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What Magnitude of Force is a Slopestyle Skier Exposed to When Landing a Big Air Jump?

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ABSTRACT

International Journal of Exercise Science 13(1): 1563-1573, 2020. The purpose of this study was to investigate the magnitude of force a slopestyle skier is exposed to when landing either forward or switch in a big air jump. Ten male freeskiers (age 23 ± 6 years; height 179.2 ± 5.4 cm; body mass 72.5 ± 8.6 kg; mass of equipment 16.7 ± 1.4 kg; total mass 89.2 ± 8.6 kg) participated and each performed five 180 jumps and five switch 180 jumps in a randomized order. Forces were quantified using pressure insoles. The results showed a force of 1446 ± 367 N (2.04 ± 0.46 times body mass) for the 180 jump and a force of 1409 ± 257 N (1.99 ± 0.28 times body mass) for the switch 180 jump. There was no difference in force between the 180 jump and the switch 180 jump, p=0.582. There was a trend for the switch 180 for a correlation between a heavier body mass and a greater force ($r = 0.604$, $r^2 = 0.365$, $p = 0.064$) as well as a heavier total mass and a greater force ($r = 0.621$, $r^2 = 0.385$, $p = 0.055$). This study shows that the force when landing a big air jump is roughly twice the slopestyle skier's body mass, but no difference in force was seen between performing a 180 or a switch 180 jump. The force of twice the body mass could therefore be considered a minimum value for slopestyle skiing.

KEY WORDS: Freeride, freeskiing, freestyle, impact, skiing

INTRODUCTION

Slopestyle is a freeski sport in which athletes ski down a course with jumps and rails. Slopestyle joined the Olympics in Sochi 2014 (6). Each course contains different features that can be made of metal, plastic, wood or snow (21). The slopestyle athlete performs different acrobatic maneuvers known as "tricks" on the course. The tricks are executed at speeds of up to 90 km per hour with flight distances of 30 m in length and 7 m in height (27). World class competitions require a minimum of three jumps and at least six judged features (7).

To perform at a high level and stay injury free the slopestyle athlete needs a body that can handle a range of physical demands (26). Strength and power could be important for the slopestyle athlete, both from an injury prevention and a performance perspective (24, 26). Leg strength might be decisive in alpine skiing due to the great forces and eccentric load on the skier (18). In slopestyle, leg strength is needed because of the inevitable forces generated by each landing (26). In gymnastics, both strength and peak power are considered to be key performance indicators as they can infer the athlete's ability to produce a high magnitude of force in a short period of time (25). A similarity to this is found in slopestyle where it is important to be able to create rotation and gain the right amount of height when jumping from the kicker (the takeoff point) (24). Power is also important when performing rotations upwards, on or off rails and other features. Furthermore, good mobility could be beneficial to create a better aesthetic impression in the air by tweaking grabs and manipulating the center of gravity in different tricks. The slopestyle athlete also needs substantial body awareness and motor skills to execute these tricks (24).

Today there is a lack of literature on how to train optimally for slopestyle skiing. Neither is there anything about the ideal anthropometry and body mass for this sport (24). In gymnastics where they compete against gravity, both body mass and anthropometry are important. The ideal gymnast should have a low height, a low body mass, and a high muscle to mass ratio for greater strength (9). The physical characteristic of elite gymnasts is typically low body fat with a high amount of muscle mass (25). This could be of importance in slopestyle where the athletes are repeatedly exposed to big air jump landings. Having a high muscle to mass ratio could perhaps lower the stresses on the body (4).

The slopestyle sport has evolved quickly, with athletes pushing the limits further every year. Today the athletes are spinning in all three planes (sagittal, transverse and frontal) and performing doubles, triples and quad flips (26). To perform more advanced tricks and add more rotations, the size of the jumps was increased. This means the slopestyle athletes are exposed to considerably greater forces during landings (11, 14), thus also placing a larger demand on the athlete's body. As such, slopestyle could be classified as a high injury risk sport (20, 27, 29).

