



pISSN: 2037-7452

eISSN: 2037-7460

<https://www.pagepressjournals.org/index.php/bam/index>

Publisher's Disclaimer. E-publishing ahead of print is increasingly important for the rapid dissemination of science. The **Early Access** service lets users access peer-reviewed articles well before print / regular issue publication, significantly reducing the time it takes for critical findings to reach the research community.

These articles are searchable and citable by their DOI (Digital Object Identifier).

The **European Journal of Translational Myology** is, therefore, e-publishing PDF files of an early version of manuscripts that undergone a regular peer review and have been accepted for publication, but have not been through the typesetting, pagination and proofreading processes, which may lead to differences between this version and the final one.

The final version of the manuscript will then appear on a regular issue of the journal.

E-publishing of this PDF file has been approved by the authors.

Eur J Transl Myol 2026 [Online ahead of print]

To cite this Article:

Menz V, Philippe M, Pocecco E, et al. **Handgrip strength in young recreational skiers: Is it related to the risk of falling?**. *Eur J Transl Myol*
doi: 10.4081/ejtm.2026.14764

 ©The Author(s), 2026

Licensee [PAGEPress](#), Italy

Note: The publisher is not responsible for the content or functionality of any supporting information supplied by the authors. Any queries should be directed to the corresponding author for the article.

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article or claim that may be made by its manufacturer is not guaranteed or endorsed by the publisher.

Handgrip strength in young recreational skiers: Is it related to the risk of falling?

Verena Menz,^{1*} Marc Philippe,^{2*} Elena Pocecco,^{1*} Johannes Burtscher,³ Barbara Strasser,^{4,5}
Gerhard Ruedl,¹ Martin Kopp,¹ Martin Burtscher¹

¹Department of Sport Science, University of Innsbruck, Innsbruck; ²Olympiazentrum Vorarlberg GmbH, Dornbirn; ³Department of Psychiatry, Psychotherapy, Psychosomatics and Medical Psychology, University Hospital for Psychiatry II, Medical University of Innsbruck, Innsbruck; ⁴Ludwig Boltzmann Institute for Rehabilitation Research, Vienna; ⁵Faculty of Medicine, Sigmund Freud Private University, Vienna, Austria

* shared first-authorship, equal contribution

Abstract

Handgrip Strength (HGS) is correlated with general health and fitness throughout the lifespan. However, the relationship between HGS and the frequency of sports accidents is not well understood. The aim of the present survey was twofold. Firstly, to collect HGS data from young skiers and compare them with existing normative values; secondly, to investigate whether the frequency of falls during a day of skiing is correlated with HGS. Data on HGS and falls were collected from 251 recreational downhill skiers, aged 6–25 years, on the day of recording. The results demonstrate the representative progression of HGS in boys and girls during growth and early adulthood. Additionally, the findings indicate that in young female skiers up to the age of 25 years, HGS is negatively correlated with the frequency of falls, which may be related to the generally lower muscle strength in females. Regular physical activity, including muscle strengthening and balance exercises, is crucial for preventing falls in skiers.

Keywords: downhill skiing; muscle strength; adolescence; sex

Regardless of age (including children and adolescents), sex, or sexual maturity, an association has been observed between Handgrip Strength (HGS), overall physical fitness,

and health status.¹⁻⁴ Downhill skiing requires a high level of physical fitness, particularly in terms of leg strength.^{5,6} Therefore, as is known for older skiers,⁷ muscle strength may be a limiting factor when it comes to skiing safely for children. Maturation status determines muscle strength along with regular physical and sporting activities.⁸ Since maneuvers like braking in downhill skiing require a certain degree of strength in the leg and hip muscles, weak muscles are likely to be related to a higher risk of falls. HGS, as an indicator of overall muscle strength, is associated with the frequency of falls in adults, particularly among skiers with weaker muscles.⁹ Children who start skiing lack fully developed technical expertise and sufficient strength for safe skiing. Therefore, overall muscle strength may be predictive of accidents, especially in children; however, evidence for this assumption is lacking. The aim of this survey was firstly to collect HGS data from young skiers and to compare them with existing normative values; and secondly, to investigate whether the frequency of falls during a day of skiing correlates with HGS.

