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Physiological Characteristics of Freestyle Snowboard and Freeski Athletes

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Purpose: To investigate the physiological characteristics of freestyle snowboard and freeski athletes and explore potential differences between males and females. ***Methods:*** National-team athletes, snowboard (9 males, 21 [2.3] y; 8 females, 20 [4.1] y) and freeski (10 males, 21 [2.1] y; 8 females, 18 [2.2] y), underwent physiological assessments: maximal oxygen uptake ($\dot{V}O_2$max; indirect), countermovement-jump height, drop-jump (DJ) height, DJ contact time, reactive strength index, absolute peak force (PF_{abs}), and relative peak force. Differences were analyzed using multivariate analyses of variance Wilks lambda (Λ) and magnitude with partial-eta squared (η_p^2). Pairwise comparisons and the impact of sex and sport were analyzed with univariate tests, utilizing Cohen *d*. ***Results:*** No physiological differences were found between snowboard and freeski (Wilks $\Lambda = 0.8$, $P > .251$, $\eta_p^2 = .169$). Sex differences were observed (Wilks $\Lambda = 0.2$, $P < .001$, $\eta_p^2 = .79$), without an interaction between sex and sport ($\Lambda = 0.8$, $P > .449$, $\eta_p^2 = .120$). For snowboard, sex differences included $\dot{V}O_2$max ($P < .001$, $d = 1.04$), countermovement-jump height ($P < .001$, $d = 2.5$), DJ height ($P < .001$, $d = 1.45$), DJ contact time ($P < .001$, $d = 0.36$), reactive strength index ($P < .001$, $d = 1.36$), front-limb PF_{abs} ($P < .001$, $d = 1.77$), rear-limb PF_{abs} ($P < .001$, $d = 1.36$), front-limb relative PF ($P < .003$, $d = 0.88$), and rear-limb relative PF ($P < .021$, $d = 0.65$). In freeski, differences included $\dot{V}O_2$max ($P = .005$, $d = 0.81$), countermovement-jump height ($P < .001$, $d = 1.3$), DJ height ($P < .001$, $d = 1.17$), DJ contact time ($P < .040$, $d = 0.54$), reactive strength index ($P < .001$, $d = 1.0$), left-limb PF_{abs} ($P < .001$, $d = 2.2$), right-limb PF_{abs} ($P < .001$, $d = 1.88$), left-limb relative PF ($P < .001$, $d = 1.1$), and right-limb relative PF ($P < .001$, $d = 1.33$). ***Conclusions:*** Differences between the sexes, rather than between sports, explained the largest variance. A broad concurrent training approach with the aim of developing resilient athletes is likely warranted while acknowledging and adapting to individual needs.

Keywords: skiing, physical fitness, physical endurance, muscle strength

Freestyle snowboard and freeski are technical snow sports comprising 3 Winter Olympic events: slopestyle, big air, and halfpipe. Freestyle snowboard and freeski athletes often share training venues and compete in similar locations, with several International Ski and Snowboard Federation (FIS) World Cup competitions occurring simultaneously. The comparative youth of these individuals, coupled with methodological challenges in terms of data collection, has resulted in a lack of normative data (notably within elite populations), and to the authors' knowledge, there have been no studies that have investigated any potential physiological differences between these disciplines and between the sexes. Establishing the physiological profile of high-level freestyle snowboard and freeski athletes is important for obtaining a better understanding of the factors that may underpin performance, subsequently orient training, and ultimately, help athletes progress.

Freestyle snowboard and freeski require an array of technical, tactical, and psychophysical qualities.[1] Although repeatedly performing complex multiaxis tricks with technical competence clearly requires a certain degree of mobility, muscular strength, and snow-specific work capacity, freestyle snowboard and freeski are primarily viewed as technical sports in the field.[1,2] Consequently, athletes and their coaches predominantly focus on skill acquisition and trick refinement. Emphasis is also placed on the emotional load that athletes may experience due to the risk of severe injury[2] and other context-specific nonphysical training factors, such as developing coach–athlete relationships, belief in training plans, and managing life stress.[3] Nonetheless, there is surprisingly limited information on the physical qualities displayed in each sport, and the current consensus is largely based on anecdotal evidence. Consequently, understanding the specific physiological profiles of athletes in each sport is important for preparing athletes to perform and be resilient to injury.

