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Regular Exercise and Functional Adaptation Strategies to Improve Physical Readiness and Performance of High-Risk Mountain Climbers

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Abstract
The increasing interest of the population in mountaineering does not always go hand in hand with sufficient physical preparation. This situation is influenced by a lack of continuity in training before the ascent as well as limited knowledge. The aim of this study is to identify differences in the fitness levels of climbers based on their physical activity before the ascent, to analyze adaptation strategies in risk groups, and to establish basic guidelines for pre-ascent training. The study uses a descriptive-comparative quantitative approach with climber participants selected through purposive sampling. Data were collected using fitness questionnaires and interviews. The results show that regular aerobic exercise 3-4 times per week plays an important role in improving climbers' physical fitness and safety. Mountaineers with physical disabilities can still safely climb mountains through adaptive strategies and risk management.

Keywords: endurance; physical readiness; pre-hike physical activity; risk management

1. Introduction

Sport has become an integral part of social life, and one activity that is now increasingly popular is mountain climbing (Aditia et al. 2022). Public interest in mountain climbing has grown rapidly in recent years. This activity is no longer merely a form of entertainment, but is viewed as a means of personal development and the improvement of physical and mental health (Abidin, Yunus, and Christine 2024; Romdhoni 2022). Social media has played a role in accelerating this trend, particularly among teenagers, in line with a 27% increase in visits to nature tourism sites according to the latest data (Cahaya D. Silitonga et al. 2024; Tediantoro and Abrori 2025).

However, the rise in the number of hikers has been accompanied by an increase in accidents, largely due to inadequate physical preparation, fatigue, and a lack of technical knowledge (Nurajab 2019; Rahmi and Djunaidi 2021). Nevertheless, certain groups with physical limitations, such as the elderly, obese individuals, or those with disabilities, have been shown to be capable of climbing safely when supported by systematic training and adaptive interventions that enhance functional ability and self-confidence (Collins et al. 2018; Passi et al. 2025). These findings confirm that physical preparation, encompassing cardiovascular endurance, muscle strength, flexibility, and mental readiness, is a key factor in reducing the risk of injury and increasing the likelihood of successfully reaching the summit (Permatasari and Sidarta 2021; Sukarmin 1995).

Mountaineering is any activity involving long-distance walking up and down hills in the wilderness, and this activity demands significant exertion of the cardiovascular system, muscle strength,

flexibility, and mental stability (Sahri et al. 2024). These physical factors not only determine performance but also influence risk perception and the adaptation strategies employed by mountaineers. Therefore, understanding how these physical variables operate, particularly in relation to training habits and the adaptation needs of at-risk groups of climbers, is a crucial foundation for analysing the variations in fitness that emerge among climbers.

Physical activity, defined as bodily movement involving skeletal muscle contraction and increased energy expenditure, serves to maintain physical fitness and support mental and spiritual health (Baharudin 2016; Permadi et al. 2025). Climbers who are not physically or mentally prepared are more prone to accidents; therefore, regular exercise is one of the most effective ways to maintain optimal function of the heart, muscles and respiratory system (Fitria Soamole and Muslim Fadel 2023). Aerobic exercise has been shown to improve cardiovascular capacity and accelerate physical recovery, which is crucial for high-performance mountaineering (Palar et al., 2015; Adidharma, 2016). Meanwhile, anaerobic exercises such as push-ups, sit-ups, and pull-ups strengthen the upper body muscles and help maintain stability on steep and rocky terrain (Farid Prasetyo Manggala Putra, Puji Setyaningsih, and Danang Ari Santoso 2020). Improving physical condition is one indicator of achieving better fitness, so it is not surprising that physical condition is one of the key elements (Adhi and Soenyoto 2017; Setiowati et al. 2020).

Good physical condition encompasses cardiovascular endurance, muscle strength, flexibility, and mental readiness, which are key factors for success in mountain climbing (Nurajab 2019). Pre-climb training can improve lung capacity, cardiovascular efficiency, and physical endurance to tackle long routes (Permatasari and Sidarta 2021; Sukarmin 1995). Flexibility also helps reduce injuries and adapt to movements on uneven terrain, particularly for older climbers (Collins et al. 2018). Furthermore, mental resilience and self-efficacy, strengthened through adaptive climbing activities, contribute to the success of climbers with physical limitations (Passi et al. 2025). Overall, structured physical activity combining strength, endurance and flexibility forms an essential foundation for safe and optimal mountaineering preparation.