Materials and Methods

This is an extension of a study on HGS in recreational downhill skiers aged 18–69 years published recently in this journal.¹⁰ HGS of this adult age group could readily be compared with existing reference values from a normal adult population.¹¹ As the original survey collected data from people aged 6 years and older,¹² here we present data for children and adolescents in the age group of 19-25 years for comparison purposes.

In brief, recreational downhill skiers (N=251, from various nations) of both sexes aged 6–18 years (N = 116, 52% male) and 19–25 years (N = 135, 46% male) were included. Data were collected on all days of the week during one winter season, at rest points on the slopes, ski huts, ski lifts and cable cars. Participants completed a short questionnaire on demographics, lifestyle, and number of falls on the day of recording and underwent HGS testing.

A Camry EH101 dynamometer was used to assess the HGS. The skiers were instructed to squeeze it as hard as possible while standing upright, with their arms by their sides, elbows flexed at 90°, and forearms in a neutral position. The dominant hand was tested once in a submaximal trial, followed by a maximal trial for 3-5 seconds after rest.

The study was performed according to the Declaration of Helsinki and approved by the Institutional Review Board of the Department of Sport Science (University of Innsbruck).¹²

Statistics

Data are presented as means \pm Standard Deviation (SD) and sex- and age-dependent individual grip strength values. The normal distribution of the data was tested using the Kolmogorov–Smirnov test. Depending on the normality distribution, independent t-tests or Mann-Whitney U tests were used to compare differences between age groups, and Pearson's or Spearman's correlation coefficients were applied to evaluate relationships between HGS and other variables, *i.e.*, frequency of falling. Partial correlation was performed to control for confounding variables, *such as* age. Differences were considered statistically significant at $p < 0.05$. Data analyses were conducted using the SPSS statistical software package (version 24.0).

Results

The characteristics of both sexes in the two age groups, including HGS and the number of falls, are shown in Table 1.

HGS in the dominant hand increased similarly in both sexes from 6 to 13 years, rising from below 10 kg to approximately 28 kg (Figure 1). Average values (SD) of absolute HGS in this age group were 21.3 (8.2) kg for males and 18.7 (7.3) kg for females ($p = 0.15$), and respective relative values were 0.53 (0.13) and 0.46 (0.12) kg/kg body mass ($p = 0.046$). From this age onwards (until 18 years), HGS increased to approximately 47 kg in male skiers and slightly above 30 kg in female skiers (Figure 1). Average values (SD) of absolute HGS in the age group 14 to 18 years were 40.9 (9.4) kg for males and 27.7 (5.6) kg for females ($p < 0.01$), and respective relative values were 0.64 (0.11) and 0.51 (0.10) kg/kg body mass ($p < 0.01$). The corresponding average values (SD) of absolute HGS in the age group 19-25 years were 52.1 (9.2) kg for males and 31.2 (6.3) kg for females ($p < 0.01$), and that of relative HGS 0.68 (0.10) and 0.51 (0.09) kg/kg body mass ($p < 0.01$).

Table 2 shows existing normative HGS data for young, healthy people from European Union (EU) countries and other countries, which can be used to draw comparisons with those of young skiers.

In both male and female skiers, absolute HGS until the age of 18 years was positively correlated with age ($r = 0.84$, $p < 0.05$ and $r = 0.79$, $p < 0.05$), and BMI ($r = 0.60$, $p < 0.05$ and $r = 0.27$, $p < 0.05$). While BMI was still positively correlated with absolute HGS in male ($r = 0.35$, $p < 0.05$) and female ($r = 0.25$, $p < 0.05$) skiers, HGS was no longer correlated with age

in the 19-25 age groups.

