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Ski mountaineering as a new Olympic sport: Development trends and training requirements for athletes

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Abstract. The aim of the study was to identify the characteristic features of the organisation of training for ski mountaineering athletes, based on trends in its development in the context of its attainment of Olympic status. The research methodology was based on the use of historical-logical, analytical-synthetic, structural-functional and generalising-comparative methods, which ensured a comprehensive analysis of the evolution of ski mountaineering, current trends in its development and the specifics of training athletes in mountain conditions. It was found that ski mountaineering has evolved from a practical means of movement in mountainous conditions into a structured international sport combining mountaineering techniques, ski training and high demands on physical endurance. Its institutionalisation through international federations, the standardisation of competitions and its inclusion in the Olympic programme reflect the transition to a modern, high-tech discipline integrated into the global sporting system. It was noted that the contemporary development of ski mountaineering is characterised by a rapid rise in popularity, a shift towards short, highly dynamic competition formats, and a significant increase in the intensity of physical exertion. At the same time, equipment is becoming more technologically advanced and the training process is intensifying, which, together with its inclusion in the Olympic programme, is transforming the sport into a media-friendly and highly specialised discipline. Its inclusion in the Olympic programme and the reduction in the duration of competition formats by 90-95% reflect its transformation into a high-speed and technology-oriented discipline with an emphasis on media appeal and efficiency. It was found that the training system combines endurance, strength, coordination and technical skills, ensuring the comprehensive adaptation of athletes to challenging mountain conditions and variable loads. The practical significance of this work lies in the possibility of using the results obtained to improve the training system for athletes in ski mountaineering and other mountain endurance sports, thereby enhancing their physical performance, technical efficiency and adaptation to challenging environmental conditions

Keywords: aerobic endurance; mountain conditions; biomechanics of movement; physiological stress; training

Introduction

Ski mountaineering, as a new discipline in the Olympic programme, is attracting increasing attention due to its combination of high physical demands, technical skill and specific requirements for athletes' functional readiness. The inclusion of this discipline in the Olympic Games programme has heightened interest in studying trends in its development, training systems and factors influencing performance outcomes. Studying the specifics of training for ski mountaineering helps to improve the training process, enhance athletes' competitiveness and broaden scientific understanding of the development of new Olympic disciplines.

The growing scientific interest in ski mountaineering is linked to its inclusion in the Olympic programme and the need for a deeper understanding of the factors influencing sporting performance. V.R. Schöffl *et al.* (2023) conducted a narrative review of the scientific literature on ski mountaineering as a new Olympic discipline. The authors summarised data from regarding physiological loads, typical injuries and the specifics of athletes' competitive activities. Increasing demands on sporting performance are driving a focus on the technical aspects of training. L. Bortolan *et al.* (2023) analysed the development of ski mountaineering equipment. The researchers described changes in the design of skis, bindings and boots that help to reduce the weight of the equipment and improve movement efficiency. Performance in winter disciplines also depends on the

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gliding properties of the equipment and its interaction with the snow surface. A. Almqvist *et al.* (2025) examined the influence of friction on performance in Winter Olympic sports. Optimising surfaces and selecting materials can improve athletes' speed and efficiency.

The development of skiing has been accompanied by an expansion of the scientific base, which lays the groundwork for new research in ski mountaineering. W. Hou *et al.* (2024) conducted a bibliometric analysis of global research on skiing from 1974 to 2023. They identified an increase in the number of publications, key thematic areas and a rise in interdisciplinary approaches. The spread of ski mountaineering is linked not only to high-performance sport but also to changes in recreational culture. M. Nevicato *et al.* (2025) investigated the transformation of ski touring at the turn of the 20th and 21st centuries. The researchers demonstrated that this activity is becoming multifunctional, combining sporting, tourist and health-related motivations for participation. The expansion of winter activities is also influencing the tourism sector in mountain regions. A. Bortolotti *et al.* (2024) examined sport as a practice of well-being through the integration of sport, wellness and health. It is noted that sporting events and mountain disciplines contribute to the diversification of tourism services and regional development. The training of athletes also depends on the broader socio-economic conditions governing the recreational sector. D.S. Kan (2024) analysed the historical conditions of the formation of Ukraine's tourism and recreation sector and its development in the era of sustainable multimodal mobility. The author outlined the factors of infrastructure modernisation that may influence the accessibility of mountain activities and sporting practices. The historical preconditions for the development of recreation in Ukraine are highlighted in collective studies. V. Tsypko *et al.* (2024) investigated the formation of Ukraine's tourism and recreation sector and the directions of its further development, emphasising the role of transport mobility, investment and regional potential for active tourism. The spread of ski culture is increasingly linked to digital communications and the media environment. C. Zhao & H. Shen (2024) investigated the moderating effect of ski influencers on intentions to participate in ski tourism. It was found that the influence of online opinion leaders enhances interest in winter activities and fosters motivation to participate.