Physical and mental preparation for mountain climbing requires an understanding of exercise theory, as the body's adaptation to the challenges of the mountains is influenced by the type, intensity, frequency, and duration of training. Consistent training improves cardiovascular capacity, strength, and endurance. The principle of progressive overload states that a gradual increase in load can enhance a climber's strength, endurance, and aerobic capacity. Aerobic exercises such as jogging, cycling, and light hiking also improve VO_2max, lactate threshold, and muscle efficiency, which are crucial aspects for mountaineering (Midgley, McNaughton, and Wilkinson 2006). Strength training is equally important as it increases muscle mass, body stability, and reduces the risk of injury during climbing (Fleck and Kraemer 2014). However, the effectiveness of training is highly dependent on adequate recovery, as insufficient recovery time can lead to fatigue and increase the risk of injury (Kellmann 2010).

A climber's preparedness is the result of the interaction of various internal and external factors, with physical fitness being the most dominant component. Components such as cardiovascular endurance, muscular strength and endurance, flexibility, and body composition have been shown to make a significant contribution to climbing ability; indeed, physical fitness accounts for 74.7% of a climber's physical preparedness. Furthermore, metabolism and energy management play a crucial role, particularly as calorie requirements increase with altitude and the duration of the climb.

A balance between energy intake and expenditure is key to maintaining endurance, preventing fatigue, and avoiding injury (Rezha et al. 2025).

Other factors such as planned physical preparation, technical knowledge, mental readiness, and the use of appropriate equipment also contribute to reducing the risk of accidents. Aerobic and strength training have been shown to be effective in improving cardiovascular capacity and muscle strength, making them essential for tackling challenging terrain (Sukarmin 1995). Daily physical activity also supports physical preparation; climbers in the Mount Panderman-Buthak region generally demonstrate high levels of activity according to GPAQ measurements, indicating the benefits of regular physical activity habits (Permadi et al. 2025). Therefore, a climber's preparation is a combination of physical fitness, energy management, training planning, and daily activities, which form an essential foundation for formulating training strategies and practical recommendations to ensure safer and more optimal climbing.

Although various studies emphasise the importance of physical fitness, aerobic exercise, and muscle strength to support safety and performance in mountain climbing (Nurajab 2019; Permatasari and Sidarta 2021; Sukarmin 1995), the majority of these studies still focus on physiological aspects in isolation or emphasise populations of climbers with ideal physical conditions. Research on climbers with risk factors, such as older adults, those who are overweight, or climbers with a history of injury, is generally descriptive or involves limited interventions, without directly linking preparatory training routines to measurable fitness levels and the adaptation strategies applied in the field (Collins et al. 2018; Passi et al. 2025).

Furthermore, to date, there have been only a few studies combining a comparative quantitative approach with research into adaptive strategies based on climbers' experience, to develop realistic and applicable training guidelines for recreational athletes. Therefore, this study offers novelty by integrating an analysis of physical fitness differences based on the regularity of prior activity, an investigation of adaptation in at-risk groups, and the formulation of basic training guidelines based on empirical evidence. It is hoped that this approach can bridge the gap between training theory, practical experience, and the real needs of climbers with varying physical backgrounds.

Based on this framework, this study aims to: (1) identify differences in the level of physical readiness among climbers based on physical activities undertaken prior to the climb, (2) identify the forms of preparatory activities undertaken by climbers with suboptimal physical condition, and (3) develop basic guidelines for general physical improvement that can be used by the community as a reference in preparation for climbing.

2. Method

This study employs a descriptive-comparative quantitative approach to analyse differences in physical readiness levels between climbers who engage in pre-climb physical activities and those who do not, as well as to describe the forms of physical preparation undertaken by climbers with less than ideal physical conditions. The study respondents were mountain climbers who had undertaken a climb within the last two years in Indonesia, selected using purposive sampling.

