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Comparison of lower extremity strength and strength symmetry among U.S. Ski Team sports

Benjamin J. Adams

Comparison of Lower Extremity Strength and Strength Symmetry Among U.S. Ski Team Sports

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Benjamin J. Adams

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THESIS OF BENJAMIN J. ADAMS APPROVED BY

____ DATE________________
JENI MCNEAL, Ph.D., GRADUATE STUDY COMMITTEE

____ DATE________________
KATRINA TAYLOR, Ph.D., GRADUATE STUDY COMMITTEE

____ DATE________________
JUSTIN BASTOW, Ph.D., GRADUATE STUDY COMMITTEE

ABSTRACT

Most research in ski sports performance, injury, and sport physiological demands focuses on alpine ski racing. Very little research is available describing aerial and moguls ski competitors. **Purpose**: Compare lower extremity strength limb symmetry index (LSI) and relative strength (RS) among alpine, mogul, and aerials ski competitors. **Methods**: Archival data from 156 males and females from the U.S. Ski Team at Olympic, World Cup, and national levels were analyzed to compare RS and LSI among ski sports. Strength data consisted of maximal isometric bilateral squat strength values from each leg independently. A 3x2x2 factorial ANOVA was conducted to determine differences and interactions between sex, competitive level, and sport type on LSI. A second factorial ANOVA was conducted to compare RS among the same factors. **Results**: The main effects of sport type ($p = 0.194$), competitive level ($p = 0.061$), and sex ($p = 0.260$) were not significant for LSI. There were no significant interactions between independent variables for LSI. The main effects of sport type ($p = 0.041$) and sex ($p < 0.001$) were significant for relative strength. Alpine racers were significantly stronger than moguls ($p = 0.002$) and aerials ($p = 0.001$) competitors. Males were significantly stronger than females ($p < 0.001$) in all three disciplines. No other significant findings for main effects or interactions were found. **Conclusion**: The low presence and variation in LSI may indicate that a bilateral maximum strength test may not be ideal for identifying LSI. Strength differences among sports may exist due to exposure to forces associated with speed. Sex differences in relative strength may be due to anthropometric variations.

Table of Contents

Introduction

A high incidence of injury has been reported in ski sports at the elite level. At the World Cup level, 36.7 injuries per 100 athletes have been reported for alpine ski racing (Steidl-Müller, Hildebrant, Muller, Fink, & Raschner, 2018). Research on the rate, mechanism, prediction, and prevention of injuries mainly focuses on alpine ski racers. There is very little research on injuries in other ski sports, even ones thought to have higher rates of injury. In the 2014 Sochi Winter Olympics, skiing freestyle aerials had more injuries than all other winter sports (Soligard et al., 2014). In 2018, ski halfpipe had the highest rate of injury (Soligard et al., 2019). In alpine ski racing, injuries primarily occur when the athlete is turning or landing (Bere, Florenes, Krosshaug, Haugen, Svandal, Nordsletten, & Bahr, 2014; Gilgien, Sporri, Kroll, Crivelli, & Muller, 2014). Since other ski events also involve landing and turning, we may be able to extrapolate ski injury findings in alpine ski racing to other ski events that contain these elements.

Limb symmetry index (LSI), or the amount of difference in function between limbs, is a measure widely used to aid in the return to sport decision for injured athletes (Schmitt, Paterno, & Hewett, 2012). LSI is expressed as a percentage of symmetry or asymmetry between sides. Researchers and clinicians have used LSI to determine symmetry for strength (Jordan, Aagaard, & Herzog, 2014), balance (Promsri, Longo, Haid, Doix, & Federolf, 2019), and various unilateral jumping tasks (Yanci & Camara, 2016). An LSI of 10% or less is typically used as a requirement for return to sport (Myer, Paterno, Ford, Quatam, & Hewett, 2006; Schmitt et al., 2012). LSI has also been used to predict injury in youth alpine racers. Stiedl-Müller et al. (2018) found leg strength asymmetry in a seated unilateral leg press to be a significant risk factor for traumatic injury, especially involving the lower extremities, in youth alpine ski racers. Promsri et al. (2019) suggested that sensory motor control differences between dominant and non-dominant legs may contribute to injury risk more than strength differences. This was in contrast to the findings from Steidl-Müller et al. (2018), who found leg strength in the unilateral leg press to be the only asymmetry among a battery of unilateral strength, balance, and jump performance tests that significantly correlated with traumatic injury. Promsri et al. (2019) used isometric knee extensor and flexor strength as their strength measurement as well as the ratio of knee flexor to extensor strength (HQ). A greater HQ, or stronger hamstrings compared to quadriceps, is theorized to reduce anterior cruciate ligament (ACL) injury risk due to the hamstrings limiting the amount of anterior movement of the tibia relative to the femur. However, an optimal HQ ratio to decrease the risk of ACL injury has not been found (Sporri, Kroll, Gilgien, & Muller, 2017). To measure strength LSI, Steidl-Müller et al. (2018), used a unilateral leg press, which coactivates the quadriceps and hamstrings similarly to how the lower limbs are used while skiing. It may be that strength measures to predict injury in skiing become more reliable as strength measures increase in similarity to the position and force application of skiing (Jordan et al., 2015).

