the development of sensors, tools and training diaries that collect and systematize data from training and competitions/tests is accelerating. By using data-driven machine learning algorithms (so-called neural networks) or artificial intelligence on such "big" data, on both one athlete through time and between athletes, we can probably reveal interesting patterns that are positively and/or negatively related to an athlete's or a group's development. I predict that such methods, when combined with theory-hypothesis-driven studies, will have the potential to drive future research further in such complex areas. This also includes the way in which training is scheduled and "timed" towards important competitions, often called tapering, which is also a highly complex field to study experimentally since various factors may have influence on the outcome.

Training to maintain strength

This leads us to the competition period, starting in November, where one weekly session of strength training seems to be sufficient to maintain strength throughout the season. This session should contain the most important components of the programme developed in the preparation period. However, less training volume (reduced number of exercises and sets) is normally practised, whereas quality/intensity needs to be on a high level. This includes high (intended) movement velocity and relatively high loads, as well as fine-tuned technical execution. In the competition-free periods with 2-3 weeks of a high-volume training during the winter, a weekly "full strength session", similar to those used in the preparation period, is used to stress the strength component extra.

In Table 1 one can see a typical training week for a successful XC skier in the competition period and Table 3 illustrates a typical strength session in the competition period. In the competition period, a strength session is typically performed on Tuesday morning. This session is built on the sessions performed in the preparation phase, but bears less overall load. In addition, shorter sessions of stabilization/core exercises and jumps on Friday and Saturday are used to optimize muscle tension and mobilization abilities before the competitions in the weekend. Overall, the strategies used before competitions are highly individual and an unexplored scientific area. Due to my experience, the optimal strategy might differ between days with high versus low muscle tension before warm-up, and I think it is crucial that each athlete strive to developing optimal routines for a given situation.

Individualization of strength training programmes

Similar procedures as described in Table 1 are used by many of the top XC skiers, although each athlete needs to find his/hers own pattern of how to optimally puzzle the strength and endurance components of their training programme, as well as the optimal preparation pattern for competitions. The same applies for the typical strength training sessions of a world-class cross-country skier presented in Tables 2 and 3. While these programmes are representative for skiers at the elite level in XC skiing, each athlete needs to modify his/hers programme to their individual needs. First, the training programme should be set so to avoid the possible molecular interference of concurrent strength-

Table 3. Typical strength training session for a world-class cross-country skier during the competition period with the goal of maintaining strength and optimize endurance performance

Activity	Duration	Series and reps	Intensity
General warm-up: easy running	20-30 min		Low intensity – first 15 min at 70% HR_{max}, thereafter at 75-80% HR_{max}
Mobility	5-10 min		Slow, dynamic movements
Part 1: Core/stabilization exercises			
Mat exercises: hollow sit, ab roller, back raise	8 min	3 tasks x 2 x 30/15 s work/rest ratio	Slow and controlled movement
Medicine ball: front throw, side throw	8 min	2 tasks x 3 x 30/45 s work/rest ratio	Controlled, accelerated movement
Skating simulation: with control jump	5 min	1 task x 3 x 20/40 s work/rest ratio	Controlled, accelerated movement
Part 2: Maximal strength training*			
Jump squats	8 min	3x5 reps at 25-50% of body mass	Maximal mobilization, high velocity
Reversed flies	5 min	2x10 reps, low load	Controlled, accelerated movement
Seated pull-down	8 min	3x4-5 reps at 80-90% of 1RM	Maximal mobilization, high intended velocity
Standing double poling	5 min	2x5 reps at 60-70% of 1RM	Maximal mobilization, explosive movement
Recovery: easy running/cycling	10 min		Low-intensity 60-70% HR_{max}

*Each exercise includes one warm-up set with low weight; recovery between sets 2 min.

and endurance-training by training planning with awareness and by including optimal nutrition plan. How skiers respond to endurance training after a strength session is highly individual, which also applies to the recovery time needed to fuel and prepare muscles for strength training after high loads of endurance training. Second, different mechanisms (overloading force component, power, timing of force production/application, etc.) should be triggered in different individuals, depending on the relationship between the individual's current capacity for a given movement/exercise and the demands of XC skiing. These subsequently influence the choice of load, series, repetitions and type of exercises. Thus, there is no "ideal" strength training program for XC skiing, but rather main principles and a toolbox that coaches and athletes should choose from in a given context. In my opinion, this individualized way of using training principles is a main area where the best XC skiers distinguish from those at a lower standard level. A possibility for future studies in this area could be to screen individual requirements of an athlete, and thereafter compare general strength training programmes with the individualized, more targeted ones.

Execution of strength sessions

As illustrated in Tables 2 and 3, most XC skiers perform a relatively long warm-up of approximately 30 min. This is purely due to tradition in endurance sports and it can be discussed whether such a long general warm-up is really needed. However, these athletes are highly endurance trained, and a 30-min warm-up does not exert any fatiguing effects on the subsequent strength part of the session. Thereafter, some minutes of dynamic mobility is common practice, followed by 20-40 min of core/stabilization exercises before the main part with heavy strength training.