Absolute HGS (when controlled for age by the use of partial correlation analysis) was negatively correlated with the number of falls only in female skiers ($r = 0.28$, $p < 0.05$ for the age group 6-18 years, and $r = -0.24$, $p < 0.05$ for the age group 19-25 years). The time spent on the slopes before the survey (and assessment of handgrip strength) did not differ between the two age groups or sexes and was approximately three hours (Table 1).

Discussion

Our results demonstrate the characteristic progression of HGS in young male and female skiers during growth and early adulthood. Furthermore, HGS in female skiers up to the age of 18 and in the age group 19-25 years was negatively correlated with the frequency of reported falls.

The magnitude and developmental trajectory of HGS in the present cohort aged 6-18 years were largely consistent with reference data from European and U.S. populations (Table 2).¹³⁻¹⁷ Across all ages, HGS increased progressively in male and female skiers, with male skiers having slightly higher absolute and relative HGS from early childhood to adolescence. The modest differences observed between male and female skiers align with prior evidence indicating limited sex divergence before puberty.^{16,18}

From mid-adolescence onward, sex differences were more pronounced. In the 14-18-year age group, males exhibited an almost 50% higher average HGS than that of females. This pattern reflects the well-documented pubertal acceleration of sex differences in muscular strength, driven by divergent hormonal profiles and muscle mass gains.^{16,19,20} In line with previous research, age and body mass were the main predictors of HGS in skiers younger than 25 years.^{21,22} Although stature has been reported as an additional determinant,²³ no significant association between height and HGS was observed in this study, potentially reflecting cohort-specific characteristics or variations in body composition. The further increase of HGS among young adults aged 19-25 years is in accordance with established normative ranges reported for European populations (Table 2),²⁴⁻²⁶ but range above typical values for Asian populations.²⁷ Overall, the HGS levels observed in this study were within the expected norms, particularly aligning with European reference values, underscoring the need for caution in cross-regional comparisons due to population-specific differences.

The weak negative correlation between HGS and the frequency of falls among female skiers

suggests that reduced strength in women compared to men may play a greater role in the risk of falling and related injury.²⁸ In older adults, HGS is a well-established predictor of falls, consistently showing that lower HGS is associated with a higher risk of falling.²⁹⁻³³ While HGS has been identified as a strong marker of bone health in paediatric populations,³⁴ no direct links between HGS and the risk of falls have been described in children. However, epidemiological data indicate that children and older adults have a higher risk of falling, with deficits in balance and muscle strength identified as mediators or key contributing factors.³⁵⁻³⁷ In addition, balance itself may affect muscle strength through transfer effects.³⁸ This emphasizes the critical role of sufficient muscle strength for safe skiing, as supported by the findings of the present study. Additionally, especially in sports that require contractile explosive capacities in situations with high postural demands, such as skiing, and balancing exercises on unstable bases are recommended. This is further supported by evidence identifying the musculoskeletal immaturity of children as a major factor in ski-related injuries.³⁹ Since the level of skiing experience – which is also a contributor to falls and accidents on ski slopes³⁹ – was not evaluated in this study, it is not possible to distinguish between the involvement of both factors.

Besides strengthening exercises, effective preventive measures include developing skills through professional instruction, such as at a ski school, and using properly fitted equipment based on weight, height, and experience.³⁹ Protective gear like helmets and back protectors is essential for safety during falls. Importantly, pre-season resistance training tailored to age and sport can effectively build strength and likely contribute to the reduction of fall and injury risk.³⁵ HGS assessment can help identify insufficient muscle strength.

