

# Mental conditioning and pulse oximetry monitoring in short-term training of alpine skiers aged 13–16 years

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Authors’ Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

## Abstract

**Background and Study Aim** Mental conditioning is an important part of modern athletic preparation. It helps regulate arousal, focus, and performance stability. This study examined the psychophysiological effects of a short mental training routine that combined relaxation and sport-specific imagery in junior alpine skiers.

**Material and Methods** Fourteen athletes (7 from CSS Gheorgheni; 7 from CSS Baia Sprie) took part in a pre–post observational protocol. The Gheorgheni group performed imagery on a ski simulator. The Baia Sprie group followed the same routine without simulator support. Pulse oximetry (CMS-50F) was used to measure pulse rate (PR, bpm) and oxygen saturation (SpO<sub>2</sub>, %) at rest, after relaxation, and during imagery. All recordings were taken under standardized seated conditions to ensure measurement consistency. Repeated-measures ANOVA and non-parametric equivalents (Friedman test, Wilcoxon test) were applied to evaluate within-group changes. Between-group comparisons used t-tests or Mann–Whitney U tests, with significance set at  $p < 0.05$ .

**Results** Descriptive analysis showed that PR consistently decreased after relaxation and increased during imagery. SpO<sub>2</sub> remained within normal limits (96–98%). The simulator group showed a greater increase in PR (+18.5 bpm) compared to the control group (+11.2 bpm). This indicates clear autonomic modulation: parasympathetic activation during relaxation and sympathetic activation during imagery. These trends were consistent across all participants. Statistical tests confirmed significant phase effects for PR ( $p < 0.001$ ), with large effect sizes observed within both groups.

**Conclusions** Mental rehearsal produced measurable physiological changes without physical activity. This suggests its role in enhancing athletes’ internal regulation. While limited by the small sample, the study supports further research using larger groups and more advanced autonomic measures, such as heart rate variability, to refine mental training protocols in alpine skiing.

**Keywords:** mental training, alpine skiing, imagery; relaxation, psychophysiology, pulse oximetry, heart rate, oxygen saturation, biofeedback, performance readiness

## Introduction

Alpine skiing places unique demands on athletes, requiring precise coordination, rapid decision-making, and continuous adaptation to environmental conditions. This sport involves high-speed movement, unpredictable terrain, and complex technical execution under physical and psychological stress. Maintaining consistent performance in such a setting depends not only on

physical preparation but also on the athlete’s ability to regulate focus, emotional state, and readiness during competition.

Alpine skiing places unique demands on athletes, requiring precise coordination, rapid decision-making, and continuous adaptation to changing terrain and weather. This high-intensity winter sport combines speed, technical execution, and psychological control under pressure. The complex interaction of physical strain and cognitive load makes skiing especially sensitive to fluctuations in attention, emotional stability, and readiness. Fatigue, fear of mistakes, and unpredictable course

conditions can impair focus and increase the risk of performance errors or injury. As a result, optimal performance in alpine skiing depends not only on physical preparation but also on mental regulation and psychological conditioning [1, 2, 3].

Mental conditioning, also referred to as mental training, is a structured process through which athletes learn to regulate arousal, focus, and emotional stability. These skills enhance their ability to perform under pressure [4, 5]. Mental training includes a variety of cognitive-behavioral techniques such as goal setting, imagery, relaxation, self-talk, and mindfulness [6]. Numerous studies have shown that these strategies improve attention, confidence, and resilience during competition [7]. For example, Thelwell and Greenlees [3] demonstrated that mental skills training helps endurance athletes maintain consistent performance by enhancing focus and reducing perceived fatigue. Similarly, mindfulness-based interventions have been linked to better emotional regulation, sleep quality, and psychophysiological recovery in elite athletes [8].

In recent years, researchers have increasingly emphasized the integration of mental training into regular technical and tactical preparation routines [9, 10]. Psychological skills training is now considered essential by coaches and sport psychologists for enhancing both mental and physiological performance. It contributes to improved motor learning, motivation, and adaptability [11].

