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Climbing Speed and Acclimatization are determinants of Acute Mountain Sickness on Mount Sumbing, Indonesia

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Abstract

Background: Acute Mountain Sickness (AMS) commonly affects individuals ascending above 2,500 meters due to inadequate adaptation to hypobaric hypoxia. Climbing speed and acclimatization are important modifiable risk factors, although evidence regarding their contribution among Indonesian mountain climbers remains limited. **Aims:** To investigate the relationships between climbing speed, acclimatization, and the incidence of acute mountain sickness among climbers of Mount Sumbing, Wonosobo Regency, Central Java. **Methods:** A quantitative study with a correlational cross-sectional design was conducted among 109 Mount Sumbing climbers recruited using a consecutive sampling technique. Climbing speed was assessed based on ascent performance, acclimatization status was evaluated using predefined acclimatization criteria, and acute mountain sickness was measured using the Lake Louise Acute Mountain Sickness Score (LLAMS). Spearman's rank correlation test was performed to examine the relationships between variables, with statistical significance set at $\alpha = 0.05$. **Results:** Significant positive correlations were identified between both independent variables and the incidence of acute mountain sickness. Climbing speed demonstrated a moderate positive correlation with AMS ($p < 0.001$; $r = 0.444$), indicating that faster ascent was associated with a greater likelihood of developing AMS. Acclimatization also showed a statistically significant positive correlation with AMS ($p < 0.001$; $r = 0.874$), suggesting that inadequate acclimatization substantially increased the risk of acute mountain sickness. Among the two variables, acclimatization exhibited the strongest association with AMS. **Conclusions:** Climbing speed and acclimatization significantly influence acute mountain sickness among Mount Sumbing climbers. Appropriate ascent pacing and adequate acclimatization are essential to reduce AMS risk and support preventive guidelines and climber safety education.

Keywords: acute mountain sickness, acclimatization, climbing speed, mountain climbers

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Introduction

Acute Mountain Sickness (AMS) is the most common form of high-altitude illness (HAI), resulting from inadequate physiological adaptation to hypobaric hypoxia following rapid ascent to high altitude. AMS typically develops at elevations above 2,400–2,500 m and is characterized by headache, nausea, dizziness, fatigue, and sleep disturbances (Berger et al., 2020; Beidleman et al., 2023; Li et al., 2025; Guo et al., 2022). Although AMS is generally self-limiting, delayed recognition and inappropriate management may lead to life-threatening complications, including High-Altitude Cerebral Edema (HACE) and High-Altitude Pulmonary Edema (HAPE) (Cai et al., 2026; Jia et al., 2026). HACE is considered a severe progression of AMS and is characterized by altered consciousness and ataxia, whereas HAPE commonly develops within two to three days after ascent and presents with dyspnea and cough (Jia et al., 2026; Simancas-Racines et al., 2018).

The pathophysiology of HAI is primarily driven by hypoxemia caused by reduced atmospheric pressure at high altitude. However, susceptibility to AMS varies considerably among individuals because of differences in physiological adaptation, genetic predisposition, and acclimatization capacity (Berger & Luks, 2023; Jia et al., 2026). Recent studies have emphasized the importance of identifying predictive biomarkers and developing comprehensive prediction models integrating clinical, proteomic, and metabolomic data to facilitate early risk assessment and personalized preventive strategies, including pharmacological interventions such as acetazolamide and lifestyle modifications (Li et al., 2025; Jia et al., 2026). Current preventive approaches also include dexamethasone, supplemental oxygen, and non-pharmacological strategies such as gradual acclimatization, although evidence supporting some interventions remains limited (Garay et al., 2018; Franco et al., 2019; Simancas-Racines et al., 2018).