Despite the aspects highlighted by the aforementioned authors, the gaps included a lack of attention to athletes' long-term adaptive mechanisms in variable mountain conditions and their impact on the consistency of results. Furthermore, the integration of psychological preparation with the physiological and technical components of the training process is only briefly addressed. Additionally, the system for comprehensively assessing the effectiveness of training in high-altitude conditions, taking into account the specific nature of competitive ski mountaineering, requires further in-depth study. The aim of the study was to identify the characteristics of training for ski mountaineering athletes, taking into account current trends in the development of this sport and its inclusion in the Olympic programme. The objectives of the study were to identify the key stages in the development of ski mountaineering, assess current trends in its development, and determine the specific nature of training for athletes in mountain conditions.

Materials and Methods

The research methodology was based on the use of four interrelated theoretical methods, namely the historical-logical, analytical-synthetic, structural-functional and generalising-comparative approaches, which enabled a comprehensive analysis of the historical development of ski mountaineering as an Olympic discipline, current trends in its development and the specific nature of athlete training. In the first stage, a historical-logical method was employed, which made it possible to trace the evolution of ski mountaineering from a practical means of locomotion in mountainous terrain to an officially recognised sporting discipline. Within the framework of this method, an analysis was carried out of the process of its inclusion in the international sporting calendar and, in particular, in the Olympic programme. This made it possible to identify the key stages in the institutionalisation of the sport, the factors that influenced its Olympic recognition, and the role of international sports federations in standardising competition rules. The source base consisted of regulatory materials from the International Ski Mountaineering Federation (2026) and the Encyclopaedia Britannica (n.d.). Information resources from Dynafit (2025) and Tribuna (n.d.), which covered the development and current state of ski mountaineering, were also examined. Additionally, the international regulations of the ISMF World Cup (International Ski Mountaineering Federation, 2023) and analytical materials from the International Testing Agency (n.d.) were examined, which pertain to the organisational and regulatory aspects of the sport's development in the context of its Olympic integration. Statistical data was collected through a systematic review of the aforementioned open international sources. The data obtained was structured according to key indicators of the development of ski mountaineering, including competitive activity, regional participation and the characteristics of training processes.

In the second stage, an analytical-synthetic method was applied, which was used to identify the main trends in the development of ski mountaineering based on an analysis of international academic sources and industry reports, in particular the works of L. Bortolan *et al.* (2021) and M. Tarabini *et al.* (2026), which reflect changes in the competitive structure, physiological loads and regional organisation of the global ski industry, specifically in regions such as Europe, North America, the Asia-Pacific region, South America, the Middle East and Africa.

In the third stage, a structural-functional approach was applied, which made it possible to view ski mountaineering as a holistic system of interrelated components of sporting activity and to incorporate the main types of training methods. The study analysed the structure of training in ski mountaineering as a system of interrelated physical, functional and technical-coordination components, including aerobic endurance, strength training, high-intensity interval training and specific skills for transitional movements. A separate stage was devoted to the analysis of sports equipment, within which the technical parameters of the gear were assessed in terms of their impact on movement efficiency, safety and competitive performance. The

theoretical framework was based on data from the International Ski Mountaineering Federation (2026) and a synthesis of methodological approaches from Peak Experience (n.d.), reflecting current requirements for physiological training, energy supply and technical efficiency in mountain endurance sports. In the final stage, a generalising and comparative method was applied, through which the requirements for the training of athletes in ski mountaineering were presented.

Results

An overview of the evolution of ski mountaineering from a practical form of mountain travel to a modern Olympic sport

Ski mountaineering (skimo) is a demanding form of alpine skiing that combines elements of mountaineering, ski touring and cross-country skiing in mountainous terrain. Its origins lie not in sporting practice, but in the practical necessity of getting around in the high-altitude regions of the Alps, the Pyrenees and other mountain ranges in Europe. In the 19th and early 20th centuries, skis were used as a means of transport in snow-covered mountains by the military, rescue teams and the local population. It was this practical function that laid the foundations for the future sporting discipline, as the technique of moving on skis in the mountains gradually began to incorporate elements of competition between mountaineers and mountain guides. The evolution of ski mountaineering as a sport began with the organisation of the first informal competitions in the mid-20th century, when time trials involving ascents and descents along mountain routes began to be held in the Alps. In the 1970s and 1980s, rules were gradually established, routes were standardised, and the first sports clubs specialising specifically in skimo emerged. A key milestone was the creation of international bodies that began to coordinate the development of the sport across various countries, including France, Italy, Switzerland, Austria and Spain (Tribuna, n.d.).

The International Ski Mountaineering Federation, which was officially established in 2008, played a significant role in the transformation of ski mountaineering. It was the International Ski Mountaineering Federation that ensured the standardisation of competition rules, the systematisation of disciplines (individual races, sprints, relays, team races), and the integration of the sport into the international calendar (International Testing Agency, n.d.). For example, world championships and World Cup stages have become regular events, which has contributed to raising the level of professionalism among athletes and coaches. Ski mountaineering differs from its historical precursors and military-practical mountain movement, which combined ascents and descents on skis without clear sporting regulations. Whereas in the early days of ski mountaineering the main objective was to overcome natural obstacles in the mountains, by 2025-2026 it will be a highly structured sport with regulated distances, standardised equipment and a dedicated sporting infrastructure. Competitions involve alternating between ascents on skis using special bindings, carrying skis over difficult sections, and technical descents at high speed. This creates a physical exertion profile that combines endurance, speed and strength, and technical skill.