Today, knowledge is lacking on how great the forces acting on slopestyle athletes are. Therefore, the scale of impact and training load are difficult to estimate. With better knowledge of the impact forces on the slopestyle athlete, strategic training programs could be improved to optimize the athlete's physical ability prior to the snow season. This could also help to build the physical profile of the sport, which in turn can determine if an athlete should compete at a certain level. Therefore, the purposes of this study were 1) to examine the magnitude of force a slopestyle skier is exposed to when landing a big air jump and 2) to determine if there is a difference in landing force between landing forward or switch in a big air jump.

METHODS

Participants

A power analysis was performed on a previous data set based on similar snow sports, using mean and standard deviations for forces. With α set at 0.05 and β at 0.8, a t-value of 2.26 for unpaired and paired comparisons showed 10 subjects would be required to avoid a type 2 error in the present study. Ten males participated in the study (Table 1). The participants were either students from Freeskigymnasiet Malung or professional freeskiers. These groups were chosen because the implementation of the study required high-level ski performance. The inclusion criterion for the students required that they had competed internationally at least once during the last two years. The professional freeskiers should have had a career competing internationally or alternatively today have professional sponsorship deals with one or more ski brands. The participants had to be acquainted with, and comfortable executing, a big air jump and land both forward and switch (backwards). They should not have been injured within the last three months, nor had any illnesses in the week prior to the data collection which could have affected their ability to perform maximally. The participants received both written and verbal information before they gave informed consent. This study followed the Helsinki declaration and was pre-approved by the Swedish Ethical Review Authority (#2019-00939). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (17).

Table 1. Characteristics of participants (n=10).

Variable	Mean ± SD
Age (years)	23 ± 6
Height (m)	1.79 ± 0.05
Body mass (kg)	72.5 ± 8.6
Mass of equipment (kg)	16.7 ± 1.4
Total mass (kg)	89.2 ± 8.6

Protocol

The study design was a randomized crossover where half of the participants started by performing five jumps with a 180-degree spin followed by five jumps with a switch 180-degree spin and vice versa for the other half of participants. The participants also refrained from alcohol 24 hours before the test. They were not allowed to perform any unaccustomed training 24 hours before the test. The test protocol for each participant lasted for approximately 40 to 60 minutes and was completed in one test session.

The warmup was performed as alpine skiing on a regular slope. Thereafter the skiers performed the big air jump twice to determine what speed they needed to safely perform the landing afterwards.

Kinetics: After the completion of the skiing warmup, the ski boot insoles were replaced and fitted with pressure insoles Moticon SCIENCE Pro Sensor Insole (Moticon GmbH, München, Germany), validation done by Stöggl & Martiner (22). The pressure insoles were connected and then zeroed when the participant stood on one foot whilst balancing the other in the air, and vice versa. Impact force was calculated with the Moticon SCIENCE Pro + Software 01.11.00 (Moticon GmbH, München, Germany). The pressure insole measured plantar pressure to compute normal plantar forces with a recording at 50 Hz. Peak force was defined when the left and right insoles had the highest combined value at the point where the landing occurred.

The skiers were then instructed about which trick they were supposed to start with and how many jumps of each they should perform. The recording started and the participants performed five jumps with the first trick and then five jumps with the remaining trick (180 and switch 180 irrespectively). The participants were checked after each jump that they felt comfortable performing the jump with the pressure insoles. After completing the jumps, the participants had the pressure insoles removed from their ski boots and the recording was stopped. The pressure insoles memory unit stored the recorded data and after each measurement, the raw data was imported to the associated computer and then saved as raw (Moticon) files on a USB stick. The jumps were recorded at 50 Hz with a camera A6000 (Sony, Tokyo, Japan) to make sure the landings were approved and could be used for further data analysis. Approved meant that the participants performed the landing below the marked blue line (Figure 1). The video analyses were performed in Windows Media Player (version 12; Redmond, WA, USA).

