

## Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Johannes Burtscher,<sup>1\*</sup> Barbara Strasser,<sup>2,3\*</sup> Gerhard Ruedl,<sup>1</sup> Elena Pocecco,<sup>1</sup> Verena Menz,<sup>1</sup> Marc Philippe,<sup>4</sup> Martin Kopp,<sup>1</sup> Martin Burtscher<sup>1</sup>

<sup>1</sup>Department of Sport Science, University of Innsbruck, Innsbruck, Austria; <sup>2</sup>Ludwig Boltzmann Institute for Rehabilitation Research, Vienna, Austria; <sup>3</sup>Faculty of Medicine, Sigmund Freud Private University, Vienna, Austria; <sup>4</sup>Olympiazentrum Vorarlberg GmbH, Dornbirn, Austria.

\*shared first-authorship, equal contribution.

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### Abstract

Hand-grip strength was evaluated in 757 recreational downhill skiers and compared to 1021 community-dwellers. Findings are reported for age and sex categories consistent with community-dwelling norms. Effect size (Cohen's *d*) was calculated to estimate the clinical relevance of strength differences between populations. Most male and half of the female age categories of downhill skiers demonstrated higher grip strength of the dominant hand (moderate to large effect size) compared to the reference population. Hand-grip strength in skiers declined with age at a similar rate as in the reference population. Relative grip strength (per kg body mass) was significantly and positively correlated with physical activity (hours/week), and with the number of ski days per year, and negatively with body mass. Thus, hand-grip strength may be related to the type, volume and intensity of exercise regularly performed. These results can help to assess whether the individual hand-grip strength is above or below average with regard to the normal population and the skier population as well and will support advice for training and/or rehabilitation.

**Key Words:** downhill skiing, muscle strength, aging, sex.

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Downhill (alpine) skiing is the most popular winter sport, exceeding 400 million skier days yearly, recorded in more than 2000 downhill ski areas worldwide.<sup>1</sup> This sport is practiced by recreational skiers of a wide age range (about 3 to 90+ years) of both sexes.<sup>2</sup> Downhill skiing at an older age, *i.e.*, >60 years, requires the maintenance of appropriate muscle strength, which can be achieved through a generally physically active lifestyle and/or specific preparatory training.<sup>3</sup> The biomechanical characteristics of downhill skiing are challenging for older people and include the coordinated performance of repetitive (primarily eccentric and static) loading of the leg muscles across a broad range of intensities.<sup>4</sup> Insufficient muscle strength makes skiing down steep slopes and getting up after a fall more difficult and increases the risk of injury.<sup>5</sup> High values of leg muscle strength are characteristic for downhill skiers and may represent a crucial pre-requisite for good skiing performance and the prevention of injury.<sup>6-8</sup> Thus, being still able to ski at a higher age could be an indication of appropriate muscular power and healthy aging. As hand-grip strength is an acceptable indicator of overall muscle strength,<sup>9</sup> including of lower limb strength,<sup>10</sup> the present study was aimed at evaluating hand-grip strength in a large population of downhill skiers and comparing these values

to the normal population, considering age and sex. We hypothesized that muscle strength, *i.e.*, hand-grip strength (as an easy-to-use test) of active downhill skiers is higher at all ages and declines more slowly with age than in the normal population.

### Materials and Methods

The full methods of the study have been reported elsewhere.<sup>11</sup> Briefly, the characteristics of skiers (by interview) and grip strength (by hand dynamometry) have been recorded/assessed in six large ski resorts in Tyrol, Austria.

### Participants

Recreational downhill skiers (N=757, from various nations) of both sexes aged from 18 to 69 years were included. Data were collected throughout all days of the week for one winter season in 2014: during rest periods on the slope, at ski huts, or the ski lifts/cable cars. Skiers were randomly selected with no in- or exclusion criteria other than age. Participants completed a brief survey including questions about basic anthropometric data, *i.e.*, age, height, weight, and lifestyle characteristics, *i.e.*, smoking, alcohol drinking, and physical activity. The re-

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Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

jection rate was below 3% and the reasons for rejections were “no interest” or “no time to participate”.

### Hand-grip strength testing

A calibrated electronic hand dynamometer (Camry, EH101, Camry Scale, CA, USA) was used. Skiers were instructed to squeeze the dynamometer as hard as possible standing upright, with arms by their sides, elbows flexed to 90°, and forearms in a neutral position. A single submaximal practice trial was done for each (right and left) hand, and after one-minute rest, a single maximal trial of 3 to 5 seconds was performed for each hand (the results of which were recorded and analyzed).

### Ethics

The study was performed according to the Declaration of Helsinki and was approved by the Institutional Review Board of the Department of Sport Science (University of Innsbruck);<sup>11</sup> informed consent was received and the rights of the subjects were protected.