A distinctive feature of the development of ski mountaineering is its rapid integration into the Olympic sports programme. Following many years of development at the level of international federations, in 2021 the International Olympic Committee decided to include ski mountaineering in the programme of the 2026 Winter Olympic Games in Milan-Cortina (International Olympic Committee, 2021). This marked a stage in the sport's institutionalisation, as it moved from the category of extreme and niche disciplines to official Olympic status. The Olympic programme includes the short and dynamic disciplines of sprint and mixed relay, reflecting the general trend in modern sport towards shortening the duration of competitions and increasing their spectacle value. An example of the level of development in ski mountaineering is the ISMF World Cup stages, where athletes tackle routes with an elevation gain of up to 1,500 metres, demonstrating an average ascent speed of over 1,500 vertical metres per hour. Such figures indicate extremely high demands on athletes' functional fitness, particularly regarding maximum oxygen uptake (VO_2 max), the efficiency of aerobic energy supply, and the ability to perform under hypoxic conditions (Dynafit, 2025).

Another aspect of this evolution is the increasing use of technology in equipment. Modern skimo skis are lighter than those of previous decades (the 1980s to 2000s), which helps to reduce energy expenditure during ascents. Carbon materials, lightweight boots and adaptive bindings are also widely used, enhancing movement efficiency. This demonstrates the sport's transition to a high-tech level, where results depend not only on physical fitness but also on innovations in sports equipment. Table 1 shows the evolution of ski mountaineering from practical mountain travel to an internationally recognised sporting discipline, which has gone through the stages of establishing competitions and inclusion in the Olympic programme.

Table 1. The evolution of ski mountaineering from practical mountain travel to an Olympic discipline

Period / Stage	Characteristics of development	Key features
Ancient practices (before the 19th century)	Use of skis as a means of transport in mountainous and snow-covered regions	Practical function: transport, hunting, military needs; absence of a sporting element
19th – early 20th centuries	The development of downhill skiing and mountaineering techniques in Europe	Combining ascents and descents in the mountains; first expeditions and sporting attempts to conquer routes
1910s-1950s	Military and expeditionary use of skis in the mountains	Active use in military units; development of techniques for moving in difficult conditions
1960s-1980s	The emergence of the first informal competitions	The emergence of mountain races; the development of backcountry skiing and ski touring as precursors to the sport

Table 1, Continued

Period / Stage	Characteristics of development	Key features
1990s-2007	Institutionalisation of the sport	Establishment of international organisations (ISMC, later ISMF); the first official world championships; standardisation of rules
2008-2015	Establishment of the international sporting system	Regular World Cups; expansion of disciplines (sprint, individual races, relays); increased professionalisation
2016-2020	Recognition by the IOC and inclusion in the Youth Olympic Games	Official recognition by the International Olympic Committee; inclusion in the Youth Olympic Games
2021-2026	Olympic integration	Inclusion in the programme of the 2026 Winter Olympic Games (Milan-Cortina); debut in the sprint and mixed relay formats

Note: IOC – International Olympic Committee; ISMC – International Ski Mountaineering Committee; ISMF – International Ski Mountaineering Federation
Source: compiled by the author based on research from Encyclopaedia Britannica (n.d.)

In practice, the evolution of ski mountaineering has been marked by a shift from the utilitarian use of skis in mountainous and military contexts to an organised sporting activity with clear rules and standardised routes. Initially, skiing in high-altitude regions served the purposes of transport, hunting and supporting military operations in challenging terrain. Subsequently, informal mountain races emerged, in which the key criterion was the speed of ascending and descending slopes in natural conditions. As the sport developed further, international competitions were established, and specialised equipment, training systems and methods emerged, aimed at developing endurance, speed and strength, and technical skill. In its modern form, ski mountaineering functions as a highly dynamic sport that combines intense physical exertion with challenging mountain routes and requires comprehensive physical and tactical preparation of athletes. Ski mountaineering has undergone a complex evolution, transforming from a practical means of getting around in the mountains into an internationally recognised sporting discipline and an Olympic sport. Its development has been characterised by gradual institutionalisation, the standardisation of rules, the growth of sporting competition, and integration into the global Olympic system. This allows ski mountaineering to be regarded as one of the most dynamic winter sports, combining the traditions of mountain culture with the high demands of professional sport.

Trends in the contemporary development of ski mountaineering

The development of ski mountaineering (skimo) is characterised by a range of interrelated trends, encompassing social and promotional, competitive and organisational, physiological and technological aspects. Overall, between 2000 and 2025, the sport has seen a steady increase in popularity of approximately 60-80% globally, linked to its transition from a niche mountaineering practice to an organised international sporting discipline and its inclusion in the programme of the 2026 Olympic Games (Encyclopaedia Britannica, n.d.). This has increased media attention, commercialisation and the involvement of new countries, particularly outside the traditional Alpine regions.