Big air jump: The big air jump had a distance of 14 m from the kicker to the knuckle (where the landing starts) and was built as a "tabletop jump" (11) (Figure 1). The jump was categorized as a black feature that is the most advanced jump in a snow park. In the landing area there was a blue line drawn horizontally from one side to the other (Figure 1). The blue line was drawn approximately 2 m down from the start of the knuckle. The participants were told to land below the line for each jump.

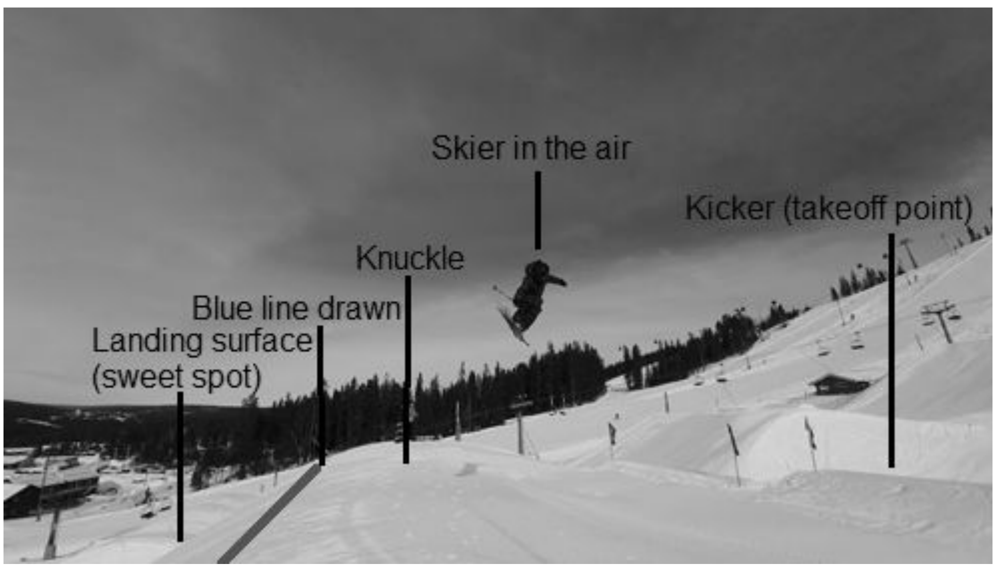

Figure 1. A tabletop jump in Kläppen Snow Park.

Statistical analysis
Normality of all data was checked with Shapiro Wilk test while the methodological error was evaluated using standard error of measurements (SEM). Hedge's g was used to determine the meaningfulness of the differences ranked as small (0.2), medium (>0.5) or large (>0.8) effect size. A paired t-test was conducted to compare differences between the 180 jump and the switch 180 jump as well as left and right foot forces within each type of jump. To investigate if there were any associations between body mass and landing force, a bivariate correlation was used. A partial correlation was used where the raw mass of the equipment (total mass – body mass of the participants) was set as a controlled variable. The Pearson correlation level was ranked as poor (0.3<), fair (0.3.-0.5), moderately strong (0.6-0.8), or very strong (>0.8) respectively (2). The analyses were performed in Microsoft Excel (version 16.0.1; Redmond, WA, USA) and IBM SPSS

Statistics (version 25; Armonk, IL, USA). All data are presented as mean ± standard deviation (SD) unless otherwise stated. Levels of significance were set to $\alpha<0.05$ (8) while trends are denoted for $\alpha<0.08$.

RESULTS

The results showed a force of 2.04 ± 0.46 and 1.99 ± 0.28 times body mass ($p = 0.618$, $g = 0.131$) for the 180 jump and the switch 180 jump respectively. Furthermore, there were no differences in absolute force between 180 jump and switch 180 jump ($p = 0.582$, $g = 0.117$) (Figure 2). The force distribution between the left and right foot was 54 vs 46% for the 180 jump ($p = 0.148$, $g = 0.578$) and 55 vs 45% for the switch 180 jump ($p = 0.053$, $g = 0.883$). All participants showed a right foot dominance (100%, 10 out of 10).