The core/stabilization exercises aim to 1) mobilize the muscles involved in force transfer during the specific ski movements, such as shoulders, trunk, hip, and knee muscles; 2) improve these muscles' ability to stabilize and move these segments functionally while skiing, and 3) prevent injuries. It is highly important that this section of the strength sessions is individualized for each athlete, so that the individual's "weak links" for optimal skiing technique and performance are targeted. Many of these submaximal exercises are performed with relatively slow movements and control in the initial phase of using a new exercise, whereas the movement speed and load can gradually be increased. There are hundreds of different exercises that can potentially be useful, performed with own body mass, weights, slings/redcords, elastic bands, swissballs, medicine balls, etc. In addition, there are many different ways to organize and perform the exercises. However, they should all be organized so the intended effect is targeted and in accordance with the overall load/fatigue placed on the athlete, especially if the section is performed before heavy strength training. The athlete should not lose physical or mental power needed for the subsequent heavy strength part of the session. While this part makes some athletes more ready to mobilize in the heavy strength exercises, others would rather perform these as own sessions or after the heavy strength session. Overall, there is lack of scientific information about this type of training and its effects on performance and the underlying factors. As a coach, I would recommend most XC skiers to include such training and we know the best athletes in many other sports have used it for decades. However, it sorely needs further examination.

The heavy strength training exercises need to be movement-specific, but at the same time performed in exercises where athletes are able to mobilize maximally during the concentric phase. Mentally and technically (at least at the level of muscle recruitment and mobilization) a XC skier should feel that he/she is doing the exercises as they almost would be when "skiing on snow". This feeling assures improved transfer effects to skiing. Since the legs get more strength stimulus during jumps, sprinting and other activities during other types of training than the arms/upper-body, there is a main emphasis on the upper-body during strength training in XC skiers. However, the focus on upper-body strength also reflects the role of the upper-body in skiing, with the briefest, explosive push-offs and long recovery times where the poles are repositioned for the next poling cycle. The legs work all the time, especially during skating, and need to constantly carry the skier's body mass. Hence, more explosive movements are required in the upper- than in the lower-body and typical heavy strength training programmes consist of one or two leg exercises and three to four upper-body exercises. Leg exercises would be, for example, squats, jump squats, (hang) power clean, back-split squats, or step-up. Upper-body exercises such as seated pull-down, standing double poling, pull-ups with weights, muscle-up, lying bench-pull, French-press, pullover, and triceps press are common. These upper-body exercises often use handgrip widths similar to those in XC skiing or custom-made handlebars designed to imitate the pole-grip in XC skiing (Losnegard, et al., 2011).

For each exercise, normally one warm-up set with low load is followed by two to four sets with high loads. The training load and number of repetitions range from 3RM to 10RM, depending on the time of year and exercise. When the execution technique has been optimized, each repetition is conducted with maximal mobilization in the concentric phase that is lasting approximately one second, followed by a slower eccentric phase (2-3 s);

rests between sets are 1-3 min. See examples in Tables 2 and 3. The lowest number of repetitions is used in exercises where the athletes are able to mobilize maximally and thereby lift heaviest. In contrast, exercises that are more technically complex or where less muscle mass is included seem to energetically cost less and more repetitions can therefore be added.

As a preference, I would suggest that leg exercises should be done before arm exercises, as well as technically easy exercises with full muscular mobilization before more complex, ski-specific ones. In addition, the sessions are normally finalized with an explosive exercise, using a ski-specific exercise and high-velocity movements. In this context, the way strength training is executed is likely as important as the content of the training programme. My impression is that a greater focus on optimizing each session and thereby improve training quality and enhance adaptations is what differentiates high responders from those responding less. This includes mental preparations for the session, as well as optimized technical execution and the athletes' ability to mobilize maximally during the sessions. In order to continuously optimize the training programme and execution I recommend that athletes and coaches should focus on the following key points:

1. Optimized execution of each strength session:
    - Planning: Each session needs to be prepared with a clear aim of the session, where the design, choice of exercises, loads, sets, repetitions etc., match the specific aim of each session. Work tasks should be clarified before the session.
    - Performing: Be 100% present during the session and place emphasis on optimizing technique and movement velocity. Keep focus only on a few checkpoints (aligned with the clarified work tasks) to reinforce the specific focus areas, e.g., by using video, feedback from coach, etc.
    - Debriefing: Reflect on what went well as soon as possible after the session, and discuss what could be done better next time and what will be the future consequences.
2. Optimization of strength and performance adaptations:
    - Key strength sessions should be implemented in the programme puzzle so they can be completed with the highest possible quality, but with minimized interference with the aerobic sessions.
    - Monitor load/velocity of the lifts in key sessions to acquire performance indices and ensure expected progress.
    - Evaluate training by output (i.e., progress both in strength, aerobic capacity and performance) in order to regulate future input.

This paper describes how strength training is implemented in an endurance training regime by world-class XC skiers, athletes who have managed to build up and sustain a relatively large and strong muscle mass whilst, at the same time, having developed an outstanding endurance capacity. Due to a possible negative interference caused by high volumes of endurance training on strength adaptations, this combination is unique and probably ahead of current scientific evidence. Thus, learning from common practices of such outstanding athletes should be used as a framework for generating new hypotheses in this area. Most of the presented examples agree with the scientific evidence presented in short-term studies, with heavy strength training being included approximately two times per week to build up strength in the preparation period and once per week to maintain strength in the competition period. Furthermore, individualized, movement-specific strength programmes, aiming to improve skiing technique, exercise economy/efficiency and/or to delay fatigue, are employed. However, the systematic use of core/stabilization exercises by the best skiers has scarce if any scientific support and sorely needs further examination, which is also the cause for the placement of strength sessions in the weekly training puzzle and the order of strength exercises when training both the legs and arms. The influence of skiers' mental abilities, technical execution and the ability to maximally mobilize oneself during the sessions on physical adaptations are additional areas that are relatively unexplored scientifically, but of high importance for practice. In order to facilitate better general understanding and individualization of the timing of concurrent strength and endurance training sessions in different periods, data-driven machine learning models/algorithms and artificial intelligence used on "big" data will be helpful to find positive and/or negative patterns related to the athlete or group's development.

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