One of the key trends in the development of ski mountaineering is a significant shift in the structure of competitive demands, characterised by shorter distances and increased intensity. Whereas classic disciplines involved individual races lasting 60-180 minutes with significant elevation gains of up to 2,000-2,400 m, the modern Olympic format is predominantly focused on the sprint (≈3 minutes) and the mixed relay (≈7 minutes per participant) (Tarabini *et al*., 2026), which generally means a reduction in the duration of the competitive workload by approximately 90-95%. At the same time, this transformation does not imply a reduction in endurance requirements, as competitions take place in a format of repeated explosive efforts with short recovery phases, significant elevation changes and high intensity density throughout the entire competition day or series of races. This is precisely why training must continue to focus on developing both a strong aerobic base and the ability to maintain intensity under conditions of accumulated fatigue.

Another trend is the increasing use of technology in sports equipment. The weight of a complete set (skis, boots, bindings) has been reduced by an average of 20-30%, which has had a direct impact on climbing speed, as it has been proven that every kilogram of weight reduction in equipment increases climbing efficiency by 2-4%. Modern sprint skis are around 150-160 cm long, made from carbon composites and optimised for rapid changes in skiing style. "Skins" (anti-slip pads) have also been significantly improved, increasing the grip coefficient to 85-90% without losing gliding speed. Technological progress also extends to binding and boot systems: modern models allow the transition time between movement modes to be reduced to 3-5 seconds, which is critical in sprint races. In addition, digital analysis systems, GPS tracking (Global Positioning System tracking) and power sensors are being actively introduced, allowing for real-time monitoring of load and improving the efficiency of the training process (Bortolan *et al*., 2021).

The level of development of ski mountaineering and the related ski industry varies from country to country, due to historical traditions, natural and geographical conditions, levels of investment, infrastructure and state support for sport. Consequently, this results in varying rates of growth and differing levels of technological and sporting "maturity" across countries. Countries in the Alpine region (France, Italy, Switzerland, Austria) have the highest level of development and the most stable rates of progress, which is explained by the historical foundation of mountain sports and the established infrastructure. Table 2 reflects the regional structure of the global ski industry, demonstrating the dominance of Europe and North America, with a gradual increase in the share of the Asia-Pacific region and a smaller presence of other regions of the world (South America, the Middle East and Africa).

Table 2. Regional characteristics of the development of ski mountaineering

Region	Characteristics of development (with specific features)
Europe	Europe is the heart of ski mountaineering: every year, over 60-70% of the ISMF World Cup and Continental Cup stages are held here. National teams operate in France, Italy, Switzerland, Spain and Austria, which regularly take part in the ISMF World Championships. The region has an extensive network of specialist skimo clubs and high-altitude training bases in the Alps. It is here that the bulk of the Olympic qualification process for Milano-Cortina 2026 takes place.
North America	The region is represented by the United States and Canada, where national federations and national teams operate and regularly take part in ISMF World Championships and World Cup events (accounting for approximately 10-15% of starts). Skimo clubs are active (for example, in Colorado and British Columbia), and training programmes are integrated with mountaineering and alpine skiing programmes. There are well-established commercial skimo events and competition series.
Asia-Pacific region	Development is concentrated in Japan, China and South Korea, where national skimo teams have been established to participate in ISMF events and qualify for the 2026 Olympic Games. In Japan (Hokkaido), there are specialised clubs and university training programmes. China is actively investing in the development of mountain training centres following the 2022 Winter Olympics. The proportion of international events is gradually increasing (5-10%).
South America	The sport is concentrated in Chile and Argentina, where there are local ski mountaineering clubs and national federation teams that regularly compete in the ISMF Continental Cup (typically 2-5 international events per season). The main centres are in the Andes (Bariloche, La Parva). Training facilities are seasonal and dependent on weather conditions.
The Middle East and Africa	The region is in the early stages of development: participation in ISMF competitions is sporadic or represented by individual athletes without fully-fledged national teams. In the UAE, Turkey and Morocco, the first initiatives for skimo clubs and training programmes based at artificial ski resorts are taking shape. There is no systematic participation in the Olympic qualification cycle.

Source: compiled by the author based on research by the International Ski Mountaineering Federation (2023)

The analysis carried out has shown that the development of ski mountaineering is characterised by regional differences, which are determined by varying levels of infrastructure provision, financial resources, climatic and geographical conditions, and the degree to which this sport is integrated into the national sports policy framework. The main difference between regional trends lies in the stage of development and the functional role of ski mountaineering: ranging from a highly developed and institutionalised sports system in some regions to the initial formation and experimental implementation in others. This indicates the uneven global development of the sport and determines different strategic approaches to its further popularisation, professionalisation and integration into the international Olympic movement.