The methodological error (SEM average) was 161 N and 87 N, for the 180 jump and the switch 180 jumps respectively. In all, the mean difference between the 180 jump and the switch 180 jump was markedly less than the SEM for both jumps. This corroborate the results that there was no difference between the jumps in landing force.

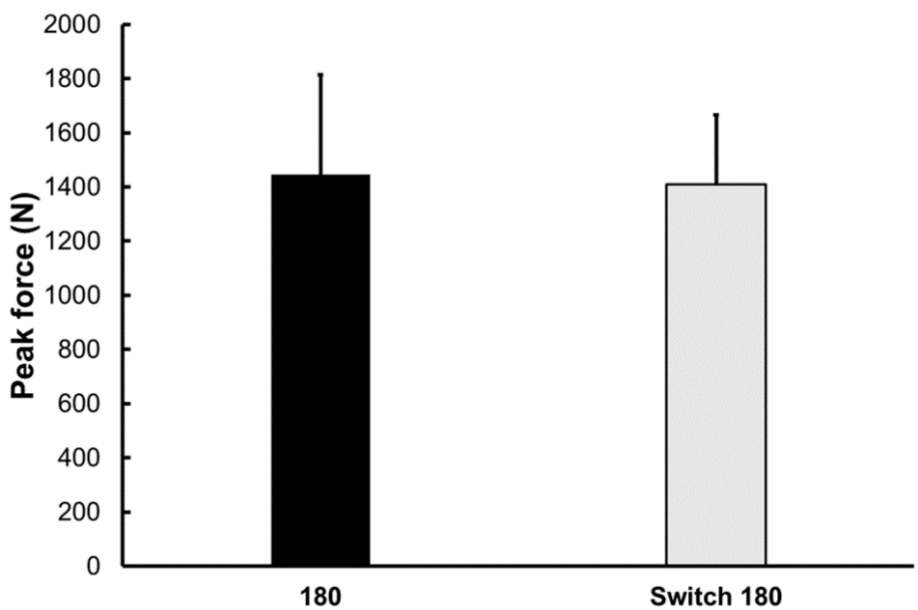

Figure 2. 180 jump with switch landing. Switch 180 jump with forward landing.

The bivariate correlations showed a trend between a heavier body mass and a greater force when landing the switch 180 jump ($r = 0.604$, $r^2 = 0.365$, $p = 0.064$) but not for the 180 jump ($r = 0.511$, $r^2 = 0.261$, $p = 0.131$) (Figures 3 and 4).

There was also a trend between the total mass (including the equipment) and a greater force when landing the switch 180 jump ($r = 0.621$, $r^2 = 0.386$, $p = 0.055$) but again not for the 180 jump ($r = 0.576$, $r^2 = 0.332$, $p = 0.081$) (Figures 3 and 4).

With the equipment mass as a controlled variable, the partial correlations showed no relationship between the total mass (including equipment) and the force, for either the switch 180 jump ($r = 0.601$, $r^2 = 0.361$, $p = 0.087$) or the 180 jump ($r = 0.538$, $r^2 = 0.289$,$p = 0.135$).