Currently, there is a lack of understanding of the between-limbs force capacities that underpin aspects of freestyle snowboard and freeski, such as during moments of compression or throughout the execution and landing of tricks. Accordingly, the degree to which enhanced specific capabilities (eg, instantaneous peak force [PF] application to snow) might contribute to improved performance is unknown. In addition, slopestyle and big air tricks are often performed at high speeds and amplitudes, and technical errors can result in severe falls, collisions, and noncontact injuries.[4–6] A better understanding of the physical capacities displayed by high-level athletes could help them better orient conditioning programs to both improve performance and lessen injury.

In snowboard and freeski slopestyle, competition runs last 30 to 45 seconds. Athletes usually complete 15 to 25 runs in a 2- to

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3-hour training session, but they can accumulate >40 runs over consecutive days, often at high altitudes (2800–3400 m). There is a lack of recent data on potential reference values for aerobic capacity and the physiological internal and external load responses during on-snow practice as well as whether these factors directly limit or contribute to performance. Although explorations of associations between "off-snow" profiles and performance level may provide insight into certain codes,[7] such analyses are complicated by the ever-changing FIS ranking system and the fact that many athletes are multidisciplinary (competing in both slopestyle and big air). Thus, establishing reference values for elite-level athletes across sports and sexes is an important first step in understanding the profile necessary to perform at the highest level.

The aims of this study were to (1) investigate the anthropometric and physiological characteristics of male and female snowboard and freeski athletes and (2) characterize and identify potential differences between freestyle snowboard and freeski athletes and between sexes.

Methods

Subjects

Nine male and 8 female national team snowboard athletes (males: aged 21 [2.3] y, 177.6 [4.4] cm, 70.8 [4.7] kg and females: aged 20 [4.1] y, 166.5 [2.5] cm, 61.3 [3.3] kg) and 10 male and 8 female national team freeski athletes (males: 21 [2.1] y old, 176.2 [4.1] cm, 70.1 [5.1] kg and females: aged 18 [2.2] y, 165.3 [2.8] cm, 60.43 [2.9] kg) provided written consent to participate in the study. All participants competed in either the Europa Cup or World Cup competitions. Subjects did not take part in any strenuous physical activity in the 48 hours prior to testing. The study was approved by the Ethical Committee of the University of Jyväskylä and was conducted according to the provisions of the Declaration of Helsinki.

Design

The current study was an observational study design.

Methodology

Testing occurred at a training center and was completed over a 2-day period during which the athletes participated in anthropometric assessment as well as strength and power testing on day 1 and a graded cycle ergometer test the following day. All participants were familiar and experienced with the testing methods and wore normal training clothes during testing.

Upon reporting to testing on day 1, height and body mass were measured with an in-office stadiometer and scale, respectively. Following a 15-minute warm-up, the athletes performed unilateral isometric maximal voluntary contractions using a hex bar test and force plate. This test has previously been shown to be a reliable measure of strength in freeski athletes.[8] Participants were instructed to prepare for a bilateral hex bar dead lift from the ground, ensuring a knee angle of 115° flexion, as assessed using a handheld goniometer. For taller participants, blocks were placed beneath the weights to achieve the desired knee angle. After assuming the correct starting position, participants lifted the uninvolved non-weight-bearing limb backward while maintaining a consistent trunk position. A brief pause of 2 to 3 seconds was observed before engaging in warm-up trials at 70%, 80%, and 90% of self-estimated maximal effort. Each limb was then subjected to 3 trials with a 60-second rest interval between each attempt. Participants were directed to exert maximal force for 4 seconds by "pulling against the bar and pushing into the ground as hard as possible." The testing took place in a training facility using a force plate (1000 Hz, HUR Labs), which underwent calibration before each independent test. The force plate was securely embedded into the ground of a weightlifting platform to ensure it was flush with the floor, avoiding any elevation above the surface. Raw force–time data were collected using the Coachtech online measurement and feedback system from the University of Jyväskylä, Finland.[9]

Participants performed the countermovement jump (CMJ) and drop jump (DJ) tests with their hands placed on their hips throughout the entirety of the jump to avoid upper-body interference.[10] CMJ tests were performed with a self-selected knee flexion angle depth of ~90°, with instructions to rapidly descend and then immediately jump as high as possible with maximum effort. During the DJs, participants were instructed to avoid any initial upward propulsion and to drop and land on the same spot. To maximize their jump height while minimizing ground contact time, athletes were instructed to drop with only slight knee flexion.[11] The participants performed 3 trials each of the CMJ and DJ tests with a 15- to 30-second rest between each jump. A trial was disallowed if the hands left the hips at any point. During the trials, raw force–time data were collected using the same force plate and system as stated earlier.