In alpine skiing, mental training plays a particularly important role due to the sport's reliance on anticipation, rhythm, and trajectory planning. Visualization and imagery techniques help skiers mentally rehearse course segments, including gate sequences, pitch transitions, and turning points. This mental rehearsal improves timing, reaction accuracy, and movement economy [12, 13]. According to Joksimovic and Joksimovic [7], imagery in skiing involves a deliberate and structured repetition of mental routines simulating the full course, which promotes more efficient motor programming.

Experimental studies have shown that systematic mental training, especially when combined with neurolinguistic programming (NLP) and relaxation techniques, can improve concentration, confidence, and emotional stability in junior athletes [14, 15, 16]. Grosu and colleagues [14, 16] reported that specific NLP-based routines reduce anxiety and improve attentional control in ski performance. These results are consistent with newer findings indicating that mental rehearsal, when paired with biofeedback, enhances self-awareness and reduces performance variability [17, 18].

The connection between cognitive processes and physiological activation has received growing attention in recent years. During imagery and other mental tasks, the central nervous system

reproduces activation patterns similar to those seen during real movement. These processes affect cardiovascular, respiratory, and muscular functions [19, 20]. Functional neuroimaging studies show that motor imagery activates premotor and parietal brain regions involved in movement planning and control [21]. This neural similarity helps explain why mental rehearsal causes measurable changes in heart rate, breathing patterns, and skin conductance, even when no physical movement occurs [22].

Such physiological changes can be tracked with simple, non-invasive instruments and offer useful feedback for athletes and coaches. Pulse oximetry, for example, measures pulse rate (PR) and oxygen saturation (SpO<sub>2</sub>), both of which reflect autonomic nervous system activity [23]. Changes in these values indicate shifts between parasympathetic and sympathetic dominance and can act as indirect markers of arousal or relaxation during mental routines [24, 25]. In sports such as alpine skiing, which involve brief, high-intensity efforts lasting 80 to 150 seconds [26], these indicators are especially relevant. Understanding how mental training affects such physiological responses can improve strategies for managing performance readiness and recovery.

The combination of mental training and physiological monitoring offers a promising direction in applied sport science. Previous studies have used biofeedback tools, such as heart rate variability monitors and oximeters, to improve athletes' awareness of internal states [21]. These tools allow real-time visualization of physiological changes and support the development of self-regulation and concentration skills [27]. In alpine skiing, such integration is helpful for managing transitions between relaxation and activation during pre-competition routines. New wearable devices now make it possible to measure psychophysiological responses during or immediately after mental tasks. This enables more accurate tracking of autonomic changes [28, 22].

These developments point to a shift toward individualized, data-based mental preparation. Combining subjective perception with objective physiological data may improve performance control [29]. However, despite the wide use of mental techniques such as imagery and relaxation in skiing, few studies combine these methods with physiological feedback. The use of wearable pulse oximeters to track autonomic responses during mental routines remains underexplored. In addition, little research has compared traditional imagery with embodied formats, such as simulator-assisted rehearsal. This limits current understanding of how mental preparation connects with physiological regulation in winter sports.

Analysis of research findings has shown that

mental training improves cognitive control, emotional stability, and psychophysiological readiness in high-performance sports. Authors emphasize that combining psychological strategies with physiological monitoring strengthens the connection between perceived effort and measurable internal responses. At the same time, several aspects of this interaction, including the role of sensor-based feedback and the influence of physical embodiment during mental rehearsal, remain insufficiently addressed in applied contexts. This limitation continues to affect the development of integrated approaches for preparing athletes in sports that require both technical precision and rapid adaptation, such as alpine skiing.

The aim of the present study was to assess the psychophysiological effects of a short mental training protocol that combined relaxation and sport-specific imagery in junior alpine skiers.

The following hypotheses were proposed: (1) Pulse rate (PR) would decrease after relaxation, indicating parasympathetic activation.

(2) PR would increase during imagery, reflecting sympathetic engagement and performance-oriented arousal.

(3) Oxygen saturation ( $SpO_2$ ) would remain within normal physiological limits (95–99%) and show minor fluctuations inversely related to PR.

## Materials and Methods

### *Participants*

Fourteen junior alpine skiers participated in the study, with equal representation from two training clubs: CSS Gheorgheni ( $n = 7$ ) and CSS Baia Sprie ( $n = 7$ ). Inclusion criteria included membership in a competitive junior ski team, valid medical clearance for training and testing, and absence of acute illness or injury within the previous four weeks. Exclusion criteria were a history of cardiopulmonary disease, current respiratory infection, or altitude exposure above 1500 meters within 72 hours before testing.