AMS remains a common health problem among high-altitude climbers worldwide. A recent study reported an AMS incidence of 88.6% among climbers in Nepal (Wang et al., 2025). Disease occurrence increases with altitude, with reported prevalence reaching 43% among climbers at Pheriche (4,343 m), compared with approximately 22% at lower elevations of 1,850–2,750 m in Colorado ski resorts (Wu et al., 2018; Jia et al., 2026). In severe cases, AMS may progress to systemic inflammatory response syndrome and multiple organ dysfunction, while several fatalities during the 2019 Mount Everest climbing season were partially attributed to altitude-related illnesses, underscoring the potentially fatal consequences of inadequate prevention and management (Wang et al., 2025).

Among the numerous factors influencing AMS, ascent rate is consistently recognized as one of the strongest and most modifiable predictors. Rapid ascent limits the time available for physiological acclimatization, thereby increasing susceptibility to hypoxia (Beidleman et al., 2023; Berger et al., 2020). A prospective study involving 770 climbers demonstrated that AMS incidence was significantly higher among individuals undertaking rapid ascent (37.9%) than among those ascending gradually (26.5%) at an altitude of 3,650 m (Zhao et al., 2024). Similarly, climbers in Nepal with rapid ascent profiles had a 3.13-fold greater likelihood of developing moderate-to-severe AMS (Poudel et al., 2022). Although factors such as age, sex, and educational level have shown inconsistent associations with AMS, ascent speed, altitude reached, and previous acclimatization remain the most influential determinants of disease development (Beidleman et al., 2023; Gao et al., 2024; Berger & Luks, 2023). Interestingly, endurance athletes may also experience higher AMS incidence shortly after ascent despite superior physical fitness, potentially because of elevated resting metabolic demands and distinct physiological responses to hypoxia (Sareban et al., 2020).

Acclimatization is the cornerstone of AMS prevention because it enables progressive physiological adaptation to reduced oxygen availability. Evidence indicates that gradual ascent, rather than physical fitness alone, is critical for successful acclimatization and reducing AMS risk (Beidleman et al., 2023; Zhao et al., 2024). The widely recommended "climb high, sleep low" strategy has demonstrated effectiveness in minimizing AMS incidence by promoting adaptive responses while reducing overnight

hypoxic stress (Zhao et al., 2024). Additional preventive measures, including maintaining adequate hydration (3–4 L/day), sufficient rest, and consuming a carbohydrate-rich diet, contribute to improved oxygen utilization and reduced susceptibility to acute hypoxia (Beidleman et al., 2023). Furthermore, hypoxic pre-acclimatization protocols combining intermittent hypoxic exposure with physical exercise have shown promise in enhancing tolerance to high-altitude environments (Xie et al., 2024). Collectively, these findings highlight that appropriate acclimatization strategies, together with controlled ascent rates, constitute the most effective non-pharmacological approaches for preventing AMS (Byrd et al., 2022; Berger & Luks, 2023; Ebihara et al., 2023).

Despite growing evidence regarding AMS risk factors, limited studies have simultaneously examined the roles of climbing speed and acclimatization among Indonesian mountain climbers. Preliminary interviews with five climbers who had ascended Mount Sumbing revealed that all experienced symptoms consistent with AMS, including vomiting, dizziness, and sleep disturbances while camping. These symptoms were reportedly associated with inadequate physical preparation and insufficient acclimatization before ascent. Therefore, this study aims to examine the relationship between climbing speed, acclimatization, and the incidence of AMS among climbers of Mount Sumbing, Wonosobo Regency, Central Java.

Methods

Study Design and Participants

This study employed a quantitative research approach with a correlational analytic design and cross-sectional approach. The study population consisted of 150 climbers ascending Mount Sumbing in Wonosobo Regency, Central Java. Using the Slovin formula with a 5% margin of error, a sample of 109 respondents was determined through Consecutive sampling. Inclusion criteria were: climbers willing to participate as respondents, climbers who participated in the study from beginning to end, and climbers ascending to altitudes above 2,500 masl. Exclusion criteria included climbers who were unable to communicate and those who could not read or write. Data collection was conducted from February 6 to February 14, 2026, at the Mount Sumbing climbing post via Garung, Wonosobo Regency, Central Java. This study received ethical approval from the Health Research Ethics Institute of the Institute of Health Science Nahdlatul Ulama Tuban (Approval No. 303/0084223523/LEPK.IIKNU/II/2026). All participants provided written informed consent prior to participation. The principles of anonymity, confidentiality, and voluntary participation were upheld throughout the research process.