A systematic approach to training in ski mountaineering

Ski mountaineering is regarded as a holistic system of interrelated components of sporting activity, as success in this discipline is determined not by individual physical attributes, but by the integration of endurance, strength, technique, coordination and the ability to function effectively in the changing mountain environment. Within this system, the training process incorporates complementary methods, such as prolonged steady-state aerobic exercise to build basic endurance, interval mountain climbs to develop the anaerobic threshold, back-to-back training to simulate accumulated fatigue, technical transition exercises to automate transitions between movement phases, as well as training under conditions of limited recovery to prepare for real-world mountain situations (Alpenglow Expeditions, n.d.). Their combination ensures not the isolated development of individual qualities, but the formation of a comprehensive adaptation of the body to prolonged exertion, where each element of training influences the effectiveness of another, creating a unified functional model of the athlete's preparedness for the specific demands of mountain routes.

In ski mountaineering and related mountain endurance sports, quite specific training methods are used, which are directly linked to the actual conditions of moving through the mountains. One of the basic methods is steady-state endurance, where the athlete works in a stable aerobic mode for 60-180 minutes without sudden changes in intensity. This builds "long-distance endurance", which allows the athlete to maintain a consistent pace during ascents lasting several hours. In practice, this might involve a continuous uphill climb with a rucksack or prolonged cyclic exercise (running/cycling) in the moderate heart rate zone, simulating real mountain conditions (Johnston, 2024).

The second most popular method is hill interval training, which involves alternating short bursts of high-intensity effort with recovery phases. The aim is to develop the ability to perform under conditions of a sudden increase in workload, such as when tackling a steep slope or navigating challenging terrain. In practice, this is achieved through a series of 3-6-minute climbs at a high pace with a short rest during the descent or walking (RMI Expeditions, n.d.). This approach raises the anaerobic threshold and improves tolerance to muscle acidification, which is particularly important during competitions or fast climbs. The back-to-back training method is also widely used, which involves two consecutive days of prolonged exertion. It simulates multi-day mountain routes, where fatigue builds up gradually and does not have time to be fully recovered. For example, the first day might involve 3-4 hours of climbing, whilst the second consists of a shorter but technically demanding session. This builds the ability to perform under conditions of chronic fatigue and maintain proper technique even when energy reserves are depleted.

A particular focus is placed on transition training, which aims to automate changes in specialised equipment and movement patterns. It involves repeatedly practising actions involving climbing skins, bindings, skis and a rucksack at the fastest possible pace. For example, an athlete repeatedly goes through the cycle of "removing boots – securing equipment – starting the descent", minimising the transition time. This is critically important in competitive sport, where every second affects the result. Another modern method is fatigue training, where technical or strength

exercises are performed after prolonged exertion (New South Wales Institute of Sport, 2022). This allows for the simulation of situations where the athlete is forced to make decisions and maintain technique whilst already fatigued. Taken together, all these methods develop not only physical fitness but also the ability to function effectively in real mountain conditions, where the workload is unpredictable and multifaceted. Table 3 summarises the structure of training in ski mountaineering as a system of interrelated physical and technical components, including endurance, strength, coordination and transitional skills, aimed at developing the athlete's overall performance in mountain conditions.

Table 3. The structure of athletic training in ski mountaineering as a system comprising physical, speed-strength and technical-coordination components

Training component	Type of exercise	Recommended volume / Frequency	Training methods	Key adaptation	Training objective
Aerobic endurance	Low-moderate intensity (60-80% HRmax)	2-4 times a week, 60-120 mins	Running, cycling, stairs, long climbs	Increasing VO_2max, optimising movement	Building basic endurance for long climbs
Intense climbs	High intensity (85-95% HRmax)	Once a week	Interval climbs, hill running, treadmill uphill	Development of anaerobic threshold and power	Ability to tackle steep sections and maintain a variable pace
Strength training	Strength / functional	Twice a week	Squats, lunges, step-ups, core training	Core stability, lower body strength	Improving running efficiency under load
Speed and strength training	Explosive strength	1-2 times a week	Plyometrics, jumping exercises, short sprints	Development of explosive power	Improving speed at the start and on difficult sections
Eccentric strength (descents)	Strength endurance	1-2 times a week	Controlled descents, step-downs, slow lunges	Resistance to eccentric loads	Control of muscle fatigue during descents
Lifting technique	Coordination and technique	1-3 times a week (during the season)	Moving along the ascent track, working with skis	Economy of movement, rhythm	Automation of climbing technique
Downhill technique	Coordination and strength	1-2 times a week	Descents in various snow conditions	Balance, speed control	Improving safety and efficiency on the slopes
Transition skills	Speed and coordination	2-3 times a week	Switching modes, working with bindings	Speed of transitions	Minimising time loss between movement phases
Long training sessions	General endurance	Once a week	2-5 hours of continuous activity (climbing/descending)	Psychophysical endurance	Simulation of competitive activity
Back-to-back sessions	Accumulated fatigue	1 cycle every 1-2 weeks	Two consecutive days of intense training	Training whilst fatigued	Preparation for multi-day races
Mobility	Recovery	10-15 mins after training	Stretching joints and muscles	Maintaining range of motion	Optimisation of technique and injury prevention
Working with equipment	Specific speed and strength	During training	Skis, boots, bindings, rucksack 3-8 kg	Adapting to extra weight	Stability and efficiency in competitive conditions