The research instrument consisted of a physical readiness questionnaire containing indicators of endurance, strength, flexibility, and mild physical-related mental resilience. Data were collected via

a Google Forms questionnaire and analysed comparatively (using an independent t-test or Mann-Whitney test) to identify differences between groups, as well as descriptively to illustrate variations in physical preparation. The results of the analysis were synthesised into basic guidelines for physical improvement that can be used by prospective mountaineers. In this study, there were six respondents with the initials VR, AL, NU, YN, YM, and UL.

3. Result and Discussion

Differences in Physical Readiness Levels Based on Pre-Climbing Physical Activity

This study revealed a statistically significant difference (p = 0,00045) between the endurance scores of climbers who train regularly ($\bar{x}_1 = 8{,}11$) and those who train only occasionally or not at all ($\bar{x}_2 = 6{,}00$). This difference rejects the null hypothesis (H_0) and confirms that the regularity of training has a direct influence on climbers' perception and endurance readiness. These results are consistent with previous studies emphasising the importance of cardiovascular endurance in mountaineering, particularly for maintaining oxygen supply during long routes and challenging terrain (Rezha et al. 2025). Therefore, a mountaineer's performance is not solely influenced by innate physical condition, but is more determined by the quality and consistency of training prior to the climb. Regular training promotes physiological adaptations such as improved cardiovascular efficiency, VO_2max, and recovery rate, which are reflected in higher fitness scores. Consequently, a mountaineer's physical preparation should be understood as the result of a combination of training intensity, frequency, and consistency, rather than as occasional activity in the days leading up to the climb.

The Effect of Training Regularity on Cardiovascular Endurance

Training regularity is a key factor enabling gradual physiological adaptation. Climbers who train regularly typically combine aerobic activities such as walking, running, light aerobics, and rock climbing 3-4 times a week. This pattern enhances lung capacity and cardiovascular efficiency, as described by Permatasari and Sidarta 2021 and Sukarmin (1995), and increases VO_2max as an indicator of aerobic endurance (Midgley et al. 2006). Consistent training also accelerates the recovery process and metabolic detoxification (Palar, Wongkar, and Ticoalu 2015). The principle of progressive overload (Ratamess 2012) can be effectively applied when training is carried out consistently, allowing the body to receive sufficient stimulation to adapt without excessive fatigue. This is confirmed by the experience of VR (25 years old), who trained 4-5 times a week for two years and never experienced endurance issues whilst climbing at altitude.

Conversely, sporadic training does not give the body time to adapt physiologically. AL (24 years old), who only trained for two weeks prior to the climb, reported significant fatigue midway through the journey, indicating that improvements in VO_2max and muscular endurance cannot be achieved instantly. These results confirm that mountain climbing requires high energy expenditure, which can only be met through consistent and sustained pre-climb training. Therefore, regularity of training is not merely a supporting factor, but an essential prerequisite for ensuring physical readiness and minimising the risk of acute fatigue during the climb.

Balance of Fitness Components

Although endurance was the primary focus of the statistical analysis, questionnaire and interview results indicate that climbers who train regularly not only improve their endurance but also integrate other fitness components such as strength, flexibility, and mobility. These components are crucial because climbing requires the ability to bear weight, maintain balance, and adapt to unstable terrain. VR's experience, having trained regularly at the gym, and AL's acknowledgement of the importance of strengthening the back and core muscles, support these findings. This aligns with the research by Farid Prasetyo Manggala Putra et al. (2020) and Nurajab (2019), which emphasises the role of anaerobic exercise in improving stability, structural strength, and muscle capacity on climbing terrain.

Flexibility is also a key element of physical fitness. Stretching and mobility exercises help maintain joint range of motion, reduce stiffness, and lower the risk of injury to the wrists, knees, and hips. Collins et al. (2018) state that flexibility acts as a protective factor against musculoskeletal injuries, particularly in activities involving repetitive movements and extreme changes in height. In addition to physical factors, mental preparedness contributes to climbing success; both sources emphasise the importance of pacing oneself, maintaining concentration, and prioritising safety. This aligns with Passi et al. (2025), which states that self-efficacy is a key factor in reaching the summit and managing risk. Therefore, a mountaineer's physical preparation involves not only strengthening cardiovascular endurance but is the result of the interaction between endurance, strength, flexibility, and mental preparation, enabling the climber to synergistically cope with various terrain conditions and physical-psychological pressures during the climb.