Instruments

Three instruments were used in this study:

1) Climbing Speed Questionnaire: A 15-item questionnaire using a 4-point Likert scale (Never, Rarely, Often, Always) covering three dimensions: initial climbing speed, mid-journey consistency, and endurance toward the summit. Scores were categorized as: Very Fast (54–66), Fast (41–53), Slow (28–40), and Very Slow (15–27) (Stoltz,1997).
2) Acclimatization Questionnaire: A 15-item questionnaire using a 4-point Likert scale assessing three dimensions: acclimatization preparation, physiological readiness, and symptom management. Scores were categorized as: Very Good (54–66), Good (41–53), Low (28–40), and Very Low (15–27).
1) Lake Louise Acute Mountain Sickness Score (LLAMS): A standardized 7-item questionnaire measuring the incidence of AMS through six dimensions: headache, gastrointestinal symptoms, weakness, dizziness, insomnia, and body imbalance. Scores were categorized as: Severe (17–21), Moderate (12–16), and Mild (7–11). LLAMS questionnaire demonstrates high reliability and diagnostic accuracy in assessing altitude acclimatization. The instrument exhibits strong internal consistency (Cronbach's α = 0.79–0.83), robust convergent validity (r = 0.95), and superior diagnostic precision (AUC = 0.91–0.94), with a sensitivity of 84%–89% and a specificity of 88%–92%

in detecting Acute Mountain Sickness (AMS) (Roach et al., 2018).

Data Analysis

Data were analyzed using SPSS version 23. Descriptive statistics were used to summarize participant characteristics and the distributions of the study variables. Spearman's rank correlation coefficient (Spearman's rho) was used to examine the relationships between climbing speed and acute mountain sickness (AMS), as well as between acclimatization and AMS. Statistical significance was set at $p < 0.05$. A p-value of ≤ 0.05 was considered statistically significant, indicating a significant relationship between the variables, whereas a p-value of > 0.05 indicated no statistically significant relationship.

Results

The study involved 109 respondents. The majority were in the 17–23 years age group at 48.6% (n=53), followed by 24–30 years at 35.8% (n=39), and 31–37 years at 15.6% (n=17). Gender distribution showed a predominance of males (73.4%, n=80) compared to females (26.6%, n=29). Regarding climbing experience, nearly half of the respondents fell into the beginner category (1–3 times), as many as 43 respondents (40.2%), followed by intermediate (3–5 times) at 33.6% (n=36), and professional (>5 times) at 26.2% (n=28). Assessment of climbing speed showed that the majority climbed in the slow category at 35.8% (n=39), followed by fast and very fast at 29.4% each (n=32), and very slow at 5.5% (n=6). Assessment of acclimatization showed that the majority had low acclimatization at 30.3% (n=33). Assessment of AMS severity showed that the majority experienced mild AMS at 37.6% (n=41), followed by severe at 33.9% (n=37), and moderate at 28.4% (n=31).

Table 1. Characteristics of respondents (n=109)

Characteristis	Category	Frekuency	Percentage (%)
Age	17-23 years old (adolescents)	53	48.6%
	24-30 years old (young adults)	39	35.8%
	31-37 years old (late adulthood)	17	15.6%
Gender	Male	80	73.4%
	Female	29	26.6%
Climbing Experience	Beginner (1-3)	43	40.2%
	Intermediate (3-5)	36	33.6%
	Professional (>5)	28	26.2%
Climbing Speed	Very slow	6	5.5%
	Slow	39	35.8%
	Fast	32	29.4%
	Very fast	32	29.5%
Acclimatization	Very low	27	24.8%
	Low	33	30.35
	Good	32	29.4%
	Very good	17	15.6%
AMS	Mild	41	37.6%
	Moderate	31	28.4%
	Severe	37	33.9%

Cross-tabulation analysis demonstrated a clear pattern. In the very fast climbing group, almost all respondents (78.1%, n=25) were in the severe AMS category. The slow climbing group was predominantly mild AMS (41.0%, n=15), while the very slow group was predominantly mild AMS (66.7%, n=4). The Spearman test results show a significant positive correlation (r = 0.444; p = 0.000), indicating that the faster the climbing pace, the higher the risk of AMS (Table 2).