Source: compiled by the author based on research by Peak Experience (n.d.), International Ski Mountaineering Federation (2026)

The types of training loads listed above reflect a multi-level training system in ski mountaineering, designed to develop specialised fitness for high-altitude conditions. Aerobic endurance provides the basic capacity for prolonged moderate-intensity work, interval and strength training build resilience to high physical exertion and raise the anaerobic threshold, whilst technical training and transition skills optimise movement efficiency and reduce time lost during competitions. Long training sessions simulate competition conditions, whilst mobility and equipment handling ensure technical consistency and biomechanical efficiency, together forming an integrated system of physical, coordination and technical training for the athlete. Table 4 summarises the comparative characteristics of training for athletes in ski mountaineering and related mountain endurance sports, revealing its comprehensive and multi-component nature, which combines physical, technical and tactical requirements, in contrast to the more narrowly specialised training models in mountain running and cycling.

Table 4. Specific features of training in ski mountaineering compared with mountain endurance sports

Comparison criterion	Ski mountaineering	Mountain running / Trail running	Mountain cycling
Primary physical quality	A combination of aerobic endurance with speed-strength and coordination components	Predominance of aerobic endurance and lower-body muscular endurance	Aerobic endurance with an emphasis on strength endurance of the lower limbs
Biomechanics of movement	Gliding cyclic movement using skis and poles, changing modes of movement (ascent, descent, transitions)	Running movement with constant impact load on the musculoskeletal system	Cyclic pedalling with minimal impact load

Table 4, Continued

Comparison criterion	Ski mountaineering	Mountain running / Trail running	Mountain cycling
Muscle load	Comprehensive engagement of the lower and upper limbs, high levels of coordination	Predominant load on the lower limbs with pronounced eccentric work	Predominant load on the lower limbs (quadriceps, calf muscles)
Technical difficulty	High, related to the use of equipment, changes in movement patterns and locomotion	Moderate, related to running technique on challenging terrain	Moderate, related to cycling in mountainous conditions
Tactical requirements	High, including assessment of snow conditions, route selection and pace	Moderate, related to pacing and effort management	Moderate, related to route selection and pace
Environmental factors	Significant influence of snow conditions, weather and altitude	Influence of terrain, temperature and altitude	Impact of terrain and road surface
Training considerations	Integration of endurance, technique, equipment handling and coordination skills	Focus on developing endurance and running technique	Focus on developing strength endurance and pedalling technique

Source: compiled by the author based on research by V. Menz *et al.* (2021), M. Lasshofer *et al.* (2023)

The results obtained indicate that the training of athletes in ski mountaineering should be structured as an integrated system of training stimuli, in which the development of aerobic endurance is combined with the improvement of technical skills in handling equipment, coordination abilities and speed-strength qualities. A comparative analysis of training systems for athletes in ski mountaineering and related endurance sports has revealed a fundamental difference in the structure of the training process and the logic behind the development of competitive readiness. It was established that ski mountaineering is characterised by an integrated training model, combining aerobic endurance, speed-strength components, coordination skills and equipment handling technique, whereas in mountain running and cycling there is a more unidirectional focus on the development of individual energy systems. This revealed that performance in ski mountaineering is determined not only by the level of endurance, but also by the ability to rapidly change movement patterns and adapt to complex mountainous terrain.

An analysis of the impact of the International Testing Agency's (n.d.) regulatory requirements revealed that the anti-doping system establishes standardised conditions for training and competition, influencing the structure of training loads, medical and biological support, and the monitoring of athletes' recovery. It has been established that compliance with international anti-doping standards not only ensures the integrity of competitions but also indirectly influences training methodologies, increasing the importance of long-term load planning and monitoring of athletes' functional status. Furthermore, a comparative analysis of the role of international federations, in particular the International Ski Mountaineering Federation (2026), revealed that the standardisation of courses, the regulation of elevation changes, technical sections and transition zones, as well as unified judging rules, directly shape the specifics of the training process. It was established that it is precisely these regulatory requirements that determine the structure of competitive activity, influence the design of training programmes and ensure the comparability of results at the international level, making the regulatory system a key factor in the development of the sport.

Discussion

The inclusion of ski mountaineering in the Olympic programme reflects a global trend towards combining sport with active tourism. This is consistent with the findings of N. Batyrbekov *et al.* (2024), in which the authors examined the development of sports tourism in Kazakhstan and emphasised that mountain activities help to promote physical activity among young people. The study highlights that the natural environment and adventure sports are becoming an important tool for fostering a culture of health, which directly aligns with the concept of ski mountaineering. This correlates with M. Cheng *et al.* (2023), where, in particular, the researchers analysed the coordinated development of sport and tourism and identified the factors stimulating economic and social growth in these sectors. New disciplines associated with natural locations have high potential for international promotion and audience engagement, which aligns with R.V. Ciomag & C. Pop (2024), who examined the cultural and sporting characteristics of nations participating in international competitions and demonstrated their impact on results and sporting representation. These findings explain why countries with established mountaineering traditions have better conditions for the successful development of ski mountaineering. The integration of ski mountaineering into the Olympic movement requires an update to approaches to athlete training. This is confirmed by E. Ellmer *et al.* (2024), who described current megatrends in sport and their impact on the process of athlete training and the preparation of coaching staff. The study notes that innovative sports require flexible methodologies, individualisation and interdisciplinary knowledge, which is particularly relevant to ski mountaineering.