In summary, the average young recreational downhill skier has a normal HGS for their age and sex. It can only be cautiously assumed that the reason why female skiers with lower HGS fall more often is, at least partially, a consequence of their generally lower muscle strength. Nevertheless, as HGS is widely recognized as a good, accessible marker for overall muscular fitness, the findings suggest that – what is well established for adults – physical preparation before skiing trips is certainly an important preventive factor for children and adolescents, especially for female skiers and people from non-alpine regions who are less accustomed to skiing-related demands.

References

1. Agostinis-Sobrinho C, García-Hermoso A, Ramírez-Vélez R, et al. Longitudinal association between ideal cardiovascular health status and muscular fitness in adolescents: The LabMed Physical Activity Study. *Nutr Metab Cardiovasc Dis* 2018;28:892-9.
2. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes (Lond)* 2008;32:1-11.
3. Ramírez-Vélez R, Tordecilla-Sanders A, Correa-Bautista JE, et al Handgrip strength and ideal cardiovascular health among colombian children and adolescents. *J Pediatr* 2016;179:82-89.e81.
4. Wind AE, Takken T, Helders PJ, Engelbert RH. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? *Eur J Pediatr* 2010;169:281-7.
5. Morrissey MC, Seto JL, Brewster CE, Kerlan RK. Conditioning for skiing and ski injury prevention. *J Orthop Sports Phys Ther* 1987;8:428-37.
6. Burtscher M, Federolf PA, Nachbauer W, Kopp M. Potential health benefits from downhill skiing. *Front Physiol* 2018;9:1924.
7. Pötzelsberger B, Kösters A, Finkenzeller T, Müller E. Effect of aging on muscle and tendon properties in highly functioning elderly people. *Scand J Med Sci Sports* 2019;29:35-43.
8. Zwick EB, Kocher R. Growth dynamics in the context of pediatric sports injuries and overuse. *Semin Musculoskelet Radiol* 2014;18:465-8.
9. Ruedl G, Posch M, Tecklenburg K, et al. Impact of ski geometry data and standing height ratio on the ACL injury risk and its use for prevention in recreational skiers. *Br J Sports Med* 2022:bjsports-2021-105221.
10. Burtscher J, Strasser B, Ruedl G, et al. Hand-grip strength in recreational downhill skiers: a comparison to normative reference values. *Eur J Transl Myol* 2024;34:13021.
11. Wang YC, Bohannon RW, Li X, et al. Hand-grip strength: normative reference values and equations for individuals 18 to 85 years of age residing in the United States. *J Orthop Sports Phys Ther* 2018;48:685-93.
12. Menz V, Philippe M, Pocecco E, et al. The use of medication and alcohol in recreational downhill skiers: Results of a survey including 816 subjects in Tyrol. *J Sci Med Sport* 2019;22:S22-S26.
13. De Miguel-Etayo P, Gracia-Marco L, Ortega FB, et al. Physical fitness reference