The following day, indirect $\dot{V}O_2max$ was evaluated via a graded cycle ergometer test (Monark, LC7 TT) to estimate $\dot{V}O_2max$ $mL{\cdot}kg^{-1}{\cdot}min^{-1}$, employing the formula $\dot{V}O_2max = 11.02 \times P/m + 7$,[12] where P represents power and m denotes body mass.[13] The protocol consisted of 2 minutes of unloaded cycling followed by a 2-minute warm-up at 20 W. The initial starting workload for males was 75 W, which was increased by 25 W every 120 seconds until exhaustion. For females, the starting workload was 50 W and increased by 20 W every 120 seconds until exhaustion. Heart rate was recorded continuously using a Polar H10 heart rate monitor (Polar Electro). Throughout the protocol, raw data were collected using K-Lab software (Kuortane Olympic Training Centre).

Data Analysis

For unilateral isometric assessment, unfiltered force–time data were analyzed using the Coachtech online measurement and feedback system (University of Jyväskylä). For each trial and limb, the absolute PF (PF_{abs}) was defined as the point at which the maximum force occurred from initiation, and the relative PF was defined as the PF_{abs} divided by the body mass. The individual limb data were separated into front and rear limbs for snowboard athletes based on which limb they commonly rode forward and backward, respectively. For freeski, limb data were classified simply as left or right. The trial with the highest value was used for statistical analysis. For both CMJ and DJ, jump height was calculated using the impulse method.[11] The reactive strength index (RSI) was calculated for each DJ by dividing the jump height by the ground contact time.[14] The best jump height from each assessment was used for analysis. For $\dot{V}O_2max$, the estimated $\dot{V}O_2max$ $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ value[15] was used for analysis.

Statistical Analysis

All statistical analyses were performed in SPSS (version 28) and GraphPad Prism (version 9.2.0). Our first aim primarily involves descriptive statistics, which were computed for all dependent study variables by sex and sport, including means and SDs. Where appropriate, 95% CIs were determined.

To address our second aim, several multivariate analyses of variance using Wilks lambda (Λ) were compiled. Test assumptions, and notably, multivariate normality, were initially checked before interpreting test outcomes. These tests were performed across the collection of physiological variables, with sex, sport, and their interaction as main effects. Partial eta squared (η_p^2) was used to provide a magnitude of effect size, with the following qualitative predefined thresholds: small, moderate, and large as $\eta_p^2 < .01$, <.06, and <.14, respectively.[13] Subsequently, to compare directly between males and females within the 2 sports and between limbs, a series of univariate tests on the dependent variables were conducted to clarify pairwise differences at play, using Tukey test to account for error. Effect sizes were calculated as Cohen d with threshold values of <0.2 (trivial), 0.2 to 0.5 (small), 0.5 to 0.8 (moderate), and >0.8 (large).[13] Alpha was set at $\alpha = .05$ for all tests.

Results

Descriptive statistics of the anthropometric and physiological characteristics of the male and female snowboard and freeski athletes are shown in Table 1. Multivariate tests revealed no significant main differences between snowboard and freeski athletes across the physiological characteristic variables assessed (Wilks $\Lambda = 0.8$, $F_{1.4}$, $P > .251$, $\eta_p^2 = .169$). However, there was a large effect of sex across the collection of variables in this study (Wilks $\Lambda = 0.2$, $F_{27.4}$, $P < .001$, $\eta_p^2 = .79$), demonstrating overall differences between male and female athletes. There was no interaction effect of sex × sports ($\Lambda = 0.8$, $F_{0.95}$, $P > .449$, $\eta_p^2 = .120$). Pairwise analysis revealed significant differences, with moderate to large effect sizes between female and male snowboard athletes across multiple physiological variables. Female snowboard athletes had significantly lower $\dot{V}O_2max$ ($P < .001$, $d = 1.04$), CMJ height ($P < .001$, $d = 2.5$), and DJ height ($P < .001$, $d = 0.68$), slower DJ contact time ($P < .001$, $d = 0.36$), and lower RSI ($P < .001$, $d = 1.36$), front limb PF_{abs} ($P < .001$, $d = 1.77$), rear limb ($P < .001$, $d = 1.36$), relative front limb PF ($P < .003$, $d = 0.88$), and relative rear limb PF ($P < .021$, $d = 0.65$) than their male counterparts (Figures 1–4). Significant differences, with large effect sizes, were also found between female and male freeski athletes in $\dot{V}O_2max$ ($P = .005$, $d = 0.81$), CMJ height ($P < .001$, $d = 1.3$), DJ height ($P < .001$, $d = 1.17$), DJ contact time ($P < .040$, $d = 0.54$), RSI ($P < .001$, $d = 1.0$), left limb PF_{abs} ($P < .001$, $d = 2.2$), right limb PF_{abs} ($P < .001$, $d = 1.88$), relative left PF ($P < .001$, $d = 1.19$), and relative right PF ($P < .001$, $d = 1.33$) (Figures 1–4). No differences were observed between the front and rear limbs in male or female snowboard athletes in terms of PF_{abs} ($P = .67$ and $P = .87$, respectively) and relative PF ($P = .64$ and $P = .88$, respectively) (Figures 2 and 4). Also, no differences were found between the left and right limbs in male or female freeski athletes in PF_{abs} ($P = .30$ and $P = .18$, respectively) and relative PF ($P = .32$ and $P = .19$, respectively) (Figures 3 and 4).