Table 2. Cross-tabulation of relationship between climbing speed and AMS

Climbing Speed	Severe	Moderate	Mild	r	p value
Very Slow	0 (0.0%)	2 (33.3%)	4 (66.7%)	0.444	0.001
Slow	8 (20.5%)	16 (38.5%)	15 (41.0%)		
Fast	8 (25.0%)	11 (34.4%)	13 (40.6%)		
Very Fast	25 (78.1%)	4 (9.4%)	3 (12.5%)		

Cross-tabulation analysis shows a striking pattern. In the very low acclimatization group, all 27 respondents (100%) fell into the severe AMS category. Conversely, in the very good acclimatization group, all 17 respondents (100%) were in the mild AMS category. The Spearman test results show a very strong and significant positive correlation (r = 0.874; p = 0.000), indicating that poorer acclimatization is strongly associated with more severe AMS (Table 3).

Table 3. Cross-tabulation of relationship between acclimatization and AMS

Acclimatization	Severe	Moderate	Mild	r	p value
Very Low	27 (100%)	0 (0.0%)	0 (0.0%)	0.874	0.001
Low	13 (39.4%)	20 (60.6%)	0 (0.0%)		
Good	1 (3.1%)	11 (34.4%)	20 (62.5%)		
Very Good	0 (0.0%)	0 (0.0%)	17 (100%)		

Discussion

This study found significant relationships between both climbing speed and acclimatization and AMS in climbers on Mount Sumbing. These findings are consistent with existing theoretical frameworks and empirical evidence, while also contributing new insights to the Indonesian context.

Climbing Speed and AMS

This study confirms a meaningful relationship between ascent rate and the occurrence of Acute Mountain Sickness among climbers at Mount Sumbing, Wonosobo Regency. The relationship is positive with moderate strength, indicating that the faster the climbing pace, the greater the risk of experiencing AMS at higher severity levels. This finding directly answers the research hypothesis that ascent rate is significantly correlated with the incidence of AMS. In terms of distribution, climbers classified in the very fast category predominantly experienced severe AMS, while those who climbed at a slow pace mostly suffered only mild AMS (Hackett & Roach, 2001; Luks et al., 2019). This pattern clearly reflects the body's physiological response to a sudden drop in oxygen pressure at altitude. When ascent is performed too rapidly, the body does not have sufficient time to adjust its ventilation mechanisms, circulatory adaptation, and oxygen distribution. As a result, hypobaric hypoxia cannot be adequately compensated, and AMS symptoms such as headache, nausea, dizziness, and sleep disturbances inevitably emerge (Bärtsch & Swenson, 2013).

The present finding indicates that the rate of ascent plays an important role in the occurrence of Acute Mountain Sickness (AMS) (Hackett & Roach, 2001). A faster ascent provides less time for physiological acclimatization, increasing the likelihood of hypoxia and the subsequent development of AMS symptoms (Bärtsch & Swenson, 2013). In contrast, a slower ascent allows the body to adapt more effectively to the reduced oxygen availability at higher elevations, thereby lowering the risk of AMS (Luks et al., 2019). These findings also support the broader understanding that adequate oxygenation and successful acclimatization are key determinants of AMS development (Schoene, 2008). Although many previous studies have focused on climbers at extreme altitudes using physiological measurements, the present study demonstrates that the relationship between ascent rate and AMS is also evident at moderate elevations, such as Mount Sumbing (approximately 3,371 m above sea level), using a questionnaire-based assessment (Honigman et al., 1993; Roach et al., 2018). This suggests that the risk associated with rapid ascent is not limited to high-altitude expeditions but is also relevant to

recreational mountain climbing (Meier et al., 2017). Therefore, adopting a gradual ascent strategy remains an important preventive measure for reducing the incidence of AMS across a wide range of mountain environments (Luks et al., 2019).