The final sample consisted of 8 males and 6 females, aged 13 to 16 years (mean age:  $14.5 \pm 0.9$  years). All athletes had 3 to 6 years of competitive experience in alpine skiing. Baseline physiological parameters, pulse rate (PR) and oxygen saturation ( $SpO_2$ ), were within normal limits. No significant differences were observed between groups at the pretest stage.

Parental or guardian consent was obtained for all participants. The study followed the principles of the Declaration of Helsinki and was approved by the institutional ethics committee (protocol code 2025-ALP-MT-01, approval date: 18 February 2025).

### *Research Design*

A two-group repeated-measures design was used. Three standardized phases were

conducted on the same day in a fixed sequence: (1) Resting baseline (seated, quiet, 5 minutes) (2) Guided relaxation (grounding and respiratory focus, 8 to 10 minutes) (3) Performance-oriented imagery of a 54-gate descent (8 to 10 minutes)

Both groups followed the same mental routine. The Gheorgheni group performed imagery using a ski simulator (embodied support), while the Baia Sprie group completed imagery without the simulator (control condition).

Each phase was followed by pulse oximetry measurement. The sport context involved a short-duration, high-intensity task typical of junior giant slalom runs, lasting approximately 80 to 150 seconds. All recordings were taken at rest to isolate the psychophysiological effects of the mental routine, and not during physical effort.

The order of phases was fixed to preserve ecological validity, starting with relaxation and ending with imagery. Potential order effects were acknowledged. Within-subject contrasts and descriptive effect sizes were therefore included in the analysis.

All sessions took place in a quiet room at the athletes' training facilities, scheduled at consistent times of day ( $\pm 1$  hour). Participants refrained from consuming caffeine or engaging in vigorous exercise for at least three hours before testing. After a 10-minute seated acclimatization period, the following sequence was conducted:

- Baseline (REST): 5 minutes of seated rest.
- RELAX: 8 to 10 minutes of guided grounding involving breath pacing and body scanning. The audio script was adapted from a published protocol [28].
- IMAGERY: 8 to 10 minutes of guided, sport-specific imagery of a 54-gate descent. The task included first-person perspective, speed modulation, trajectory planning, cueing for hip, knee, and ankle coordination, gate timing, and edge transitions.

The Gheorgheni group completed the imagery phase on a ski simulator using the Dry Skiing Tech framework [29, 30] to simulate trajectory and pressure changes. The Baia Sprie group performed the same imagery task in a seated position. Coaches supervised each session to ensure adherence. No physical activity was performed during data collection.

All participants completed the full mental training sequence. Adherence was confirmed through session checklists signed by supervising coaches. There were no dropouts or protocol deviations during the intervention.

### *Outcomes and Equipment*

The primary outcome was pulse rate (PR, beats per minute), measured using a wrist-worn pulse oximeter (CMS-50F, Contec Medical Systems, Qinhuangdao, China). The secondary outcome

was arterial oxygen saturation (SpO<sub>2</sub>, percentage), measured with the same device.

*Acquisition*

After each phase (REST, RELAX, IMAGERY), PR and SpO<sub>2</sub> were recorded for 60 seconds. During measurement, the athlete remained seated with the hand supported at heart level, avoiding movement or speech. The mean value over the 60-second window was used for analysis. All sessions took place at near sea level. Device fit was verified according to the manufacturer’s instructions.

*Statistical Analysis*

All analyses were conducted using IBM SPSS, version 25. Data were screened for outliers and tested for normality using the Shapiro–Wilk test. For within-group comparisons across the three experimental phases (REST, RELAX, IMAGERY), a one-way repeated-measures ANOVA was performed separately for pulse rate (PR) and oxygen saturation (SpO<sub>2</sub>). For the control group, only RELAX and IMAGERY phases were compared using a two-level within-subject factor.

Sphericity was assessed using Mauchly’s test. When violated, the Greenhouse–Geisser correction was applied. Partial eta squared ( $\eta^2$ ) was reported as a measure of effect size. Pairwise comparisons were adjusted using the Bonferroni correction.