Forms of Preparation and Adaptation to Physical Limitations

A descriptive analysis of questionnaires and interviews indicates that success in mountaineering depends not only on initial physical condition but also on the adaptation strategies implemented during preparation. Climbers with low endurance, a history of injury, or specific health conditions can still improve their performance through structured, progressive training that takes the body's needs into account. This adaptation involves adjusting the intensity and type of exercise, strengthening supporting muscles, and regulating training pace to prevent recurrent injuries , which underscores that physical preparation is flexible and adaptable when carried out consistently.

The interviews also confirmed that risk management is a crucial component, particularly for climbers with physical limitations. Practices such as longer warm-up and cool-down sessions, reducing load, using assistive devices, and regulating climbing pace have proven useful for preventing injuries and conserving energy. Data from the questionnaire indicates that climbers with suboptimal physical condition tend to plan routes, monitor their physical condition, and use equipment that supports stability. These findings pave the way for a better understanding of how at-risk groups, such as anxious climbers, obese individuals, or those with chronic conditions, adapt their pre-climb training as a key strategy to ensure safety and improve the chances of reaching the summit.

Adaptation in High-Risk Groups

High-risk groups such as older climbers, obese climbers, and young climbers with a history of injury demonstrate more focused adaptation strategies compared to climbers in ideal physical condition. In older climbers, reduced endurance, flexibility, and strength drive the use of low-impact exercises focused on stability and cardiovascular fitness. Interviews revealed that NU (51) and YN (47) rely on walking or long-duration cardio exercises, which also help manage asthma, in line with the literature emphasising joint protection and the prevention of overuse injuries in older age. The lack of strength training in this group reflects a perception of high injury risk, leading them to opt for a conservative and measured approach to exercise.

Young climbers with a history of injury, such as AL, adopt more aggressive adaptations through terrain simulation, for example by practising climbing stairs with a 5–7 kg rucksack and wearing knee braces (Nurajab 2019). However, the case of YM demonstrates that general fitness gained in the gym is not always sufficient to cope with the stresses of altitude, as evidenced by the dizziness and breathing difficulties he experienced. This reinforces the need for specific adaptations to high-altitude environments, including education and physiological monitoring. Obese climbers face additional mechanical challenges, so they should opt for low-impact calorie-burning exercises such as cycling or swimming, and use walking poles, knee braces, or hip weight distribution as stabilisation strategies, according to the recommendations by Fleck and Kraemer (2014). Overall, adaptations for high-risk groups include a combination of functional exercises, joint and respiratory risk management, adjustments to exercise intensity, and an understanding of the body's limitations, demonstrating that physical limitations are not barriers, but challenges that can be managed through proper and consistent preparation.

Minimal Consistency Barriers and Practical Solutions

Findings regarding adaptations for high-risk groups indicate that physical capacity can improve through appropriate training; however, many climbers-whether with risk conditions or physically fit-still struggle to maintain consistency in their training. Lack of time, fluctuating motivation, and limited knowledge of training methods act as universal barriers preventing the establishment of routines and the application of effective training principles. Interviews suggest that these barriers can be overcome through simple and realistic strategies, such as the 30-minute jogs undertaken regularly by YM, the stair training implemented by AL as a simulation of climbing terrain, and moderate-intensity training 3-4 times a week by YN, which is particularly relevant for older climbers. Conversely, an excessively low training frequency, as in the case of UL who only trained once a week, led to extreme fatigue and cramps when facing cold conditions on the mountain, indicating that minimal training stimulus is insufficient to produce physiological adaptation and actually increases the risk of injury and fatigue.

Another obstacle is a lack of understanding regarding the appropriate intensity and volume of training. Both AL and VR expressed confusion regarding the appropriate training regimen prior to climbing, which can lead to ineffective or even dangerous training patterns. The lack of physical education for recreational climbers highlights the need for comprehensive and easily implementable pre-climb guidelines. It is therefore essential to develop training guidelines that not only outline the optimal frequency, duration, and intensity of training but also enhance climbers'

self-efficacy so that they are prepared to face physical challenges and environmental risks, whether for climbers in ideal conditions or for at-risk groups.