The findings of this study further support the understanding that a rapid rate of ascent is an important risk factor for the development of Acute Mountain Sickness (AMS) (Hackett & Roach, 2001). Climbers who ascend too quickly have less time to undergo physiological acclimatization, making them more susceptible to hypoxia and the onset of AMS symptoms (Bärtsch & Swenson, 2013). Conversely, a more gradual ascent provides sufficient time for adaptation to reduced oxygen availability, thereby decreasing the risk of developing AMS (Luks et al., 2019). An important aspect highlighted by this study is that the relationship between ascent rate and AMS is also evident among mountain climbers in Indonesia, where formal acclimatization practices are not yet widely implemented, particularly among recreational climbers (Setyawan et al., 2021). This condition may increase vulnerability to AMS, especially on mountains that attract large numbers of visitors with varying levels of climbing experience. The findings also emphasize that rapid ascent is not merely associated with an increased probability of AMS but has important implications for climber safety because it can lead to clinically significant symptoms that may interfere with physical performance and, in severe cases, require immediate medical attention (Netzer et al., 2013). Therefore, applying appropriate acclimatization strategies and promoting gradual ascent practices should be considered essential components of mountain safety

Acclimatization and AMS

This study further establishes a significant, positive, and strong relationship between acclimatization and AMS incidence among climbers at Mount Sumbing. The direction of the relationship found indicates that the better the acclimatization process undertaken by a climber, the lower the risk and severity of AMS experienced. The strength of this relationship, which substantially exceeds that of ascent rate (Richalet et al., 2012; Wu et al., 2018), demonstrates that acclimatization is the most dominant protective factor identified in this study, and directly answers the hypothesis that acclimatization is significantly correlated with AMS incidence. In terms of distribution, all climbers who performed no acclimatization whatsoever experienced severe AMS, while those who acclimatized properly mostly reported only mild AMS. This finding speaks volumes about the critical role of acclimatization as the body's primary defense mechanism against hypobaric hypoxia (Bärtsch & Swenson, 2013; Hackett & Roach, 2001). The acclimatization process enables the body to increase breathing frequency, stimulate red blood cell production, and adjust circulatory flow so that oxygen delivery to all tissues, including the brain, is maintained at a more adequate level (Luks et al., 2017; West, 2006).

These findings are consistent with those reported by Tsai et al. (2025), who investigated physiological responses following exposure to an altitude of approximately 4,200 m. Their study demonstrated that individuals with AMS exhibited greater improvements in oxygen saturation and heart rate after acclimatization, indicating an active physiological adaptation to hypoxic conditions. Similarly, the present study suggests that acclimatization plays a critical role in modifying the body's response to hypoxia and influencing the development of AMS. Although the two studies employed different methodological approaches—Tsai et al. (2025) used objective physiological measurements, whereas the present study assessed acclimatization using questionnaire-based instruments, including the Lake Louise Score (Roach et al., 2018)—both reported consistent findings, supporting the importance of acclimatization in reducing susceptibility to AMS.

The literature review conducted by Sharma et al. (2023) adds a further dimension by demonstrating that planned acclimatization strategies, whether through gradual elevation gain or simulated low-oxygen environments, can substantially reduce AMS incidence. This aligns closely with the conditions observed in the present study, where climbers who reported having acclimatized properly consistently demonstrated lower AMS severity levels. A distinctive feature of this study's findings is that the

protective relationship between acclimatization and AMS proved exceptionally strong even within the context of tropical mountain climbing in Indonesia, where knowledge and practice of formal acclimatization among climbers remains highly variable (Vardy et al., 2006)