To account for the small sample size (n = 7 per group), non-parametric alternatives were also computed. These included the Friedman test with Wilcoxon post hoc comparisons and r as the effect size. Between-group comparisons within each phase were conducted using either independent samples t-tests or the Mann–Whitney U test, depending on distribution. The significance level was set at 0.05 (two-tailed). Where applicable, 95 percent confidence intervals were reported.

**Results**

All fourteen junior alpine skiers completed the full assessment protocol (Control group: Baia Sprie, n = 7; Experimental group: Gheorgheni, n = 7). Descriptive statistics for pulse rate (PR) and arterial oxygen saturation (SpO<sub>2</sub>) are presented in Tables 1 and 2.

**Table 1.** Pulse rate (PR) and oxygen saturation (SpO<sub>2</sub>) in the control group (Baia Sprie, n = 7)

Phase	PR (bpm), Mean ± SD	SpO <sub>2</sub> (%), Mean ± SD
Relaxation	60.1 ± 3.4	97.9 ± 0.3
Imagery	71.3 ± 4.0	97.4 ± 0.3

Note: The increase in PR from relaxation to imagery was statistically significant (F(1,6) = 22.84, p < 0.001, partial eta squared = 0.79). No significant change was observed in SpO<sub>2</sub> (p > 0.05).

**Table 2.** Pulse rate (PR) and oxygen saturation (SpO<sub>2</sub>) in the experimental group (Gheorgheni, n = 7)

Phase	PR (bpm), Mean ± SD	SpO <sub>2</sub> (%), Mean ± SD
Rest	64.6 ± 4.8	97.4 ± 0.6
Relaxation	58.1 ± 4.3	97.8 ± 0.5
Imagery	76.6 ± 4.9	96.8 ± 0.5

Note: Pulse rate decreased significantly during relaxation and increased sharply during imagery (F(2,12) = 34.72, p < 0.001,  $\eta^2$  = 0.85). No significant changes were observed in SpO<sub>2</sub> (p > 0.05).

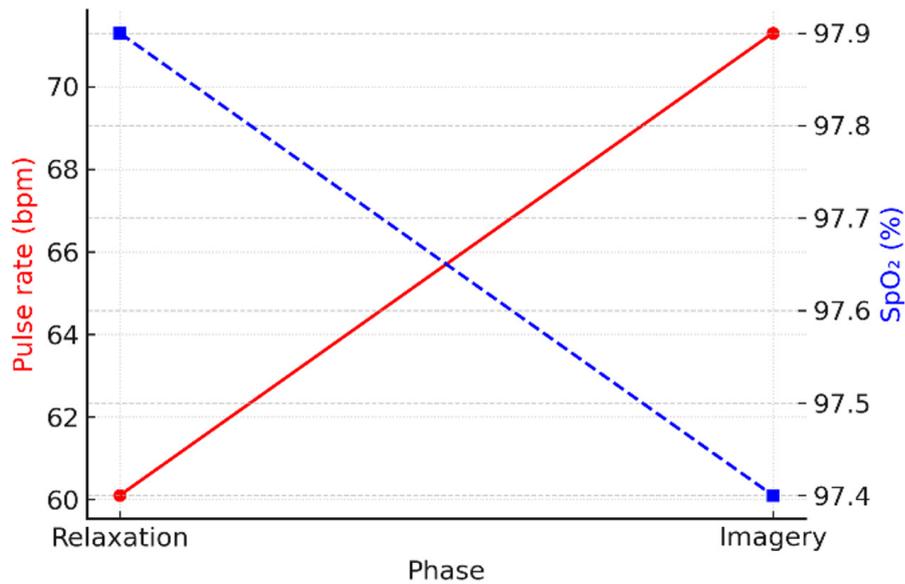
In the control group (Baia Sprie, imagery without simulator), the mean pulse rate after relaxation was 60.1 ± 3.4 beats per minute. During performance-oriented imagery, this value increased to 71.3 ± 4.0 beats per minute. The change represented an average increase of 11.2 beats per minute, corresponding to an 18.6 percent rise from the relaxation to the imagery phase. Oxygen saturation remained within normal physiological limits, with a small decrease from 97.9 ± 0.3 percent to 97.4 ± 0.3 percent (change = -0.5 percentage points). Both trends were consistent across all seven participants, suggesting a stable psychophysiological response during the imagery phase.