- standards in European children: the IDEFICS study. *Int J Obesity* 2014;38:S57-S66.
14. Saint-Maurice PF, Laurson K, Welk GJ, et al. Grip strength cutpoints for youth based on a clinically relevant bone health outcome. *Arch Osteoporos* 2018;13:92.
 15. Kocher MH, Oba Y, Kimura IF, et al. Allometric grip strength norms for American children. *J Strength Cond Res* 2019;33:2251-61.
 16. Tomkinson GR, Carver KD, Atkinson F, et al. European normative values for physical fitness in children and adolescents aged 9-17 years: results from 2 779 165 Eurofit performances representing 30 countries. *Br J Sports Med* 2018;52:1445-563.
 17. Roriz De Oliveira MS, Seabra A, Freitas D, et al. Physical fitness percentile charts for children aged 6-10 from Portugal. *J Sports Med Phys Fitness* 2014;54:780-92.
 18. Rostamzadeh S, Saremi M, Abouhossein A, et al. Normative data for handgrip strength in Iranian healthy children and adolescents aged 7-18 years: comparison with international norms. *Ital J Pediatr* 2021;47:164.
 19. Gómez-Campos R, Vidal Espinoza R, de Arruda M, et al. Relationship between age and handgrip strength: Proposal of reference values from infancy to senescence. *Front Public Health* 2022;10:1072684.
 20. Zárata-Osuna F, Zapico AG, González-Gross M. Handgrip strength in children and adolescents aged 3 to 16 years and residing in Spain: new reference values. *Children (Basel)* 2025;12:471.
 21. Richardson CG, Opatowsky AR, Chin C, et al. The relationship of handgrip strength to body composition and cardiopulmonary fitness in children and young adults. *J Pediatr Clin Pract* 2025;16:200144.
 22. Alshahrani MS, Thomas RA, Samuel PS, et al. Predictive analysis of dominant hand grip strength among young children aged 6-15 years using machine learning techniques: a decision tree and regression analysis. *Front Pediatr* 2025;13:1569913.
 23. O'Hanlon R, Grasso A, Roughton M, et al. Prognostic significance of myocardial fibrosis in hypertrophic cardiomyopathy. *J Am Coll Cardiol* 2010;56:867-74.
 24. Pettersson-Pablo P, Nilsson TK, Hurtig-Wennlöf A. Handgrip strength reference intervals in Swedish, young, healthy adults: The LBA study. *Nutrition* 2023;105:111867.
 25. Dodds RM, Syddall HE, Cooper R, et al. Grip strength across the life course: normative data from twelve British studies. *PLoS One* 2014;9:e113637.
 26. Steiber N. Strong or weak handgrip? Normative reference values for the german population across the life course stratified by sex, age, and body height. *PLoS One*

- 2016;11:e0163917.
27. He H, Pan L, Wang D, et al. Normative values of hand grip strength in a large unselected Chinese population: evidence from the China National Health Survey. *J Cachexia Sarcopenia Muscle* 2023;14:1312-21.
 28. Ruedl G, Burtscher M. Why not consider a sex factor within the ISO 11088 ski binding setting standard? *Br J Sports Med* 2019;53:1127-8.
 29. Ma Y, Qiao J, Wang Z, et al. The genetic causal effect of hand grip strength on osteoporosis and falling risk: a Mendelian randomization study. *Front Endocrinol (Lausanne)* 2024;15:1433805.
 30. Huang L, Shen X, Zou Y, Wang Y. Effects of BMI and grip strength on older adults' falls-A longitudinal study based on CHARLS. *Front Public Health* 2024;12:1415360.
 31. Pham T, McNeil JJ, Barker AL, et al. Longitudinal association between handgrip strength, gait speed and risk of serious falls in a community-dwelling older population. *PLoS One* 2023;18:e0285530.
 32. Liu H, Hou Y, Li H, Lin J. Influencing factors of weak grip strength and fall: a study based on the China Health and Retirement Longitudinal Study (CHARLS). *BMC Public Health* 2022;22:2337.
 33. Dong G, Guo Y, Tu J, et al. Association between grip strength level and fall experience among older Chinese adults: a cross-sectional study from the CHARLS. *BMC Geriatr* 2025;25:156.
 34. Torres-Costoso A, López-Muñoz P, Martínez-Vizcaíno V, et al. Association between muscular strength and bone health from children to young adults: a systematic review and meta-analysis. *Sports Med* 2020;50:1163-90.
 35. Granacher U, Muehlbauer T, Gollhofer A, et al. An intergenerational approach in the promotion of balance and strength for fall prevention - a mini-review. *Gerontology* 2011;57:304-15.
 36. Granacher U, Gollhofer A. Is there an association between variables of postural control and strength in prepubertal children? *J Strength Cond Res* 2012;26:210-6.
 37. Arvandi M, Strasser B, Volaklis K, et al. Mediator effect of balance problems on association between grip strength and falls in older adults: results from the KORA-age study. *Gerontol Geriatr Med* 2018;4:2333721418760122.
 38. Gruber M, Gruber SB, Taube W, et al. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *J Strength Cond Res* 2007;21:274-82.