Discussion

The main findings of this study were as follows: Within this cohort, no differences were found between the sports of freestyle snowboard and freeski. However, notable sex differences were observed between athletes in both sports. Compared with male snowboard and freeski athletes, female snowboard and freeski athletes had significantly lower $\dot{V}O_2max$, PF_{abs}, relative PF, CMJ and DJ height, and RSI. Furthermore, female snowboard and freeski athletes had significantly longer DJ contact times than did their male counterparts. In addition, there were no differences found between the front and rear limbs in either male or female snowboard athletes or between the left and right limbs in male and female freeski athletes. Although these results provide valuable reference values regarding the anthropometric and physiological characteristics of male and female national team-level freestyle

Table 1 Descriptive Statistics for Anthropometric Characteristics, Maximal Oxygen Uptake, and Strength Power Characteristics of Snowboard and Freeski Athletes

	Freestyle snowboard		Freeski	
Variable	**Male (n = 9)**	**Female (n = 8)**	**Male (n = 10)**	**Female (n = 8)**
Age, y	21 (2.3)	20 (4.1)	21 (2.1)	18 (2.2)
Stature, cm	177.6 (4.4)	166.5 (2.5)	176.2 (4.1)	165.3 (2.8)
Body mass, kg	70.8 (4.7)	61.3 (3.3)	70.1 (5.1)	60.43 (2.9)
Maximal oxygen uptake, $mL \cdot min^{-1} \cdot kg^{-1}$	54.9 (5.2)	44.9 (4.8)	51.5 (4.6)	44.3 (4.5)
CMJ, cm	46.8 (3.6)	32.5 (1.6)	43 (5.2)	32.2 (2.6)
DJ, cm	41.6 (4.5)	29.7 (3.9)	41.3 (5.8)	30.1 (3.6)
DJ contact time, ms	162.8 (16.8)	173.1 (11.2)	171 (14.3)	185.8 (13.4)
RSI, au	2.5 (0.3)	1.70 (0.3)	2.4 (05)	1.6 (0.2)
PF_{abs} front limb, N	1785 (140)	1400 (75)	—	—
PF_{abs} rear limb, N	1776 (180)	1401 (82)	—	—
Relative PF front limb, PF_{abs}/body mass	25.2 (1.7)	22.8 (0.8)	—	—
Relative PF rear limb, PF_{abs}/body mass	25.1 (2.8)	22.8 (1.2)	—	—
PF_{abs} left limb, N	—	—	1777 (176)	1260 (83)
PF_{abs} right limb, N	—	—	1755 (127)	1275 (94)
Relative PF left limb, PF_{abs}/body mass	—	—	25.1 (1.8)	20.9 (1.6)
Relative PF right limb, PF_{abs}/body mass	—	—	25 (1.6)	21 (1.7)

Abbreviations: au, arbitrary unit; CMJ, countermovement jump; DJ, drop jump; PF, peak force; PF_{abs}, absolute PF; RSI, reactive strength index. Note: Cells marked with "—" indicate no relevant variable for this case. Data are displayed as mean (SD).