### Statistics

Data are presented as means ± standard deviation (SD). Normal distribution of data was tested by 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 hand grip strength and other variables. Cohen’s d was calculated for effect size (ES) of all comparisons between skiers and the normal population of the same age group. Clinical relevance of differences is indicated by the value of ES, *i.e.*, ES <0.2 are negligible, 0.2 <0.5 small, 0.5 <0.8 moderate and ≥ 0.8 large. Mean differences in the decline of hand-grip strength (percentage decline from the age group with the highest value to that of

the oldest age group) have been calculated and 95% confidence intervals are reported for men and women of both populations (alpine skiers and the normal population). Differences were considered statistically significant at  $p < 0.05$ . Data analyses were conducted with the SPSS statistical software package (Version 24.0).

### Results

Anthropometric and physical activity data for 10 age groups of male and female skiers are shown in Tables 1 and 2 and the results of hand-grip testing in Table 3 and 4. Hand-grip data were compared with normative reference values of hand grip strength for the same 10 age groups of both sexes obtained from a previous study.<sup>9</sup> Figure 1 visualizes age-dependent changes in hand grip strength for skiers and the normal population.

The absolute hand-grip strength values of the dominant and non-dominant hand were closely correlated in male skiers ( $r=0.82$ ,  $p < 0.05$ ) and female skiers ( $r=0.83$ ,  $p < 0.05$ ) as well. These absolute hand-grip strength values were significantly correlated with body mass ( $r=0.25$ ,  $p < 0.05$ , in male skiers and  $r=0.22$ ,  $p < 0.05$ , in female skiers). The relative hand-grip strength (grip strength/kg) of the dominant hand was significantly and positively correlated with physical activity (hours/week) ( $r=0.21$ ,  $p < 0.05$ ), and with ski days per year ( $r=0.23$ ,  $p < 0.05$ ), and negatively with body mass ( $r=-0.44$ ,  $p < 0.05$ ); similar correlations were found between relative hand-grip strength of the non-dominant hand and physical activity (hours/week) ( $r=0.26$ ,  $p < 0.05$ ), and with ski days per year ( $r=0.26$ ,  $p < 0.05$ ), and negatively with body mass ( $r=-0.42$ ,  $p < 0.05$ ).

The decline in hand-grip strength (dominant hand) from the age group with the highest values to that of the oldest age group (64 – 69 years) was 28% (95% CI: 19.4% - 35.4%) in male skiers compared to 26% (95% CI: 13.6% - 38.0%) in men of the normal population. In contrast, this decline

**Table 1.** Characteristics of male skiers

| Age group (years) | N  | Height (cm) | Weight (kg) | BMI        | Exercise (hours/week) | Skiing (days/year) |
|-------------------|----|-------------|-------------|------------|-----------------------|--------------------|
| 18-24             | 56 | 179.5 (6.4) | 74.7 (10.1) | 23.2 (2.7) | 6.2 (4.0)             | 13.0 (11.9)        |
| 25-29             | 57 | 181.8 (6.6) | 78.6 (8.8)  | 23.8 (2.4) | 7.5 (8.2)             | 21.7 (19.4)        |
| 30-34             | 43 | 180.9 (5.2) | 80.8 (8.2)  | 24.7 (2.6) | 6.5 (5.0)             | 19.8 (25.4)        |
| 35-39             | 19 | 181.6 (7.6) | 81.1 (10.4) | 24.5 (2.0) | 6.1 (5.7)             | 20.4 (25.2)        |
| 40-44             | 37 | 179.9 (7.1) | 83.6 (12.1) | 25.9 (3.4) | 5.7 (5.1)             | 19.4 (21.7)        |
| 45-49             | 47 | 179.9 (7.3) | 83.0 (10.6) | 25.6 (2.7) | 4.8 (4.7)             | 12.0 (8.7)         |
| 50-54             | 73 | 180.7 (6.8) | 85.1 (12.2) | 26.0 (2.9) | 5.2 (5.4)             | 15.7 (18.7)        |
| 55-59             | 33 | 179.4 (6.9) | 82.3 (11.1) | 25.5 (2.4) | 5.9 (8.1)             | 16.1 (13.6)        |
| 60-64             | 29 | 179.2 (9.3) | 83.0 (11.7) | 25.8 (2.7) | 5.6 (4.5)             | 19.8 (30.4)        |
| 65-69             | 15 | 176.0 (6.3) | 81.6 (12.0) | 26.3 (3.4) | 4.4 (3.4)             | 17.0 (10.7)        |

# Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

was only 14% (95% CI: 0.6% - 28.8%) in female skiers compared to 26% (95% CI: 16.1% - 36.4%) in women of the normal population.

## Discussion

The majority of age categories of male (8 out of 10) and half of female downhill skiers demonstrated higher grip strength of the dominant hand (statistical significance and moderate or large effect size) compared to the normal population evaluated by Wang *et al.*<sup>9</sup> However, the expectedly less-pronounced age-related decline in hand-grip strength in skiers was not confirmed.