39. Meyers MC, Laurent CM, Higgins RW, Skelly WA. Downhill ski injuries in children and adolescents. *Sports Med* 2007;37:485-99.

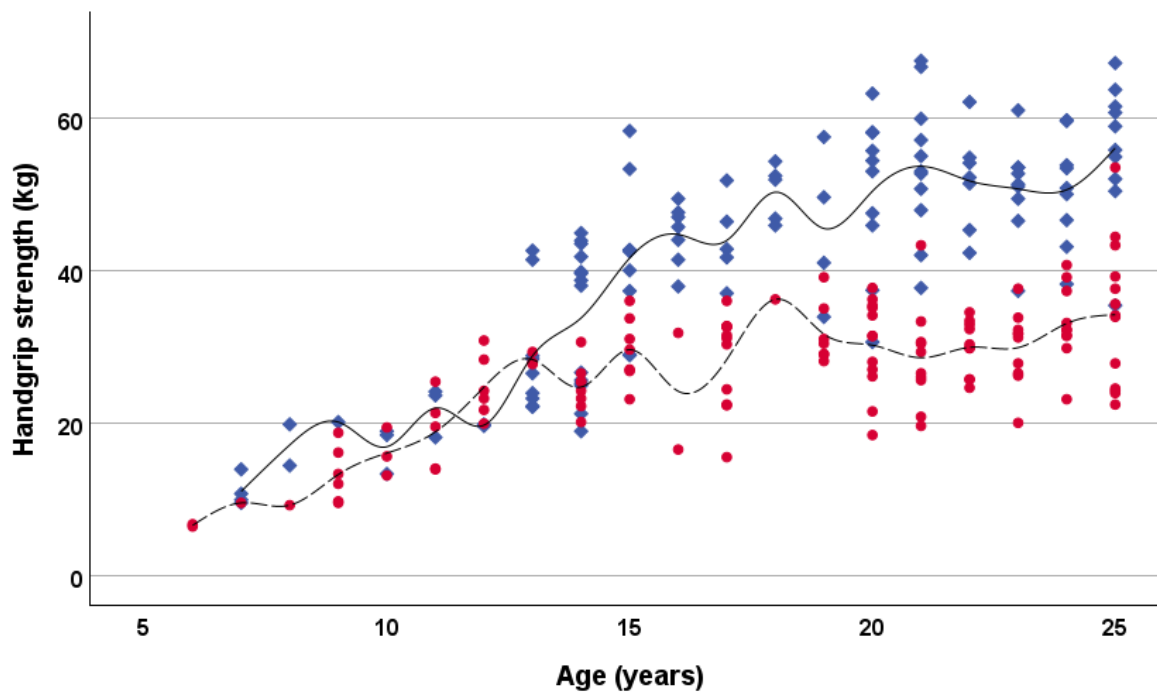
Table 1. Characteristics and number of falls (on the day of recording) for both sexes in the two age groups.

| Age Group | Male skiers | Female skiers | p-values |
|--------------------------|--------------------|----------------------|-----------------|
| 6 – 18 years | N = 60 | N = 56 | |
| Age (years) | 13.3 (2.7) | 13.0 (3.1) | ns |
| Height (cm) | 164 (16.6) | 156 (17.0) | < 0.01 |
| Body mass (kg) | 53.9 (16.3) | 48.3 (19.5) | < 0.05 |
| BMI (kg/m ²) | 19.3 (3.3) | 18.7 (3.9) | ns |
| HGS (kg) | 33.4 (13.1) | 23.0 (8.0) | < 0.01 |
| Skiing hours | 3.3 (1.4) | 3.0 (1.4) | ns |
| Number of falls | 0.7 (1.1) | 0.9 (1.6) | ns |
| Age Group | Male skiers | Female skiers | p-values |
| 19 – 25 years | N = 62 | N = 73 | |
| Age (years) | 22.3 (1.9) | 22.2 (2.0) | ns |
| Height (cm) | 181 (6.4) | 169 (6.4) | < 0.01 |
| Body mass (kg) | 76.9 (10.7) | 61.0 (7.3) | < 0.01 |
| BMI (kg/m ²) | 23.5 (2.9) | 21.3 (2.0) | < 0.01 |
| HGS (kg) | 52.1 (9.2) | 31.2 (6.3) | < 0.01 |
| Skiing hours | 3.4 (1.7) | 3.0 (1.4) | ns |
| Number of falls | 1.0 (2.1) | 1.3 (5.9) | ns |