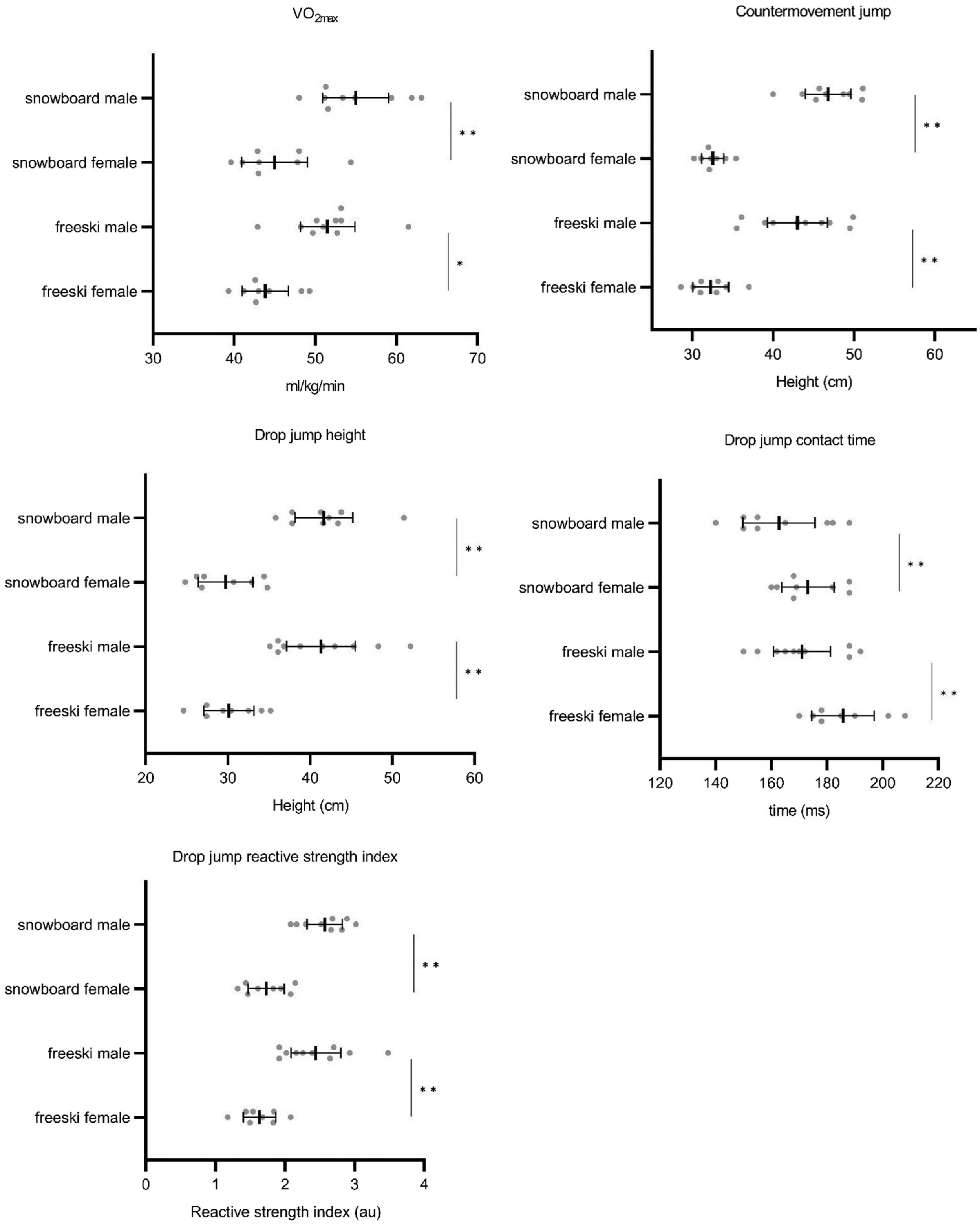

Figure 1 — Normative data and comparisons between sports and sexes. The data are shown as mean (+95% CI) and individual data (gray dots). $^*P < .05$. $^{**}P < .001$.

snowboard and freeski athletes, corroborating works from other nations are needed.

Across the collection of physiological variables used in this study, sports did not clearly explain variance across the battery of tests ($P > .05$). Rather, a large proportion of variance (~79%) was explained by the inherent differences between men and women ($P < .001$). The lack of a clear effect evoked by the sport could be attributed to the multiple performative similarities. Notably, a