The implications of these findings are far-reaching. From a public health perspective, the results firmly establish the need for more extensive and structured educational campaigns directed at climbing communities regarding the importance of acclimatization before and during ascent (Schommer & Bärtsch, 2011). Mountain area managers, climbing organizations, and healthcare professionals operating near climbing zones must collaboratively develop practical acclimatization protocols that can be realistically implemented by climbers of diverse backgrounds and experience levels (Luks et al., 2019; Netzer et al., 2013). From the perspective of nursing science and sports medicine, this study reinforces the position of acclimatization as the most effective non-pharmacological preventive intervention against AMS, and opens avenues for developing AMS risk screening protocols based on ascent behavior characteristics.

Study Limitations

Although this study successfully demonstrated meaningful relationships between ascent rate and acclimatization with AMS incidence, several limitations must be considered when interpreting the findings. First, data collection was carried out under highly dynamic field conditions on Mount Sumbing, where not all climbers could be reached as respondents. Climbers who experienced severe exhaustion or chose to descend before reaching a certain altitude were not included in the study, creating a potential selection bias that may mean the risk profile of AMS presented here does not fully represent the entire climbing population. Second, the measurement of AMS incidence and several other research variables relied entirely on subjective self-reports through questionnaires. Although the instrument used incorporated standardized symptom scoring criteria, the possibility of perceptual bias remains. Some respondents may have downplayed their symptoms due to their motivation to complete the ascent, while others may have over-reported their experiences. The absence of objective physiological measurements such as blood oxygen saturation or blood pressure monitoring during the climb represents a notable limitation that constrains the depth of physiological analysis in this study. Unpredictable weather conditions at the research site also affected the smoothness of the data collection process. These limitations should serve as a foundation for future research that integrates objective measurement approaches with longitudinal study designs to generate a more comprehensive understanding of AMS risk factors in tropical mountains across Indonesia.

Conclusion

This study demonstrates that both climbing speed and acclimatization are significant determinants of Acute Mountain Sickness (AMS) among climbers of Mount Sumbing, Indonesia. A faster ascent was associated with a higher incidence and greater severity of AMS, indicating that rapid climbing limits the body's ability to adapt to hypobaric hypoxia. In contrast, adequate acclimatization substantially reduced the likelihood and severity of AMS, with acclimatization showing a considerably stronger association with AMS than climbing speed. These findings emphasize that acclimatization is the most influential modifiable protective factor for preventing altitude-related illness in recreational mountain climbers. The results reinforce current evidence that gradual ascent and appropriate acclimatization strategies are fundamental non-pharmacological approaches for reducing the risk of AMS. Given the increasing popularity of mountain climbing in Indonesia, these findings have important implications for public health, nursing practice, sports medicine, and mountain safety management. Climbing organizers, park authorities, and healthcare professionals should collaborate to implement standardized educational programs promoting safe ascent rates, pre-climb acclimatization, early recognition of AMS symptoms, and appropriate preventive measures. Despite the study's limitations,

including its cross-sectional design and reliance on self-reported questionnaires, the findings provide valuable evidence regarding AMS risk factors in Indonesian climbers. Future studies should employ longitudinal or prospective designs and incorporate objective physiological indicators, such as oxygen saturation, heart rate, and respiratory parameters, to further clarify the mechanisms linking climbing behavior, acclimatization, and the development of Acute Mountain Sickness.

Conflicts of Interest

Nothing to declare

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Author's Contribution

MSA contributed to the study's conception and design, data acquisition, and data analysis; wrote the first draft of the manuscript; revised the final draft; and gave final approval of the version to be published. MUF contributed to the study design, data analysis, and critical revision of the manuscript. K contributed to data collection, analysis, and manuscript revision.

Data Availability Statement

The dataset generated during and analyzed during the current study is available from the corresponding author upon reasonable request.

Declaration of Use of AI in Academic Writing

The author used ChatGPT/Gemini in the writing process to improve readability and remove grammatical errors. However, he took full responsibility for the content.

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