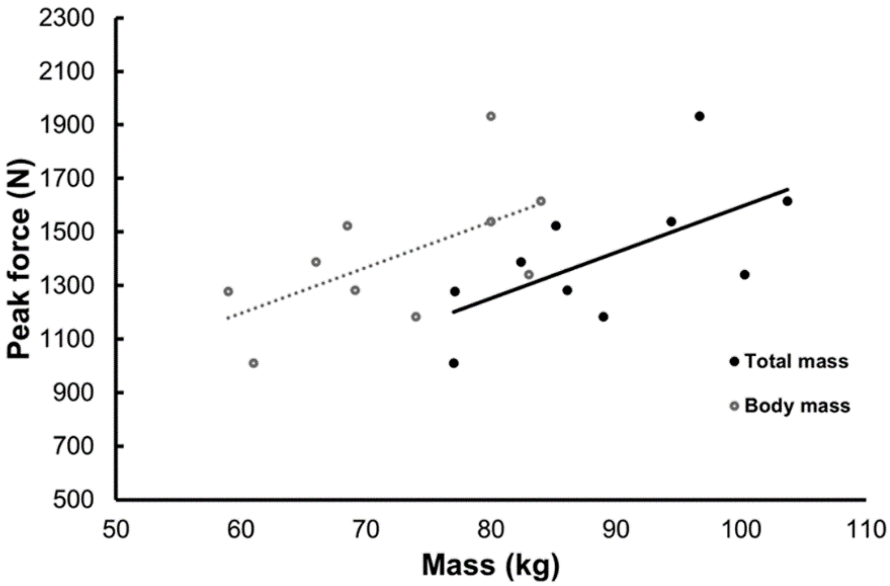

Figure 3. Switch 180 landing.

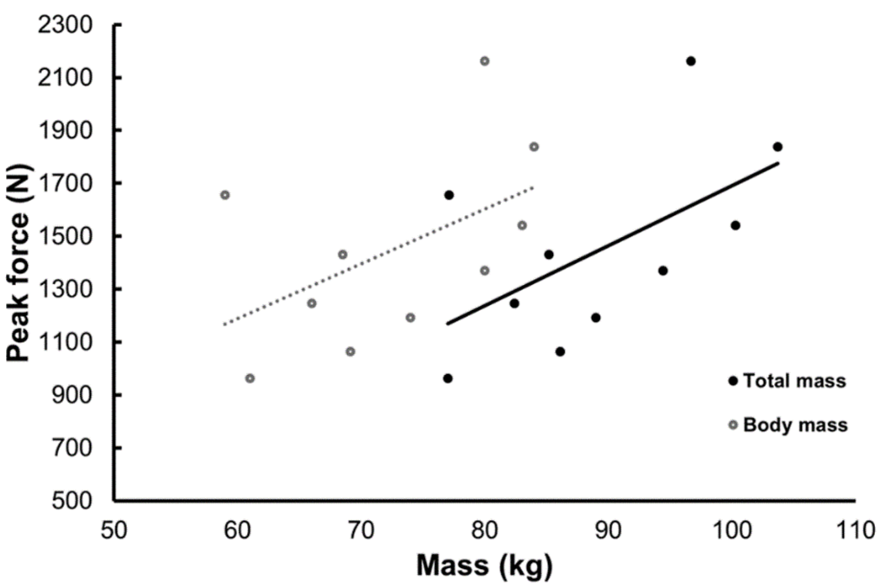

Figure 4. 180 landing.

DISCUSSION

The study purposes were to examine the magnitude of force a slopestyle skier is exposed to when landing a big air jump and further to determine if there is a difference in landing force between landing forward or switch in a big air jump. The main outcome of the study showed that the 180 jump and the switch 180 jump generated approximately twice the body mass in force. However, there was no difference in force between landing either forward or switch. These results could be of importance for planning dry land training for slopestyle athletes. The force that affected the slopestyle athletes in this current study are likely minimum values due to the degree of complexity. This knowledge could help slopestyle athletes to prepare adequately for the snow season, using dry land training and an appropriate training load. However, differences in body structures should be considered when designing training regimen.

There was no difference in the absolute or relative forces between landing forward and switch. This can perhaps be explained biomechanically, Newtons law of inertia describes that there will be both vertical and horizontal velocity when the slopestyle athlete leaves the kicker (3). These two velocities will determine the angle of the takeoff, the resultant velocity, and the flight distance. If there is no air resistance or other affecting vectors, the slopestyle athlete will act like a projectile with a pre-determined flight path and will be pulled back against the earth at a rate of 9.81 m/s^2 (3). If the slopestyle athlete has the same mass, speed, and timing when jumping off of the kicker, the athlete will fly approximately the same distance no matter if the takeoff is executed forward or switch (3). However, the landing force could still be affected by the flexion of the legs (19). From personal observations in this present study, there was a biomechanical difference between the switch and forward landing. When performing the 180 jump and landing switch, the slopestyle athlete had slightly bent legs with the upper body leant forward. For the switch 180 jump with the forward landing, the slopestyle athlete had greater flexion in the legs with the upper body in a more upright position. The slopestyle athlete possibly uses support from the boot shaft more effectively when landing switch compared to forward (3, 5). However, this present study did not show any difference in force for the 180 and switch 180 tricks respectively. Most likely, there would be differences in force when landing a more difficult trick with a greater number of degrees, but this would need further confirmation.