The imagery phase elicited a significant PR increase [F(1,6) = 22.84, p < 0.001,  $\eta^2$  = 0.79] and a minimal, non-significant decrease in SpO<sub>2</sub> (p > 0.05), as shown in Figure 1.

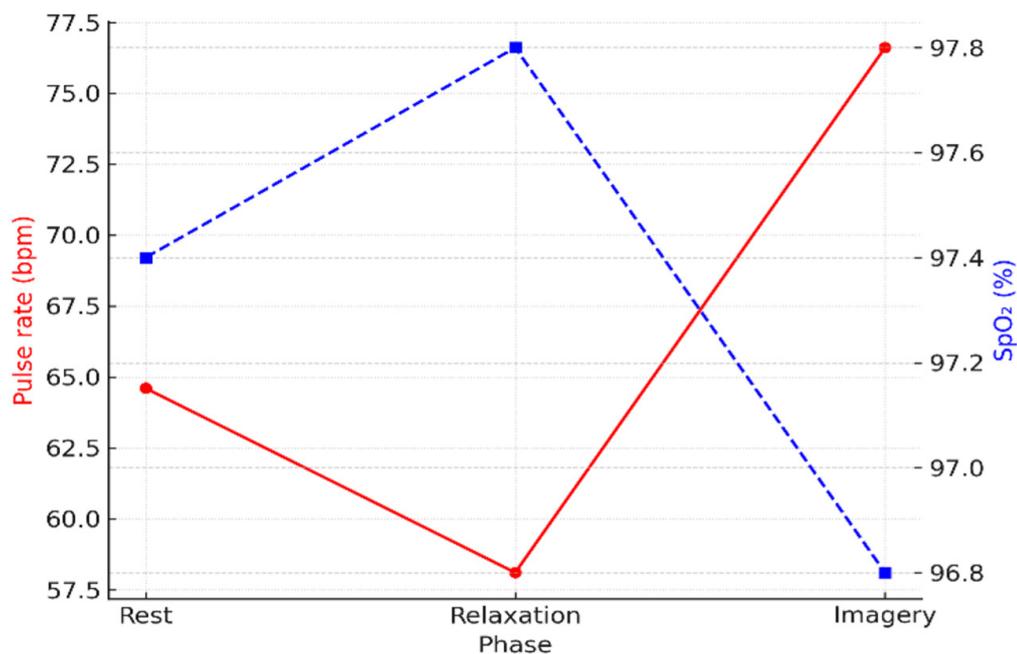
In the experimental group (Gheorgheni, imagery with simulator), pulse rate was measured across three standardized phases: resting baseline, relaxation, and imagery. At rest, the mean pulse rate was 64.6 ± 4.8 beats per minute. After relaxation, it decreased to 58.1 ± 4.3 beats per minute. This represents a reduction of 6.5 beats per minute, or 10.1 percent. During the imagery phase, pulse rate rose to 76.6 ± 4.9 beats per minute. This increase of 18.5 beats per minute from the relaxation phase corresponds to a 31.8 percent change.

Oxygen saturation showed minor, non-clinically relevant fluctuations. The values were 97.4 ± 0.6 percent at rest, 97.8 ± 0.5 percent after relaxation, and 96.8 ± 0.5 percent during imagery. From relaxation to imagery, the average decrease was 1.0 percentage point. This within-subject pattern, characterized by a decrease in pulse rate during relaxation, an increase during imagery, and a small reduction in oxygen saturation, was observed consistently in all seven athletes (Table 2; Figure 2).

PR decreased during relaxation and increased sharply during imagery, while SpO<sub>2</sub> remained within normal physiological limits, as shown in Figure 2. This response pattern was observed consistently across participants and reflects the transition from parasympathetic recovery to task-related



**Figure 1.** Mean pulse rate (PR, bpm) and oxygen saturation (SpO<sub>2</sub>, %) across the two phases (Relaxation, Imagery) in the Baia Sprie control group (n = 7)



**Figure 2.** Mean pulse rate (PR, bpm, red line) and oxygen saturation (SpO<sub>2</sub>, %, blue line) across the three phases (Rest, Relaxation, Imagery) in the Gheorgheni experimental group (n = 7).

sympathetic activation, with minimal respiratory fluctuation.