Basic Guidelines for Pre-Hike Physical Conditioning

Based on research findings regarding the importance of training consistency, the integration of fitness elements, and the need for adjustments for at-risk groups, the development of guidelines for pre-hiking physical conditioning is urgently required. These guidelines serve as a practical reference for recreational hikers with varying levels of physical fitness, ranging from beginners and those with irregular exercise routines to at-risk groups such as older adults, individuals with mild obesity, or those with a history of joint injuries. The core of these guidelines is to provide a realistic, accessible, and evidence-based training framework, enabling hikers to effectively improve their physical readiness within a limited timeframe.

Results indicate that consistency is a key factor for successful adaptation; hikers who train regularly with aerobic exercise 3 to 5 times a week have significantly better endurance compared to those who train irregularly. Therefore, the guidelines emphasise the importance of simple yet consistent routines, such as climbing stairs at AL or jogging for 20-30 minutes as in YM, to accommodate time constraints and access to exercise. Furthermore, the guidelines should include functional strength training targeting the thighs, calves, hips, back, and core through exercises such as squats, lunges, step-ups, planks, and exercises with a light rucksack. Findings from VR and AL confirm that back and core strength significantly influence comfort whilst hiking, particularly when carrying loads of 8-15 kg, whilst reducing the risk of injuries such as knee pain, lower back pain, and cramps.

Table 1. Weeks 1-2: basic adaptation

Training Components	Frequency	Duration	Focus	Example Activities
Light cardio	3 times a week	20-30 minutes	Cardiorespiratory adaptation	Light jogging, brisk walking
Lower body strength	2 times a week	20 minutes	Leg muscle activation	Squats, lunges, step-ups
Core stability	Twice a week	10-15 minutes	Balance & posture	Plank, bird-dog
Joint mobility	Daily	5-10 minutes	Injury prevention	Ankle and hip mobilisation

Table 2. Weeks 3-4: capacity building

Exercise Components	Frequency	Duration	Focus	Example Activities
Moderate-intensity cardio	3-4 times a week	25-35 minutes	Improved stamina	Interval jogging, treadmill incline
Lower body strength (progressive)	2 times a week	25 minutes	Strength & endurance	Weighted squats, hill lunges
Stair training	1-2 times a week	10-20 minutes	Climbing simulation	Going up and down 5–10 flights of stairs

Exercise Components	Frequency	Duration	Focus	Example Activities
Core + balance	Twice a week	10-15 minutes	Stability	Side plank, single-leg balance

Table 3. Weeks 5-6: climbing simulation and intensification

Training Components	Frequency	Duration	Focus	Example Activities
Moderate-high intensity cardio	3-4 times a week	30-40 minutes	High endurance	Interval running, light hiking
Lower-body bodyweight exercises + progression	2-3 times a week	30 minutes	Mountain climbing simulation	High step-ups, squat jumps (modified), walking lunges
Simulated hiking	1 time per week	1-2 hours	Practical adaptation	Climbing small hills, local trekking
Intensive stair training	1-2 times a week	15-20 minutes	Altitude adaptation	Backpack load 3-5 kg
Cool-down & mobility	Daily	5-10 minutes	Recovery	Dynamic & static stretching

4. Conclusion and Recommendation

This study confirms that consistency in training is a key factor in the physical preparation of climbers, as demonstrated by the significant difference in endurance scores between climbers who train regularly and those who do not ($p=0{,}00045$; $\bar{x_1}=8{,}11$; $\bar{x_2}=6{,}00$), where aerobic exercise 3-4 times a week was shown to stimulate physiological adaptations that prevent fatigue at altitude. These results align with systematic reviews and evidence from 8-12-week exercise interventions showing improvements in cardiorespiratory capacity and self-efficacy (Pan, Sun, and Liu 2024; Sahri et al. 2024). At-risk climbers, such as the elderly or individuals with a history of injury, can still climb safely thanks to adaptive strategies such as low-impact exercise, load simulation, and the use of assistive devices. However, common barriers such as a lack of time and limited knowledge of exercise highlight the need for flexible, home-based exercise programmes. Therefore, the basic pre-climb guidelines developed in this study provide an evidence-based framework for enhancing self-efficacy, preparing climbers safely, and minimising health risks during climbs.

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