There was a trend between a heavier body mass and a greater force, as well as a trend between a heavier total mass, i.e. including the equipment, and a greater force, both trends only seen when landing the switch 180 jump, not when landing the 180 jump. This suggests that landing switch is more technique-based and does not depend as much on the mass of the slopestyle athlete as the forward landing does. In addition, the switch landing used less knee flexion with the upper body more flexed forward compared to the forward landing. Perhaps such a body position absorbs the landing force in different structures compared to the forward landing. However, this hypothesis needs further investigation as the results showed no difference in force between the 180 and switch 180 landings.

When examining other snow sports, ski jumping produces forces around 3 times the athlete's body mass with an air time of just below 3.5 seconds (15). Greater forces from 4.3 up to 7.3 times body mass with air times of over 3.5 seconds have also been reported (1). An explanation for these greater forces and air times (slopestyle athletes had just below 2 seconds in the present study) could be that the ski jumping athlete performed the takeoff mostly horizontally with the aim of being in the air as long as possible. The slopestyle athletes perform the takeoff vertically and horizontally and only need enough air time to execute the chosen trick and land in the "sweet spot" (Figure 1).

In snowboarding, forces of 3940 N (4.96 times body mass) were reported when an athlete performed an 8 m-jump (10). Another pilot study had two snowboarders performing jumps and landings. The size of the jump is unfortunately not mentioned. However, they reported forces of 3521 N (4.79 times body mass) and 2497 N (3.74 times body mass) (12). A meta-analysis from 2012 gathered a total of 152 landings from jumps with sizes 7.5 to 15 meters. The results showed forces of 4.14 and 4.10 times body mass for the front and back feet respectively (13).

The results from the present study were not in accordance with the previous research in snowboarding. The snowboarding literature typically showed greater induced forces, but on smaller jumps than in the present study. This could be explained by the fact that the jumps in Kläppen have been built to minimize the force when landing. For example, bigger jumps are built today with steeper landings to minimize the landing force (11, 19). It would therefore follow that jumps with a flatter landing would likely induce a greater force when landing and thereby increase the risk of injury.

To our knowledge, no previous scientific study has investigated more advanced tricks than the 180 and switch 180 as performed in present study. However, Brenkus and colleagues performed a short video analysis on Ståle Sanbech's triple cork 1440 from ESPN´s X Games 2015 Snowboard Slopestyle. They estimated that the triple cork, with an air time of 2.3 seconds and a 24 meter long flight distance, demonstrated a landing force of 5784 N (589 kg) (28). Compared to this present study, there is a great difference in difficulty of the trick that is being executed. The slopestyle athletes performed 180-degree spins that are 8 times less than a 1440-degree rotation. The flight distance was also less in this present study. It was estimated to be approximately 19 to 20 meters, compared to 24 m, when calculating the cumulative distances of the jump to the knuckle, the knuckle to the blue line, and the distance traveled below the blue line. Both an increased air time and a longer flight distance could explain the greater landing force proposed by Brenkus, compared to the landing force in this present study (3). The difficulty of the trick potentially also contributed to the increased landing force due to a more exposed body position at landing, differing jump trajectory, and landing strategy (13).

If pressure insoles are compared with a force-plate system, the insoles seem to underestimate the force produced (16, 22). An explanation for this difference could be that the force-plate fits under the binding whereas the pressure insoles are located inside the ski boots. Depending on the steepness of the slope, the plantar forces measured is not necessarily equal to the ground reaction forces, as plantar forces are perpendicular to the feet and do not include shear forces. However, the pressure insoles do measure the plantar force directly under the skier's feet and provide a detailed pressure distribution (22). This might have been a more appropriate system for measuring ground reaction forces in high dynamic situations like mogul or powder skiing (16).