*Pattern consistency and group contrast*

Both groups demonstrated the expected psychophysiological pattern. The relaxation phase was associated with a reduction in pulse rate, while performance-oriented imagery led to an increase. Throughout all phases, oxygen saturation remained within the typical resting range (approximately 96 to 98 percent). The magnitude of the pulse rate increase from relaxation to imagery was greater in the simulator-assisted group. Specifically, the experimental group showed a rise of 18.5 beats

per minute, compared to 11.2 beats per minute in the control group. This difference suggests that simulator-based imagery may enhance embodiment and task engagement more effectively than imagery without simulator support.

*Analytic note*

Due to the small sample size and pilot design of the study, all findings are interpreted as descriptive and exploratory. Nevertheless, the direction and consistency of effects across all participants align with established physiological responses: a parasympathetic shift during relaxation and sympathetic activation during imagery. These

preliminary findings provide a rationale for future studies with larger samples and confirmatory designs.

## Discussion

This pilot study examined the short-term psychophysiological effects of a mental training protocol that combined relaxation and sport-specific imagery in junior alpine skiers. The main findings indicate that relaxation was associated with a decrease in pulse rate, while imagery led to a pronounced increase. These changes reflect modulation of autonomic activation. Oxygen saturation remained within normal physiological limits and showed only minor fluctuations, which were inversely related to pulse rate. The pattern was consistent across participants, with a greater magnitude of change observed in the group using a ski simulator during imagery.

These results support the hypothesis that mental routines can influence physiological activation, even in the absence of physical effort. The present study extends earlier work by Grosu et al. [14, 16] by introducing a dual-condition design (imagery with and without simulator use) and incorporating physiological markers of autonomic activity. In contrast to previous studies that focused mainly on cognitive-behavioral strategies or neuro-linguistic programming, the current protocol included objective physiological feedback. This integration reflects a shift toward embodied cognitive training in sport.

The opposite trends in pulse rate and oxygen saturation observed during relaxation and imagery reflect coordinated modulation of the autonomic nervous system. A decrease in pulse rate after relaxation is typically associated with parasympathetic dominance and reduced psychophysiological arousal. In contrast, the increase in pulse rate during motor imagery corresponds to sympathetic activation and anticipatory effort preparation. These physiological changes are well-documented indicators of mental engagement in athletes. Mental imagery frequently induces cardiovascular and respiratory adjustments that resemble those produced by actual movement. The slight decline in oxygen saturation during imagery may reflect an increased metabolic demand or subtle respiratory changes linked to focused concentration, rather than a true physiological desaturation.

Pulse oximetry offers a simple and non-invasive method for tracking autonomic activation, but its sensitivity to specific branches of the autonomic system is limited. Future studies should include additional physiological markers, such as heart rate variability, which more accurately reflect parasympathetic modulation. Prior research in endurance sports has established heart rate

variability as a reliable measure of mental workload, recovery, and autonomic balance. Applying such multimodal monitoring in alpine skiing could enhance the interpretation of psychophysiological responses to mental training. Comparative validation using heart rate variability or electrodermal activity would further clarify the reliability of pulse rate and oxygen saturation as surrogate indicators of internal state regulation.

The findings are consistent with previous studies showing that imagery-based interventions enhance motor readiness, confidence, and psychophysiological synchronization between central and peripheral systems [17, 18, 19, 21, 22, 28]. This body of research demonstrates that vivid imagery can induce measurable autonomic changes and promote perceptual-motor coupling, contributing to improved performance. The greater physiological response observed in the simulator-assisted group suggests that additional proprioceptive and visual constraints may strengthen sensorimotor integration. This interpretation aligns with effect-oriented models of action control and neural efficiency in trained athletes [21, 22, 27, 28, 29].

These findings describe how short mental routines can influence autonomic activity in sport-specific settings. The consistent physiological responses observed in both groups suggest that structured imagery and relaxation exercises affect internal regulation without physical effort. This supports the relevance of including both cognitive and sensorimotor components when examining psychophysiological responses in preparation for performance.