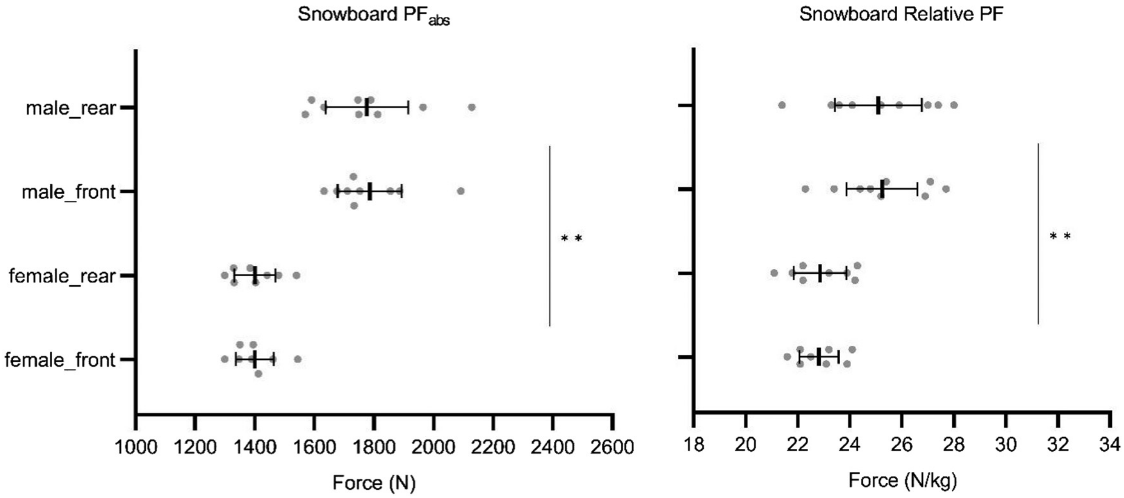

Figure 2 — Snowboard PF_{abs} and snowboard relative PF of the rear and front limbs. The data are shown as mean (+95% CI) and individual data (gray dots). $^{**}P < .001$. PF indicates peak force; PF_{abs}, absolute PF.

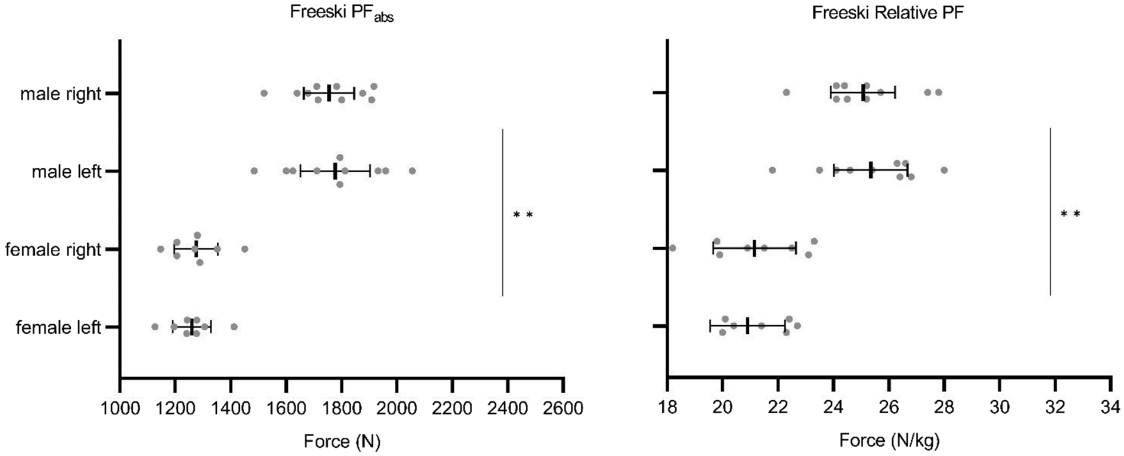

Figure 3 — Freeski PF_{abs} and freeski relative PF of the left and right limbs. The data are shown as mean (+95% CI) and individual data (gray dots). $^{**}P < .001$. PF indicates peak force; PF_{abs}, absolute PF.