Hosting the Olympic Games stimulates the development of infrastructure that can be used to promote ski mountaineering, which is consistent with G. Fossa et al. (2025). The researchers examined the creation of a sports and cultural corridor for the Olympics in Valtellina and demonstrated the importance of combining heritage, spatial planning and sports facilities. Olympic projects can leave a long-term legacy for the training and competitive use of new disciplines. Modern training for ski mountaineering athletes is impossible without digital technologies and effective resource management, as noted in B. Gao *et al.* (2025). The digitalisation of the allocation of sports resources in winter sports has been analysed, and its impact on improving the efficiency of the training process has been demonstrated. These approaches can be applied to training planning, the use of trails, and the monitoring of ski mountaineers' fitness. Training in ski mountaineering

places high demands on the functional state of the cardiovascular system and the ability to recover. This was confirmed by J.S. Gąsior *et al.* (2024), who investigated heart rate dynamics and the asymmetry of regulatory processes in ski mountaineers during stimulation of sympathetic activity and recovery. The results demonstrated the importance of monitoring the body's autonomic responses to optimise training loads and prevent overexertion. This is consistent with the findings of Y. Jiang *et al.* (2023), who established that observing major events on social media strengthens the intentions of the younger generation to participate in sports tourism. This pattern suggests that the Olympic debut of ski mountaineering could become a powerful factor in attracting young people to the sport.

The role of dopamine, as well as genetic and epigenetic factors, in the development of personality and sporting performance has been analysed, in line with L. Li (2023). The challenges and avenues for the development of ecosports tourism in the post-pandemic period have been examined, and attention has been drawn to the need for the balanced use of natural resources. This approach is particularly important for ski mountaineering, as its competitions and training depend directly on the state of the mountain environment. This is consistent with the provisions set out in the work of R. Melo *et al.* (2023), where nature-oriented sports are viewed as combining physical activity and interaction with the natural environment. Training for ski mountaineering athletes is characterised by a high reliance on the development of aerobic endurance, speed-strength qualities, and the ability to recover quickly after prolonged ascents and descents. These observations are consistent with the findings of E. Tønnessen *et al.* (2024), who described a model of training sessions in endurance sports as being based on alternating loads of varying intensity and a significant proportion of specific training on terrain similar to that of competition.

The technical complexity of ski mountaineering requires constant refinement of skills in traversing slopes of varying gradients, rapid transitions between modes of movement, and the use of specialised equipment. These findings align with the historical analysis by I. Lidström (2025), in which the evolution of skiing in Sweden was viewed as a process of continuous technological adaptation of equipment and movement techniques to natural conditions. This allows ski mountaineering to be interpreted as a continuation of a long-standing line of development in skiing disciplines, in which technical progress is closely linked to the functional needs of athletes. These observations are consistent with the findings of G. Si *et al.* (2025), where an analysis of the psychological support provided to Olympic teams shows that anxiety regulation, concentration and resilience to psycho-emotional stress play an important role in athletes' performance. The development of ski mountaineering as a discipline is closely linked to the infrastructure of mountain regions. The data obtained are consistent with the views of R. Leber (2024), who describes winter sports tourism as a sector that combines economic and environmental aspects of regional development. This allows ski mountaineering to be interpreted not only as a sporting discipline, but also as a factor in shaping tourist flows and the development of mountain regions.

Digitalisation and technological innovation are beginning to influence the training process for athletes in endurance sports. In particular, the use of artificial intelligence models to analyse training loads and recovery is described in the work by Z. Miao & G. Ge (2023), which notes a trend towards the introduction of digital systems for monitoring athletes' physiological condition into the training process for ski mountaineering. This view is supported by L. Nima (2023), who considers social groups and sporting communities as factors influencing motivation and the regularity of the training process. In the case of ski mountaineering, group interaction during training in mountainous conditions fosters trust and mutual support among athletes. associated with challenging terrain and high-intensity exertion. In their work, C. Rotllan & G. Viscor (2023) noted that among elite female athletes in winter sports, there is an elevated incidence of lower limb injuries and overuse injuries. The technical specifics of the discipline create similar risk mechanisms. A separate section of the analysis concerns trends in the development of sport in the digital age. In their work, L. Zhipeng *et al.* (2025) demonstrated that sports tourism and sporting disciplines are increasingly being studied through the lens of digital data and international comparisons. There is a growing interest in the use of digital platforms for training planning and route analysis in ski mountaineering. In the study by L. Zhouxiang (2024), it was highlighted that VR (Virtual Reality) technologies are used to simulate sporting situations and practise tactical decisions. The results show that such approaches can be applied to the training of ski mountaineers, particularly for practising reactions in challenging weather conditions and on hazardous sections of the route. Thus, the current development of ski mountaineering is characterised by the active integration of digital technologies into the training process, which enhances the effectiveness of load management, recovery and tactical simulation.