The chosen tricks in this study could differ from those in competition with higher levels of difficulty. Anecdotal observations have shown that competition tricks with greater numbers of degrees increase both the air time and distance travelled. Perhaps competition tricks would result in a greater magnitude of force and thereby also increase the risk of injury. Future research should investigate tricks with a greater number of degrees to see if the force increases with the level of difficulty of the trick.

Based on these findings, coaches in slopestyle and other freeski disciplines could create training programs for the slopestyle athletes to fulfill during the dry land training. This will facilitate the handling of similar forces during the on-snow season. The physical profile provides an index of different physiological demands of the sport. It can also determine if an athlete should compete at a certain level. The knowledge from this study could help to build the physical profile through having physical requirements for the slopestyle sport. For example, the forward landing has a similar movement pattern to a back squat, with an upright body position and bent legs. Being able to perform a back squat with twice their body mass could be a good requirement to prepare for similar forces when landing a big air jump. Additionally, for the switch landing where the legs are slightly bent and the upper body is leant forwards, the deadlift could be an appropriate option to strengthen the body through the same movement pattern. Being able to perform the deadlift with twice their body mass and a controlled eccentric phase could be a beneficial way to train with similarities to a switch landing.

There were limitations in the present study. The slopestyle athletes had to perform the first jump in order to gain enough speed for the second, where the measurements occurred. The first jump could have had an impact on the pressure insoles and made them less reliable than if only the second jump was executed. Also, the zeroing procedure was only done whilst the ski boots were on, and not whilst the ski boots were attached to the skis. Perhaps this could have had an impact on the results making them less reliable.

The skiing environment can make it difficult to perform measurements directly and accurately (23). Alterations in weather such as changes in temperature, wind, or humidity can affect the skier's speed. The hardness of the snow can affect the ground reaction force (13). In this present study no weather variables were measured or controlled, which could have caused a source of error. The National Ski Areas Association states the impossibility to have the same standard for jumps in a snow park due to the variability of the snow conditions (14). However, the Kläppen Snow Park team tried to keep the jump at the same dimensions throughout the three weeks the tests occurred.

In all, this study shows that the landing force is roughly twice the slopestyle skier's body mass when performing a 180 or a switch 180 jump. The force of twice the body mass could therefore be considered a minimum value for slopestyle skiing. If an athlete performs a more difficult trick, the requirements for the strength training may want to be higher. The slopestyle athlete may also benefit from plyometric training because of the developed muscle recruitment pattern. Plyometric training induces overloaded eccentric actions followed by rapid concentric muscle contractions by using the stretch shortening cycle. Perhaps such a type of training could help both with performing an explosive takeoff and being able to absorb energy quickly when landing a big air jump.

REFERENCES

1. Bessone V, Petrat J, Seiberl W, Schwirtz A. Analysis of landing in ski jumping by means of inertial sensors and force insoles. Proceedings 2(6): 311, 2018.

2. Chan YH. Biostatistics 104: Correlational analysis. Singapore Med J 44(12): 614-619, 2003.

3. Grimshaw P. Sport and exercise biomechanics. In: BIOS instant notes. London, UK: Routledge; 2006.

4. Haines TL, McBride JM, Triplett NT, Skinner JW, Fairbrother KR, Kirby TJ. A comparison of men's and women's strength to body mass ratio and varus/valgus knee angle during jump landings. J Sports Sci 29(13): 1435-1442, 2011.

5. Hansson R. Functional anatomy and training in alpine skiing: Performance optimization through understanding components of the skier's anatomy and physiology and their integration 1st ed. Warp Publishing AB; 2013.

6. International Olympic Committee. Freestyle skiing – winter olympic sport. Retrieved from: https://www.olympic.org/freestyle-skiing; 2018.

7. International Ski Federation. The international freestyle skiing competition rules (icr). Retrieved from: https://assets.fis-ski.com/image/upload/v1542730293/fis-prod/FS_FIS_Freestyle_ICR_2018_Fall_marked-up.pdf; 2018.