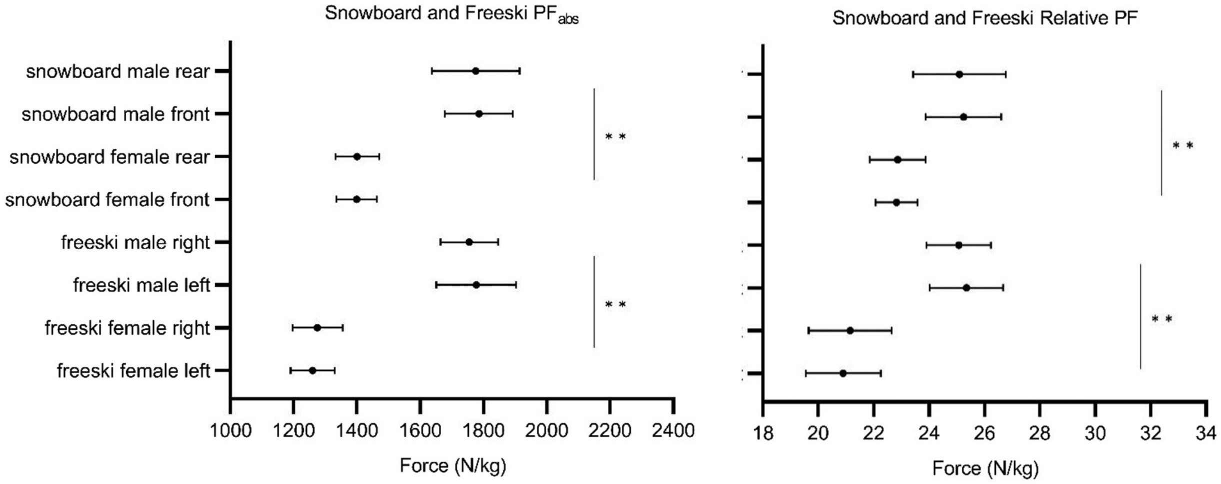

Figure 4 — Snowboard and freeski PF_{abs} and snowboard and freeski relative PFs of rear and front limbs (snowboard) and left and right limbs (freeski). The data are shown as mean (+95% CI). $^{**}P < .001$. PF indicates peak force; PF_{abs}, absolute PF.

hypothesized underlying reliance on technical and tactical factors may result in broad interindividual variation in physical profiles among high-level athletes. However, whether this is the case for developing athletes, where performance may be more likely limited by underdeveloped physical qualities, remains to be determined. Similarly, the clear effect of sex within our model is unsurprising given the widespread evidence on performance differences between the sexes.[16] For example, men possess higher testosterone and hemoglobin levels and a larger body with greater cardiac and muscle mass and relatively less fat.[17–20]

The mean $\dot{V}O_2$max was significantly greater with a large effect size in male snowboard and freeski athletes than in female snowboard and freeski athletes. Differences in endurance performance between male and female athletes are not novel and are attributable to biological differences.[21] Male freestyle snowboard and freeski athletes appear to possess aerobic capacities comparable with those of international male alpine ski racers (54.9 and 51.4 $mL \cdot min^{-1} \cdot kg^{-1}$ vs 55.9 $mL \cdot min^{-1} \cdot kg^{-1}$, respectively),[22] whereas female freestyle snowboard and freeski athletes possess a lower aerobic capacity than female alpine skiers (44.9 and 43.8 $mL \cdot min^{-1} \cdot kg^{-1}$ vs 50.2 $mL \cdot min^{-1} \cdot kg^{-1}$). Nevertheless, in contrast to research on male snowboard cross and alpine snowboard,[23] male freestyle snowboard and male freeski athletes in this study exhibited greater aerobic capacity (54.9 and 51.4 $mL \cdot min^{-1} \cdot kg^{-1}$ vs 51.2 and 49.7 $mL \cdot min^{-1} \cdot kg^{-1}$, respectively). There is some doubt whether the aerobic system is a decisive factor for success in snowboarding[23] and freeskiing. Nevertheless, elevated aerobic capacity is unlikely to detract from performance and could act to facilitate better recovery between competition and training runs[24] and year-round on- and off-snow training. As such, although the importance of $\dot{V}O_2$max and a high endurance capacity in freestyle snow sports remains debatable, an individualized approach to determining athlete needs is pertinent. Notably, the capacity of the athletes in this study varied considerably—male snowboard (95% CI, 50.9–59 $min^{-1} \cdot kg^{-1}$), female snowboard (95% CI, 40.9–49 $min^{-1} \cdot kg^{-1}$), male freeski (95% CI, 48.3–55.4 $min^{-1} \cdot kg^{-1}$), and female freeski (95% CI, 40.5–48.2 $min^{-1} \cdot kg^{-1}$)—and highlights the value of an individualized and needs-based approach to conditioning (eg, see Figure 1). Therefore, including endurance training for freestyle snowboard and freeski athletes is likely to be beneficial in certain contexts, for certain athletes, and further research is needed, particularly on female responses during exercise and adaptations to training.

Similarly, significantly reduced performance was also present for CMJ height, DJ height, DJ contact time, and DJ RSI when comparing male and female athletes in both snowboard and freeski. The mean CMJ height in our cohort was consistent with the data from female Norwegian snowboard and freestyle ski athletes (33.8 and 32.5 cm vs 32.5 and 32.2 cm, respectively)[25] and was greater for male snowboard and freeski athletes (46.8 and 43.0 cm vs 41 and 41.8 cm).[25] Compared with male snowboard and freeski athletes, female snowboard and freeski athletes had significantly lower DJ heights and RSIs. Furthermore, female snowboard and freeski athletes had significantly longer DJ contact times than male snowboard and freeski athletes did. A significantly lower maximal isometric force was observed in females compared with males in both snowboard and freeski PF_{abs}, supporting previous data from freeski athletes.[8] Sex differences in lower-body strength and power characteristics between men and women are not fully understood but are likely due to differences in muscle mass,[26] a greater proportion of fast-type fibers and glycolytic capacity[27,28] differences in tendon viscoelastic properties,[29] neuromuscular control,[30,31] and morphological characteristics such as muscle thickness, pennation angle, and fascicle length.[32]