The higher hand-grip strength values in some age categories of skiers, compared to the normal population, may be related to higher physical fitness levels and associated muscle strength,<sup>12,13</sup> which is necessary to perform downhill skiing but also promoted by general engagement in winter outdoor activities.<sup>14</sup> The favorable impact of physical activity and skiing practice is emphasized by the positive relationship between these factors and the measured hand-grip strength in the present study. The negative relationship between relative hand-grip strength and body mass in skiers may indicate unfavorable effects of increasing fat mass (and reduced lean body mass),<sup>15</sup> which is characteristic of older people not sufficiently engaged in regular physical activity.<sup>16</sup> However, besides physical activity, ethnic differences between the compared populations could have contributed to the hand-grip strength differences observed.<sup>17</sup> Although the skier population of the present study consisted of various nationalities, the proportion of Caucasian people may be dominant.<sup>18</sup> Günther and colleagues reported reference values for healthy Caucasian people (region Munich, Germany) also of a wide age range of both sexes (403 women and 366 men).<sup>19</sup> These authors report hand-grip strength values similar to those of the skiers in the present study, e.g., 54 kg (right hand) in men aged 30-39 years, and 33 kg

in the same age group of women.<sup>19</sup> Also, the decline with age was similar but slightly steeper (from 33 to 26 kg for the right hand in the age group 60 – 69 years) when compared to female skiers (from 33.1 to 28.4 kg). A significant proportion of the cohort evaluated by Günther *et al.* likely practice downhill skiing or other alpine sports activities because those people live close to the Alps.<sup>19</sup>

A study reporting hand-grip strength of senior athletes drawing comparisons to some age groups (50 – 69 years) of the same normal populations as in the present study showed similar or larger strength values of senior athletes compared to alpine skiers.<sup>20</sup> These findings are not surprising as these athletes were still competing in one of a National Senior Games event. Thus, hand-grip strength values of skiers are somewhere between those of the normal population and (still active) senior athletes.

Similar hand-grip strength values as measured in skiers of the present study have been reported in male and female athletes participating in the 2022 World Master Weightlifting Championships (considering ages from 40 to 69 years), while comparisons to community-dwelling adults revealed significantly higher and to Senior Games athletes lower grip-strength values.<sup>21</sup> Again, the rate of decline was similar across different populations (weightlifters, other athletes, community-dwelling adults).<sup>21</sup> This observation is in line with the findings from a systematic review and meta-analyses which revealed that chronic exercise training does not prevent age-related declines in muscular strength.<sup>22</sup> However, higher absolute levels of strength provide skiers with a greater strength reserve, thus delaying the onset of impaired function.

Several markers of muscular strength, including hand-grip strength, are improved by regular physical activity in older adults but inevitably decline with aging.<sup>9,19,23</sup> Our hypothesis that older skiers will better maintain hand-grip strength has to be rejected. However, both male and female skiers of the oldest age group exceeded a proposed threshold value of hand-grip strength (28 kg for men and 18 kg for women)

**Table 2.** Characteristics of female skiers

| Age group (years) | N  | Height (cm) | Weight (kg) | BMI        | Exercise (hours/week) | Skiing (days/year) |
|-------------------|----|-------------|-------------|------------|-----------------------|--------------------|
| 18-24             | 59 | 168.5 (6.3) | 61.0 (7.2)  | 21.5 (2.0) | 5.1 (3.3)             | 13.4 (11.9)        |
| 25-29             | 40 | 168.3 (6.3) | 60.4 (7.0)  | 21.4 (2.7) | 5.7 (3.9)             | 15.7 (18.3)        |
| 30-34             | 50 | 169.1 (6.7) | 63.0 (8.4)  | 22.0 (2.6) | 5.2 (3.1)             | 13.2 (14.5)        |
| 35-39             | 19 | 166.8 (5.3) | 61.3 (7.2)  | 22.0 (2.1) | 4.6 (3.3)             | 8.9 (8.0)          |
| 40-44             | 38 | 169.6 (5.9) | 62.7 (8.9)  | 21.8 (2.7) | 3.9 (2.3)             | 14.4 (11.5)        |
| 45-49             | 50 | 167.1 (5.6) | 64.2 (8.7)  | 22.9 (2.3) | 5.6 (6.4)             | 13.6 (11.6)        |
| 50-54             | 46 | 168.0 (6.5) | 66.5 (11.9) | 23.5 (3.6) | 4.4 (3.4)             | 12.9 (10.0)        |
| 55-59             | 21 | 164.6 (5.9) | 63.1 (8.9)  | 23.3 (2.7) | 4.8 (3.2)             | 18.8 (19.4)        |
| 60-64             | 17 | 164.6 (5.2) | 65.7 (8.9)  | 24.3 (3.6) | 3.6 (2.5)             | 13.7 (8.4)         |
| 65-69             | 8  | 165.1 (7.6) | 66.1 (13.0) | 24.2 (4.4) | 4.4 (3.4)             | 14.2 (8.9)         |

### Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

clearly, indicative for above average muscle strength and physical fitness.<sup>24</sup> These observations provide a clue for hand-grip strength necessary for being able to perform

(safely and enjoyable) usual downhill skiing activities.<sup>4</sup> Furthermore, the maintenance of muscle power is critical to preserve sports performance and functionality in ad-

**Table 3.** Results of the hand-grip tests (dominant and non-dominant hand) of 409 male alpine skiers in 10 age groups from 18 to 69 years compared to data from the normal male US population (Reference; 348 men).<sup>9</sup>

| Age group                     | Population | N  | Mean (kg) | SD   | Cohen's d |
|-------------------------------|------------|----|-----------|------|-----------|
| <b>Men, dominant hand</b>     |            |    |           |      |           |
| 18-24                         | Skiers     | 56 | 50.7*     | 8.1  | 0.5       |
|                               | Reference  | 36 | 47.0      | 8.1  |           |
| 25-29                         | Skiers     | 57 | 54.2      | 9.9  | 0.4       |
|                               | Reference  | 35 | 49.7      | 11.6 |           |
| 30-34                         | Skiers     | 43 | 54.8*     | 8.3  | 0.8       |
|                               | Reference  | 29 | 46.5      | 12.1 |           |
| 35-39                         | Skiers     | 19 | 53.5*     | 8.4  | 0.6       |
|                               | Reference  | 41 | 47.1      | 11.9 |           |
| 40-44                         | Skiers     | 37 | 54.9*     | 8.3  | 0.8       |
|                               | Reference  | 47 | 46.7      | 11.7 |           |
| 45-49                         | Skiers     | 47 | 50.9*     | 9.2  | 0.8       |
|                               | Reference  | 32 | 42.8      | 10.9 |           |
| 50-54                         | Skiers     | 73 | 50.6*     | 8.4  | 0.7       |
|                               | Reference  | 46 | 44.0      | 10.3 |           |
| 55-59                         | Skiers     | 33 | 47.8*     | 8.3  | 0.8       |
|                               | Reference  | 27 | 40.7      | 10.4 |           |
| 60-64                         | Skiers     | 29 | 47.1*     | 7.8  | 1.0       |
|                               | Reference  | 33 | 38.4      | 10.3 |           |
| 65-69                         | Skiers     | 15 | 39.4      | 5.6  | 0.3       |
|                               | Reference  | 22 | 36.8      | 10.5 |           |
| <b>Men, non-dominant hand</b> |            |    |           |      |           |
| 18-24                         | Skiers     | 56 | 48.2      | 9.5  | 0.4       |
|                               | Reference  | 36 | 44.9      | 7.8  |           |
| 25-29                         | Skiers     | 57 | 50.8*     | 8.6  | 0.5       |
|                               | Reference  | 35 | 46.5      | 9.6  |           |
| 30-34                         | Skiers     | 43 | 52.3*     | 8.3  | 0.7       |
|                               | Reference  | 29 | 45.8      | 11.3 |           |
| 35-39                         | Skiers     | 19 | 52.1*     | 7.7  | 0.7       |
|                               | Reference  | 41 | 45.5      | 11.0 |           |
| 40-44                         | Skiers     | 37 | 51.4*     | 8.5  | 0.6       |
|                               | Reference  | 47 | 44.9      | 11.7 |           |
| 45-49                         | Skiers     | 47 | 47.8*     | 8.8  | 0.7       |
|                               | Reference  | 32 | 41.2      | 10.0 |           |
| 50-54                         | Skiers     | 73 | 48.8*     | 7.7  | 0.7       |
|                               | Reference  | 46 | 42.3      | 10.6 |           |
| 55-59                         | Skiers     | 33 | 45.1*     | 7.9  | 0.8       |
|                               | Reference  | 27 | 38.5      | 9.6  |           |
| 60-64                         | Skiers     | 29 | 44.3*     | 9.0  | 0.8       |
|                               | Reference  | 33 | 37.2      | 9.1  |           |
| 65-69                         | Skiers     | 15 | 38.3      | 6.5  | 0.3       |
|                               | Reference  | 22 | 35.4      | 10.3 |           |

\*Indicates significant statistical difference between skiers and the normal population,  $p < 0.05$ .

## Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

vanced age. Current evidence indicates that the age-related decline in muscle power better predicts health outcomes than muscle strength.<sup>25,26</sup> The Longevity Check-up 7+

(Lookup 7+) project recently provided normative values of lower extremity muscle power, estimated according to five-repetition sit-to-stand equations.<sup>27</sup> Absolute muscle power

**Table 4.** Results of the hand-grip tests (dominant and non-dominant hand) of 348 female alpine skiers in 10 age groups from 18 to 69 years compared to data from the normal female US population (Reference; 673 women).<sup>9</sup>

| Age group                       | Population | N   | Mean (kg) | SD  | Cohen's d |
|---------------------------------|------------|-----|-----------|-----|-----------|
| <b>Women, dominant hand</b>     |            |     |           |     |           |
| 18-24                           | Skiers     | 59  | 30.7*     | 5.2 | 0.4       |
|                                 | Reference  | 54  | 28.1      | 7.1 |           |
| 25-29                           | Skiers     | 40  | 31.2      | 5.8 | 0.2       |
|                                 | Reference  | 102 | 29.6      | 7.0 |           |
| 30-34                           | Skiers     | 50  | 32.5*     | 4.7 | 0.6       |
|                                 | Reference  | 105 | 28.9      | 6.2 |           |
| 35-39                           | Skiers     | 19  | 31.8      | 4.5 | 0.4       |
|                                 | Reference  | 90  | 29.2      | 6.2 |           |
| 40-44                           | Skiers     | 38  | 33.1*     | 6.3 | 0.5       |
|                                 | Reference  | 88  | 29.9      | 6.2 |           |
| 45-49                           | Skiers     | 50  | 29.3      | 5.3 | 0.1       |
|                                 | Reference  | 52  | 28.8      | 7.2 |           |
| 50-54                           | Skiers     | 46  | 30.4      | 5.3 | 0.4       |
|                                 | Reference  | 65  | 28.2      | 6.3 |           |
| 55-59                           | Skiers     | 21  | 27.2      | 4.2 | 0.4       |
|                                 | Reference  | 30  | 25.1      | 6.2 |           |
| 60-64                           | Skiers     | 17  | 28.9*     | 7.8 | 0.7       |
|                                 | Reference  | 58  | 23.6      | 6.5 |           |
| 65-69                           | Skiers     | 8   | 28.4*     | 5.6 | 1.0       |
|                                 | Reference  | 29  | 22.1      | 6.6 |           |
| <b>Women, non-dominant hand</b> |            |     |           |     |           |
| 18-24                           | Skiers     | 59  | 28.6      | 5.1 | 0.3       |
|                                 | Reference  | 54  | 26.6      | 6.4 |           |
| 25-29                           | Skiers     | 40  | 29.5      | 5.0 | 0.3       |
|                                 | Reference  | 102 | 27.9      | 6.6 |           |
| 30-34                           | Skiers     | 50  | 30.1*     | 4.2 | 0.5       |
|                                 | Reference  | 105 | 27.7      | 5.9 |           |
| 35-39                           | Skiers     | 19  | 30.7      | 5.6 | 0.5       |
|                                 | Reference  | 90  | 28.0      | 6.0 |           |
| 40-44                           | Skiers     | 38  | 31.4*     | 6.4 | 0.4       |
|                                 | Reference  | 88  | 28.9      | 6.4 |           |
| 45-49                           | Skiers     | 50  | 27.9      | 5.8 | 0.1       |
|                                 | Reference  | 52  | 27.4      | 7.2 |           |
| 50-54                           | Skiers     | 46  | 28.0      | 6.0 | 0.2       |
|                                 | Reference  | 65  | 26.5      | 6.6 |           |
| 55-59                           | Skiers     | 21  | 26.2      | 3.1 | 0.5       |
|                                 | Reference  | 30  | 23.6      | 6.4 |           |
| 60-64                           | Skiers     | 17  | 26.1      | 4.2 | 0.6       |
|                                 | Reference  | 58  | 22.9      | 6.3 |           |
| 65-69                           | Skiers     | 8   | 25.5      | 4.0 | 0.8       |
|                                 | Reference  | 29  | 21.0      | 6.6 |           |

\*Indicates significant difference between skiers and the normal population,  $p < 0.05$ .



# Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

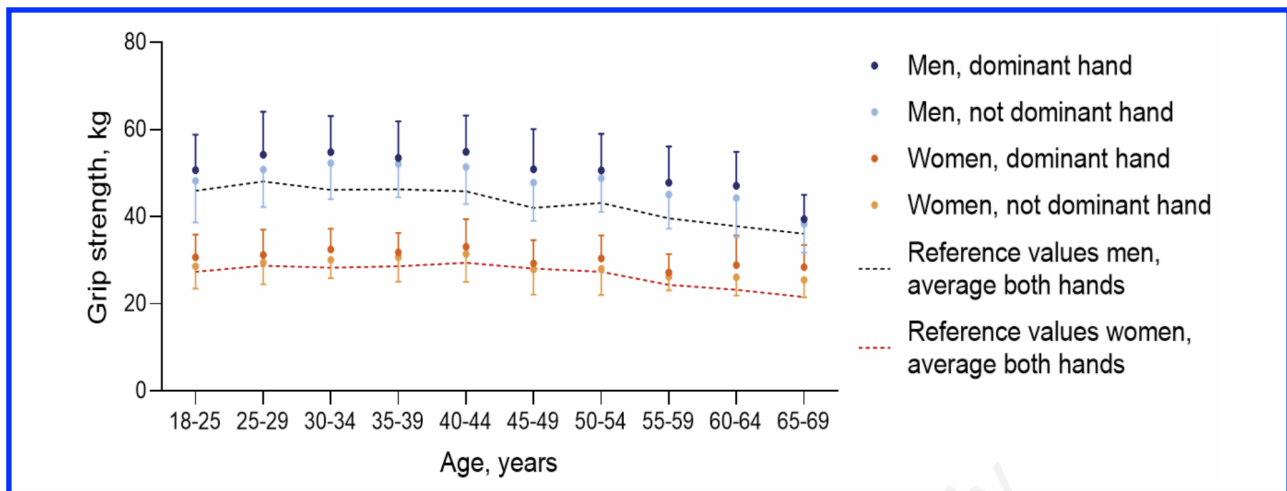


Figure 1. Visualization of age-dependent grip strength values in skiers compared to reference values of a normal population.

peaked at 41–50 and 31–40 years in men and women, respectively. Subsequently, a rate of decline of approximately 12% per decade was observed, regardless of sex. This is in agreement with data from World Records of Master athletes, demonstrating an absence of sex differences in the decline of performance with aging.<sup>28</sup>

Low values of hand-grip strength may not only provide information on the fitness status of downhill skiers but are also closely related to morbidity and mortality of various causes,<sup>29–31</sup> and this association tended to be stronger in women.<sup>32</sup> Thus, the overall health effects in regular long-term downhill skiers are not surprising.<sup>2</sup> On the other hand, the injury risk during downhill skiing should not be underestimated,<sup>33,34</sup> but higher muscular strength has been suggested as a preventive factor, particularly considering the relatively high risk of an anterior cruciate ligament (ACL) injury in female skiers.<sup>35</sup> This risk is about three times greater in women than men, which may, besides neuromuscular factors, be attributed to hormonal and anatomical, but also environmental and equipment-related factors.<sup>34,36</sup>

Furthermore, increased hand-grip strength is associated with a reduced risk of falls in older age, but is partly mediated by balance problems.<sup>37</sup> Generally, the maintenance of appropriate musculoskeletal fitness with aging is a long-known measure for the prevention of injury in sports.<sup>38</sup> As demonstrated by the association between lower hand-grip strength with higher all-cause, cardiovascular, and cancer mortality risk,<sup>29</sup> as well as a higher risk of falls, grip strength measurements in skiers may provide possible clues about the ability to ski and the associated injury risk in older people. Hand-grip strength values are markers for the strength of knee extensor muscles,<sup>10</sup> which are predominantly used in downhill skiing.<sup>39</sup> Both appropriate strength training and performing regular downhill skiing improve lower leg strength and consequently also hand-grip strength.<sup>39</sup> However, it must be noted that muscle strength is only one factor contributing to skiing performance and other parameters, e.g., aerobic and anaerobic endurance, agility, balance capability, and technical skills are also crucial.<sup>8,40</sup>

## Limitations

First, besides age and sex, multiple factors such as height, body mass, type, volume, and intensity of physical activity, pre-existing diseases, and dietary behavior may all influence hand-grip strength, all of them have not been sufficiently considered in the present study. Second, the sample size of some age groups is small likely provoking a type II error. Third, no detailed information was collected, e.g., on geographic, sociocultural and economic characteristics of participants. Hence, potential selection biases cannot be ruled out. Finally, refinements of hand-grip strength measurement protocols are needed<sup>41</sup> for a deeper understanding of age-dependent trajectories of muscle strength in downhill skiers.

In conclusion, this study provides average values of hand-grip strength for 5-year age categories of male and female skiers from 18 to 69 years and draws comparisons to a normal population. On average, recreational alpine skiers have greater hand-grip strength than individuals of the normal population but may have lower strength values than competitive athletes of both sexes across all age groups considered. Differences may be a consequence of the volume and intensity of exercise regularly performed. These results can help to assess whether the individual hand-grip strength is above or below average with regard to the normal population and the skier population as well and will support advice for training and/or rehabilitation. Future studies should determine more precisely the potential impact of hand-grip strength on the age-related skiing ability and the associated risk of injury.

## List of abbreviations

ACL, Anterior cruciate ligament  
CI, Confidence Interval  
ES, Effect size  
SD, Standard deviation

## Contributions

MB was responsible for the conception and design of the study; EP, VM, GR and MP were involved in data collection; MB, JB, and BS were involved in the processing and statistical analysis of data; MB, JB, BS, and MK were involved in the drafting of the manuscript; and all authors contributed to the interpretation of the data for the work and revising it critically for important intellectual content. All the authors finally approved the manuscript. MB was responsible for obtaining project funding and takes responsibility for the integrity of the work as a whole. All authors have read and agreed to the published version of the manuscript.