Table 2. Age-dependent reference values (median or mean) for handgrip strength (in kg) from several countries/cities of the European Union (EU) in bold and from individual countries.

| | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------------|--|--|--|--|------|--|--|--|--|------|--|------|--|--|------|--|--|--|--|------|--|--|------|
| Dodds et al. (median) | | | | | | | | | | | | | | | | | | | | | | | |
| UK | | | | | 16.0 | | | | | 24.0 | | | | | 28.0 | | | | | 30.0 | | | 31.0 |
| Steiber et al. (mean) | | | | | | | | | | | | | | | | | | | | | | | |
| Germany | | | | | | | | | | | | 31.5 | | | 23.5 | | | | | 33.6 | | | |

Figure 1. Age-dependent handgrip strength (dominant hand) development (interpolation lines) from childhood to the age of 25 years. Males are marked with blue and females with red symbols.



List of Abbreviations

BMI, Body mass index

EU, European Union

HGS, Handgrip strength

SD, Standard deviation

UK, United Kingdom

US, United States of America

Corresponding Author

Martin Burtcher, University of Innsbruck, A-6020 Innsbruck

E-mail: martin.burtscher@uibk.ac.at

0000-0002-5232-3632

Verena.menz@uibk.ac.at; orcid.org/0000-0003-1833-6568

Marc.philippe@olympiazentrum-vorarlberg.at; orcid.org/0009-0005-3868-9880

Elena.pocecco@uibk.ac.at; orcid.org/0000-0002-3730-1961

Johannes.burtscher@i-med.ac.at; orcid.org/0000-0002-2889-0151

Barbara.strasser@med.sfu.ac.at; orcid.org/0000-0002-4318-5629

Gerhard.ruedl@uibk.ac.at; orcid.org/0000-0001-5036-7984

Martin.kopp@uibk.ac.at; orcid.org/0000-0002-3011-387X

Martin.burtscher@uibk.ac.at; orcid.org/0000-0002-5232-3632

Contributions

Martin Burtscher was responsible for the conception and design of the study; Verena Menz, Marc Philippe, Elena Pocecco, and Gerhard Ruedl were involved in data collection; Martin Burtscher, Johannes Burtscher, and Barbara Strasser were involved in the processing and statistical analysis of data; Martin Burtscher, Johannes Burtscher, Verena Menz, and Marc Philippe were involved in the drafting of the manuscript; all authors contributed to the interpretation of the data for the work and revising it critically for important intellectual content. Martin Burtscher was responsible for obtaining project funding and takes responsibility for the integrity of the work as a whole. All authors have read and approved the final version of the manuscript.

Conflict of interest

None of the authors report any conflict of interest related to this study.

Ethics approval: the Institutional Review Board of the Department of Sport Science (University Innsbruck) approved this study (see Reference 10, 12). This study was conducted in accordance with the Helsinki Declaration of 1964, as revised in 2013, concerning human and animal rights.

Informed consent: all participants (both children and their parents) in this study provided verbal informed consent (on the ski slope).

Availability of data and materials: all data generated or analyzed during this study are included in this published article.

Acknowledgements

We thank the Austrian Ski Federation for their valuable support in this study.