Moreover, there were no significant differences between left and right limb PF_{abs} or relative PF measures in freeski athletes or between the front and rear limbs in snowboard athletes when tested with the unilateral isometric hex bar pull test. This finding supports previous data on freeski athletes[8] and further supports the view that freeski is an equilateral sport characterized by similar physical demands on each limb. In contrast, snowboarding occurs in an asymmetrical position on the board, so one might hypothesize that there is some difference between the limbs as a product of their on-snow training. Nonetheless, our data indicated no clear differences between the front and rear limbs in either female or male snowboard athletes, which supports previous findings in male freestyle snowboard athletes but contrasts with those observed in the alpine snowboard discipline.[23] This might be attributed to a lack of clear differences in the actions of the front and rear limbs for alpine snowboard athletes or perhaps a lack of transfer of these differences to what was observed from our battery of tests. Another possible explanation is the off-snow training practices of this cohort of athletes, which tend to emphasize unilateral work and may reduce the potential deleterious transfer of on-snow training to emphasized asymmetry. In any case, the lack of difference in these athletes is likely not indicative of a lack of need to balance training to reduce undue asymmetry.

Despite the need for further research exploring factors associated with performance, prior evidence has shown that improvements in muscular strength are related to greater performance in general sports skills, such as jumping, sprinting, and changing direction tasks.[33] In addition, emphasis placed on developing lower-body strength has been recommended in snowboard cross and alpine snowboard[23] as well as in alpine skiing.[7] These disciplines share certain physiological characteristics with freestyle snowboard and freeski, and although further data are needed, it could be argued that maximal strength is an important capacity to develop for both performance and reducing the risk of acute and overuse injuries.[34]

Practical Applications

Although developing and retaining technical skills on snowboard and freeski have the greatest effect on performance, coaches should consider implementing physical training to help support their athletes. Until further research is performed, it appears that adopting a concurrent training strategy that includes both endurance and resistance training may be beneficial for freestyle snowboard and freeski athletes from both performance and injury prevention standpoints. Moreover, this approach could also help support year-round on- and off-snow training. However, well-designed training studies are required to validate the insights outlined. Determining the optimal allocation of physical training, in conjunction with supporting skill development on snow at the group and individual levels throughout the season, requires further research. This approach is crucial for refining our understanding of the nuanced interactions between physical conditioning and technical proficiency in freestyle snowboard and freeski athletes.

Furthermore, coaches should consider when best to implement physical training in a season plan without negatively harming the overall process by interfering with skill acquisition on slopes. There may be scenarios in which the stimulus of on-snow training is sufficient to elicit or maintain strength and endurance training adaptation. Nevertheless, coaches should also be aware that detraining may occur, and it is important to consider its potential impact on performance or injury risk.[35] However, further research in this area is broadly warranted, including exploring sex-specific physiological responses, psychological preparedness, and the distribution of training.

There are several methodological limitations regarding the current study. Owing to the limited availability of elite athletes and the quota of national team athletes in freestyle snowboard and freeski, our sample size is small and potentially underpowered; therefore, it is difficult to generalize the findings to the broader population of freestyle snowboard and freeski athletes. Moreover, as the athletes' training backgrounds, including the duration and specificity of their training for these sports, are not fully documented, and no clear connection between their physical metrics and actual performance has been established, the data should be interpreted with caution. It must be made clear that the data's aspirational value is unknown, and their utility for developing normative values is restricted due to the sample size. Consequently, the data are descriptive in nature, and further research is required to validate and expand upon these findings. It is necessary to present physiological profiles that are not influenced by a training methodology specific to a particular nation.[36] Although we carefully selected the tests to include within this battery, it is possible that other tests may better characterize these athletes. For example, relying exclusively on an isometric MVC for maximal strength assessment may not fully depict the entire spectrum of force capabilities[37] given that various limb arrangements can impact force production and muscle recruitment patterns.[38,39] Despite the outcomes of the study, it is advisable to conduct further research examining knee flexor and extensor and abduction and adduction neuromuscular function throughout a wider range of motion.[40,41]

Conclusions

Based on the present results obtained from this cohort of national-team athletes wherein no notable differences between freestyle snowboard and freeski were identified in the measured parameters, it can be inferred that the physical demands necessary to perform at high levels overlap. However, there are distinct sex differences in several physiological characteristics that practitioners should consider when prescribing training. The factors influencing performance in freestyle snowboard and freeski disciplines are not fully understood but may be attributed to a variety of trainable variables.

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