## Conflict of interest

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

## Ethics approval and consent to participate

The study was performed according to the Declaration of Helsinki and was approved by the Institutional Review Board of the Department of Sport Science (University of Innsbruck); informed consent was received and the rights of the subjects were protected.

## Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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## Corresponding author

Prof. Martin Burtscher, MD, PhD, University of Innsbruck, A-6020 Innsbruck.  
ORCID ID: 0000-0002-5232-3632  
E-mail: martin.burtscher@uibk.ac.at

Johannes Burtscher  
ORCID ID: 0000-0002-2889-0151  
E-mail: Johannes.burtscher@uibk.ac.at

Barbara Strasser  
ORCID ID: 0000-0002-4318-5629  
E-mail: Barbara.strasser@med.sfu.ac.at

Gerhard Ruedl  
ORCID ID: 0000-0001-5036-7984  
E-mail: Gerhard.ruedl@uibk.ac.at

Elena Pocecco  
ORCID ID: 0000-0002-3730-1961  
E-mail: Elena.pocecco@uibk.ac.at

Verena Menz  
ORCID ID: 0000-0003-1833-6568  
E-mail: Verena.menz@uibk.ac.at

Marc Philippe  
ORCID ID: 0009-0005-3868-9880  
E-mail: Marc.philippe@olympiazentrum-vorarlberg.at

Martin Kopp  
ORCID ID: 0000-0002-3011-387X  
E-mail: Martin.kopp@uibk.ac.at

## References

1. Vanat L. 2018 International Report on Snow & Mountain Tourism. June 2018.
2. Burtscher M, Bodner T, Burtscher J, et al. Life-style characteristics and cardiovascular risk factors in regular downhill skiers: an observational study. *BMC Public Health* 2013;13:788.
3. Pötzelberger 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.
4. Burtscher M, Federolf PA, Nachbauer W, Kopp M. Potential Health Benefits From Downhill Skiing. *Front Physiol* 2018;9:1924.
5. Morrissey MC, Seto JL, Brewster CE, Kerlan RK. Conditioning for skiing and ski injury prevention. *J Orthop Sports Phys Ther* 1987;8:428-437.
6. White AT, Johnson SC. Physiological aspects and injury in elite Alpine skiers. *Sports Med* 1993;15:170-178.
7. Raymond-Pope CJ, Dengel DR, Fitzgerald JS, et al. Anterior cruciate ligament reconstructed female athletes exhibit relative muscle dysfunction after return to sport. *Int J Sports Med* 2021;42:336-43.
8. Neumayr G, Hoernagl H, Pfister R, et al. Physical and physiological factors associated with success in professional alpine skiing. *Int J Sports Med* 2003;24:571-5.
9. 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.
10. Strandkvist V, Larsson A, Pauelsen M, et al. Hand grip strength is strongly associated with lower limb strength but only weakly with postural control in community-dwelling older adults. *Arch Gerontol Geriatr* 2021;94:104345.
11. 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:S22-6.
12. Landi F, Calvani R, Tosato M, et al. Age-related variations of muscle mass, strength, and physical performance in community-dwellers: results from the Milan EXPO Survey. *J Am Med Dir Assoc* 2017;18:88.e17-88.e24.
13. Labott BK, Bucht H, Morat M, et al. Effects of exercise training on handgrip strength in older adults: a meta-analytical review. *Gerontology* 2019;65:686-98.
14. Stanaszek M, Fugiel J, Kozieł S, et al. Effect of winter outdoor physical activity on body composition and motor performance of polish adult men. *Healthcare (Basel)* 2023;11:2348.
15. Castillo C, Carnicero JA, de la Torre M, et al. Nonlinear relationship between waist to hip ratio, weight and