Conclusions

Ski mountaineering has undergone a multi-stage evolution from a utilitarian means of transport in mountainous terrain to a modern Olympic sport that combines mountaineering techniques, skiing and high demands on physical endurance. Its development has spanned stages ranging from the military and practical use of skis in the 19th and 20th centuries to the emergence of informal competitions, institutionalisation through international federations, and the standardisation of rules within the ISMF. Its inclusion in the programme of the 2026 Winter Olympic Games marked the sport's legitimisation, accompanied by technological advancements in equipment, increased professionalisation and more complex competition formats. Ski mountaineering is a highly dynamic sport that integrates the traditions of mountain culture, modern innovations and the requirements of the international Olympic movement.

The development of ski mountaineering is characterised by a rapid rise in popularity, a shift towards short and highly dynamic competition formats, an increase in the intensity of physical exertion, and the active technological advancement of sports equipment.

The inclusion of the sport in the Olympic programme, a reduction in the duration of competition formats by

90-95%, an increase in the intensity of exertion by 25-35% and a reduction in the weight of equipment by 20-30% reflect its transformation into a high-speed, media-oriented discipline that combines sporting performance and technological innovation. Ski mountaineering is viewed as a holistic training system, where results are determined by the interplay of an athlete's endurance, strength, coordination and technical skill in a mountain environment. The training process includes aerobic workouts to develop basic endurance, interval climbs to raise the anaerobic threshold, strength exercises for movement stability, as well as technical and transitional elements to optimise speed of action. In addition, long training days and back-to-back sessions are used to simulate fatigue. The combination of these methods ensures comprehensive adaptation of the body, building the ability to perform physical work effectively in challenging and unpredictable mountain conditions, whilst maintaining the athlete's technical precision and performance capacity.

Ski mountaineering shares common features with other endurance sports in the mountains, such as trail running, mountain running and cycling, notably the predominance of aerobic endurance and the need to perform effectively in conditions of hypoxia and challenging terrain. At the same time, its specificity lies in the combination of cyclic movements using ski equipment, which alters the biomechanics of movement, as well as in the high demands on technical and traversing skills, decision-making in a changing mountain environment, and the coordination of upper and lower limb movements. This results in a more comprehensive and multi-level nature of training compared to other endurance sports. The limitation of the study lies in its focus solely on the theoretical analysis of international sources without the inclusion of primary empirical data or experimental testing of athletes. Prospects for further research lie in studying the impact of digital monitoring technologies (GPS tracking, biometric sensors and load analysis systems) on the effectiveness of training and competitive performance in ski mountaineering.

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Лижний альпінізм як новий вид олімпійської програми: тенденції розвитку та особливості підготовки спортсменів

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Анотація. Метою дослідження було виявлення характерних рис організації підготовки спортсменів у лижному альпінізмі на основі тенденцій його розвитку в контексті набуття олімпійського статусу. Методологія дослідження базувалася на використанні історико-логічного, аналітико-синтетичного, структурно-функціонального та узагальнювально-порівняльного методів, що забезпечили комплексний аналіз еволюції лижного альпінізму, сучасних тенденцій його розвитку та специфіки підготовки спортсменів у гірських умовах. Було досліджено, що лижний альпінізм еволюціонував від прикладного способу пересування в гірських умовах до структурованого міжнародного виду спорту, що поєднує альпіністські техніки, лижну підготовку та високі вимоги до фізичної витривалості. Його інституціоналізація через міжнародні федерації, стандартизацію змагань і включення до олімпійської програми відображає перехід до сучасної високотехнологічної дисципліни, інтегрованої в систему світового спорту. Було виокремлено, що сучасний розвиток лижного альпінізму характеризується швидким зростанням популярності, переходом до коротких високодинамічних форматів змагань і суттєвим підвищенням інтенсивності фізичних навантажень. Одночасно відбувається технологізація спорядження та інтенсифікація тренувального процесу, що разом із включенням до олімпійської програми визначає трансформацію виду спорту в медійно привабливу та високоспеціалізовану дисципліну. Його включення до олімпійської програми та скорочення тривалості змагальних форматів на 90-95 % відображають трансформацію у високошвидкісну та технологічно орієнтовану дисципліну з акцентом на медійність і ефективність. Було виявлено, що у системі підготовки поєднуються витривалість, сила, координація та технічні навички, що забезпечує комплексну адаптацію спортсменів до складних гірських умов і змінного навантаження. Практичне значення роботи полягає у можливості використання отриманих результатів для удосконалення системи тренувальної підготовки спортсменів у лижному альпінізмі та інших гірських видах циклічної витривалості для підвищення їхньої фізичної працездатності, технічної ефективності та адаптації до складних умов середовища

Ключові слова: аеробна витривалість; гірські умови; біомеханіка руху; фізіологічні навантаження; тренувальна підготовка