8. Jakobsen JC, Gluud C, Winkel P, Lange T, Wetterslev J. The thresholds for statistical and clinical significance - a five-step procedure for evaluation of intervention effects in randomised clinical trials. BMC Med Res Methodol 14: 34, 2014.

9. João AF, Filho JF. Somatotype and body composition of elite Brazilian gymnasts. Sci Gymnast J 7(2): 45-54, 2015.

10. Krüger A, Edelmann-Nusser J. Biomechanical analysis in freestyle snowboarding: Application of a full-body inertial measurement system and a bilateral insole measurement system. Sports Technol 2(1-2): 17-23, 2009.

11. Levy D, Hubbard M, McNeil JA, Swedberg A. A design rationale for safer terrain park jumps that limit equivalent fall height. Sports Eng 18(4): 227-239, 2015.

12. McAlpine P, Kersting U. Development of a field testing protocol for the biomechanical analysis of snowboard jump landings–a pilot study. Proceedings of the 24th ISBS Conference (2006) Archive, 2007.

13. McAlpine P, Kurpiers N, Kersting U, Determan J, Borrani F. Biomechanical analyses of snowboard jump landings. Proceedings of the 30th ISBS Conference (2012) Archive, 2012.

14. McNeil JA, Hubbard M, Swedberg AD. Designing tomorrow's snow park jump. Sports Eng 15(1): 1-20, 2012.

15. Müller E, Schwameder H. Biomechanical aspects of new techniques in alpine skiing and ski-jumping. J Sports Sci 21(9): 679-692, 2003.

16. Nakazato K, Scheiber P, Muller E. A comparison of ground reaction forces determined by portable force-plate and pressure-insole systems in alpine skiing. J Sport Sci Med 10(4): 754-762, 2011.

17. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

18. Neumayr G, Hoertnagl H, Pfister R, Koller A, Eibl G, Raas E. Physical and physiological factors associated with success in professional alpine skiing. Int J Sports Med 24(8): 571-575, 2003.

19. O'shea MJ. Snowboard jumping, Newton's second law and the force on landing. Phys Educ 39(4): 335-341, 2004.

20. Soligard T, Steffen K, Palmer-Green D, Aubry M, Grant ME, Meeuwisse W, Mountjoy M, Budgett R, Engebretsen L. Sports injuries and illnesses in the Sochi 2014 Olympic winter games. Br J Sports Med 49(7): 441-447, 2015.

21. Soulé B, Reynier V, Pabion-Mouriès J. Snowpark evolution in france from 1990 to 2010: A plurality of compromises and gradual rationalization behind a major territorial innovation. Loisir Soc - Soc Leis 39(1): 104-121, 2016.

22. Stöggl T, Martiner A. Validation of moticon's opengo sensor insoles during gait, jumps, balance and cross-country skiing specific imitation movements. J Sports Sci 35(2): 196-206, 2017.

23. Turnbull JR, Kilding AE, Keogh JW. Physiology of alpine skiing. Scand J Med Sci Sports 19(2): 146-155, 2009.

24. Turner A. Routledge handbook of strength and conditioning: Sport-specific programming for high performance. London, UK: Routledge; 2018.

25. Visscher C, Louer LEAM, Elferink-Gemser MT. The perfect elite gymnast, does he exist? A systematic review. Ann Res Sport Phys Act 2012(3): 2012.

26. Willmott T, Collins D. A retrospective analysis of trick progression in elite freeskiing and snowboarding. Int Sport Coach J 4(1): 1-12, 2017.

27. Willmott T, Collins D. Challenges in the transition to mainstream: Promoting progress and minimizing injury in freeskiing and snowboarding. Sport Soc 18(10): 1245-1259, 2015.

28. X Games. Sport science: Ståle Sandbech. Retrieved from: https://www.espn.com.au/video/clip/_/id/12226234 ; 2015.

29. Young CC. Extreme sports: Injuries and medical coverage. Curr Sports Med Rep 1(5): 306-311, 2002.