## Hand-grip strength in recreational downhill skiers: a comparison to normative reference values

Eur J Transl Myol 34 (4) 13021, 2024 doi: 10.4081/ejtm.2024.13021

- strength in elders: is gender the key? *Biogerontology* 2015;16:685-92.
16. González-Rocha A, Mendez-Sanchez L, Ortíz-Rodríguez MA, Denova-Gutiérrez E. Effect of exercise on muscle mass, fat mass, bone mass, muscular strength and physical performance in community dwelling older adults: systematic review and meta-analysis. *Aging Dis* 2022;13:1421-35.
  17. Bhat AK, Jindal R, Acharya AM. The influence of ethnic differences based on upper limb anthropometry on grip and pinch strength. *J Clin Orthop Trauma* 2021;21:101504.
  18. Burtcher M, Gatterer H, Flatz M, et al. Effects of modern ski equipment on the overall injury rate and the pattern of injury location in Alpine skiing. *Clin J Sport Med* 2008;18:355-7.
  19. Günther CM, Bürger A, Rickert M, Crispin A, Schulz CU. Grip strength in healthy caucasian adults: reference values. *J Hand Surg Am* 2008;33:558-65.
  20. Jordre B, Schweinle W. Hand grip strength in senior athletes: normative data and community-dwelling comparisons. *Int J Sports Phys Ther* 2020;15:519-25.
  21. Huebner M, Riemann B, Hatchett A. Grip strength and sports performance in competitive master weightlifters. *Int J Environ Res Public Health* 2023;20:2033.
  22. McKendry J, Breen L, Shad BJ, Greig CA. Muscle morphology and performance in master athletes: A systematic review and meta-analyses. *Ageing Res Rev* 2018; 45:62-82.
  23. Valenzuela PL, Saco-Ledo G, Morales JS, et al. Effects of physical exercise on physical function in older adults in residential care: a systematic review and network meta-analysis of randomised controlled trials. *Lancet Healthy Longev* 2023;4:e247-56.
  24. Kim SH, Kim T, Park JC, Kim YH. Usefulness of hand grip strength to estimate other physical fitness parameters in older adults. *Sci Rep* 2022;12:17496.
  25. Bean JF, Leveille SG, Kiely DK, et al. A comparison of leg power and leg strength within the InCHIANTI study: which influences mobility more? *J Gerontol A Biol Sci Med Sci* 2003;58:728-33.
  26. Hetherington-Rauth M, Magalhães JP, Alcazar J, et al. Relative sit-to-stand muscle power predicts an older adult's physical independence at age of 90 yrs beyond that of relative handgrip strength, physical activity, and sedentary time: a cross-sectional analysis. *Am J Phys Med Rehabil* 2022;101:995-1000.
  27. Coelho-Júnior HJ, Álvarez-Bustos A, Rodríguez-Mañas L, et al. Five-time sit-to-stand lower limb muscle power in older women: an explorative, descriptive and comparative analysis. *J Frailty Aging* 2024; <https://doi.org/10.14283/jfa.2024.50>
  28. Gava P, Giuriati W, Ravara B. Gender difference of aging performance decay rate in normalized Masters World Records of Athletics: much less than expected. *Eur J Transl Myol* 2020;30:8869.
  29. López-Bueno R, Andersen LL, Koyanagi A, et al. Thresholds of handgrip strength for all-cause, cancer, and cardiovascular mortality: A systematic review with dose-response meta-analysis. *Ageing Res Rev* 2022;82: 101778.
  30. Soysal P, Hurst C, Demurtas J, et al. Handgrip strength and health outcomes: Umbrella review of systematic reviews with meta-analyses of observational studies. *J Sport Health Sci* 2021;10:290-5.
  31. Jochem C, Leitzmann M, Volaklis K, Aune D, Strasser B. Association between muscular strength and mortality in clinical populations: a systematic review and meta-analysis. *J Am Med Dir Assoc* 2019;20:1213-23.
  32. Arvandi M, Strasser B, Meisinger C, et al. Gender differences in the association between grip strength and mortality in older adults: results from the KORA-age study. *BMC Geriatr* 2016;16:201.
  33. Dickson TJ, Terwiel FA. Injury trends in alpine skiing and a snowboarding over the decade 2008-09 to 2017-18. *J Sci Med Sport* 2021;24:1055-60.
  34. 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.
  35. Ruedl G, Helle K, Tecklenburg K, et al. Factors associated with self-reported failure of binding release among ACL injured male and female recreational skiers: a catalyst to change ISO binding standards? *Br J Sports Med* 2016;50:37-40.
  36. Posch M, Schranz A, Lener M, Tecklenburg K, Burtcher M, Ruedl G. In recreational alpine skiing, the ACL is predominantly injured in all knee injuries needing hospitalisation. *Knee Surg Sports Traumatol Arthrosc* 2021;29:1790-6.
  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. Kallinen M, Markku A. Aging, physical activity and sports injuries. An overview of common sports injuries in the elderly. *Sports Med* 1995;20:41-52.
  39. Narici MV, Flueck M, Koesters A, et al. Skeletal muscle remodeling in response to alpine skiing training in older individuals. *Scand J Med Sci Sports* 2011;21:23-8.
  40. Wang Z, Cai Y, Wu J, et al. Relationship between lower extremity fitness levels and injury risk among recreational alpine skiers: a prospective cohort study. *Int J Environ Res Public Health* 2022;19:10430.
  41. Núñez-Cortés R, Cruz BDP, Gallardo-Gómez D, et al. Handgrip strength measurement protocols for all-cause and cause-specific mortality outcomes in more than 3 million participants: A systematic review and meta-regression analysis. *Clin Nutr* 2022;41:2473-89.

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