### *Limitations and Future Directions*

Although the present findings offer preliminary insights, several methodological limitations should be considered. The study involved a small sample of junior skiers, which limits statistical power and restricts the generalizability of the results to other competitive levels or age groups. The short-term design, based on single-session measurements, did not allow for evaluation of long-term adaptations or retention effects. In addition, only pulse rate and oxygen saturation were assessed. Including other autonomic indicators, such as heart rate variability, electrodermal activity, or respiratory rate, would provide a more complete profile of psychophysiological regulation.

Future studies should recruit larger and more diverse samples, ensure balanced gender representation, and conduct repeated assessments across multiple training sessions. Combining physiological monitoring with psychological variables such as perceived exertion, mental workload, and attentional focus may help clarify the mechanisms linking mental rehearsal with

autonomic control and performance outcomes [30, 31, 32]. The use of wearable biofeedback devices and immersive simulation technologies may further increase ecological validity and support individualized development of mental conditioning protocols in alpine skiing and other high-demand sports.

### Practical Applications

The results of this study emphasize the practical value of combining mental conditioning with simple physiological monitoring in regular ski training. Short sessions incorporating relaxation and imagery can assist athletes in regulating arousal, maintaining attentional control, and improving self-awareness before competition. Wearable devices such as pulse oximeters offer coaches and sport psychologists objective, non-invasive measures of physiological activation (pulse rate, oxygen saturation) that complement subjective indicators of readiness or anxiety.

For coaching practice, guided relaxation and sport-specific imagery can be integrated into warm-up or recovery protocols to improve athletes' ability to transition between recovery and activation states. These routines are easily adaptable to different phases of technical preparation, such as visualizing gate sequences, timing turns, or simulating descent rhythm. In addition, feedback from physiological sensors may facilitate individualized monitoring of training load, allowing for more precise adjustments in both physical and psychological preparation [33, 34, 35].

Overall, this approach supports the implementation of biofeedback-informed mental training as a practical and cost-effective strategy to optimize focus, stress regulation, and performance consistency in alpine skiing and other technically demanding, high-intensity sports.

### Conclusions

The findings of this pilot study demonstrate that short sessions of mental training can elicit measurable psychophysiological responses in junior alpine skiers. The relaxation phase was associated

with a decrease in pulse rate, while the subsequent imagery phase produced a marked increase in cardiac activation. Oxygen saturation remained stable within normal physiological limits throughout the procedure. These results indicate that mental rehearsal modulates autonomic regulation even in the absence of physical effort.

Although exploratory in nature, the present findings suggest that combining relaxation-imagery sequences with pulse oximetry monitoring may offer a useful form of biofeedback to support focus, readiness, and emotional regulation in young athletes. The enhanced response observed in the simulator-assisted group supports the use of embodied imagery tools in alpine skiing as a means of reinforcing task realism and sensorimotor integration.

This pilot study contributes preliminary but consistent evidence that mental conditioning is a viable strategy for improving psychophysiological control and performance stability in alpine skiing. By integrating psychological training with physiological feedback, the approach supports a more holistic model of athlete development.

Unlike previous research focused exclusively on cognitive routines, this study introduces a combined mental and sensory training paradigm that incorporates wearable oximetry and ski simulation. This model represents a scalable and practical framework for embodied self-regulation training in youth alpine skiing.

### Acknowledgement

The authors thank Mr. Vlad Teodor Grosu for his collaboration. The present study forms part of the doctoral research conducted by the first author. The applications of mental training in sports span multiple domains. The integration of sports science (in this case, alpine skiing), psychology, statistics, and sensor-based technology contributes to the development of objective and interdisciplinary research.

### Conflict of Interest

The authors declare no conflict of interest.

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Cite this article as:

Grosu VT, Mancini N, Rozsnyai RA, Neagu SG, Monea D, Grosu EF, Dobrescu T, Hervás-Gómez C, Popovici C. Mental conditioning and pulse oximetry monitoring in short-term training of alpine skiers aged 13–16 years. *Pedagogy of Physical Culture and Sports*, 2025;29(6):565–573. <https://doi.org/10.15561/26649837.2025.0607>

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Received: 16.10.2025

Accepted: 30.11.2025; Published: 30.12.2025