The archival data available for the present study included unilateral strength information derived from bilateral isometric squat testing. The squat resembles skiing in position and application of force to a greater extent than the leg press (Hydren, Volek, Maresh, Comstock, & Kraemer, 2013). This is due to a greater reliance on hip extension to produce force (Wirth, Hartmann, Sander, Mickel, Szilvas, & Keiner, 2015). Not only are the gluteal muscles more incorporated for hip extension in the squat, but the hamstrings also contribute considerably to hip extension in addition to knee flexion (Escamilla, Fleisig, Zheng, Lander, Barrentine, Andrews et al., 2001; Wirth et al., 2015;). The primary purpose of this study was to investigate the maximal strength LSI of the isometric squat in uninjured Olympic, World Cup, and national level ski competitors and to compare these findings between three different ski disciplines. It was hypothesized that LSI would not be significantly different among sport types.

In addition to injury, due to the popularity of alpine ski racing, there is no shortage of scientific investigations into several aspects of the sport including physiological profiles of competitors (Neumayr, Hoertnagl, Pfister, Koller, Eibl, & Raas, 2003), metabolic demands (Bottollier, Coulmy, Quellec, & Prioux, 2020), and biomechanical influences on performance (Hebert-Losier, Supej, & Holmberg, 2014). Very little research exists for any aspect of the freestyle winter ski sports moguls and aerials. Although there are similar elements between the freestyle disciplines and alpine racing, the objectives and performances are very different and warrant their own scientific examination. Therefore, the secondary aim of this study was to observe relative strength (RS) of competitors across the three ski sports and across competitive levels. It was hypothesized that RS would be significantly different among sport types.

Methods

Participants

The original data set consisted of 609 data entries, collected between April 2010 and November 2015, from 205 males and females from US Olympic, World Cup, and national ski teams who competed in either alpine racing, moguls, or aerials. Data entries were excluded if participants were under 18 years at the time of the test, if they were reported as positive for injury status, or if squat strength data were missing. After applying exclusionary criteria, one test was randomly selected using a random number generator, for use from athletes with multiple test entries. The final data set consisted of a single data entry for 156 male and female alpine racing, moguls, and aerials Olympic, World Cup, and national competitors, collected between April 2010 and November 2015. Refer to Table 1 for participant characteristics.

Study Design

This study was a cross sectional design using archival squat strength data from U.S. Ski team athletes. Athletes were characterized by sport type, competitive level, and sex. Competitive level was separated into either Olympic and world cup competitors or national team competitors.

Procedure

This investigation utilized an existing data set obtained from the U.S. Ski & Snowboard Center of Excellence (COE) Sport Science division in Park City, UT. Therefore, procedures described here for collecting force plate data are based on conversations with COE staff by the thesis chair, who acquired the data set (McNeal and Sands, W.A., personal communication). This description has notable gaps that represent information that was not able to be clarified or specified clearly by the COE staff.

Maximal effort, isometric back squats were performed in a squat rack with the participant standing on two force plates. A barbell loaded with greater weight than could be lifted by the athlete was set at a fixed position for each skier such that they were in the deepest position of a typical back squat. The athlete attempted to produce as much force as possible by pressing against the barbell on their shoulders while standing on the force plates. The sampling rate of each force plate was 1000 Hz. Additional information about the test is unavailable, such as the warm-up procedures, instructions to the participants, the depth and joint angles of the squat, and testing attire. The same data collection procedure was used for each test. However, different coaches administered testing throughout the data collection.

The following equation was used to calculate LSI based on previous research (Jordan et al., 2014; Sato & Heise, 2012): $\text{LSI} = \left(\frac{\text{Stronger limb strength value} - \text{Weaker limb strength value}}{\text{Stronger} + \text{Weaker limb strength value}}\right)100$ where the strength value is in newtons (N). RS was calculated via traditional allometric scaling using the following equation (Suchomel, Nimphius, & Stone, 2018): $N/kg^{.67}$ where N is the sum of the stronger and weaker limb value and kg is body mass.

Statistics

Statistical analyses were conducted using IBM SPSS v27.0 (Armonk, NY). Tests of normality and homogeneity of variance were conducted using Shapiro-Wilk and Levene's tests, respectively. A 2x2x3 factorial ANOVA was conducted to determine differences and interactions between sex, competitive level, and sport type on LSI. A second 2x2x3 factorial ANOVA compared these factors for the dependent variable of relative strength. Statistical significance for main effects and interactions was achieved when $p \leq 0.05$. An LSD post hoc test was used to compare the main effects of sport type on LSI and RS.

Table 1

Participant characteristics, limb symmetry index (LSI), and relative strength (RS) by sport type, competitive level, and sex (Mean ±SD)

	Aerials				Alpine Racing				Moguls			
	Oly/WC		National		Oly/WC		National		Oly/WC		National	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
n	7	3	7	7	25	17	41	12	10	10	10	7
Age												
M	21.52	19.15	21.84	21.72	22.96	23.49	19.43	18.87	23.86	22.68	21.62	21.36
SD	±3.62	±.69	±2.32	±4.76	±3.09	±2.99	±1.88	±.57	±3.08	±3.85	±3.54	±1.89
Mass (kg)												
M	65.69	61.24	73.96	59.71	84.72	69.57	83.43	66.72	73.41	58.15	68.08	62.10
SD	±4.60	±6.10	±5.27	±5.46	±6.63	±5.63	±8.08	±6.75	±4.19	±5.29	±4.25	±4.45
LSI (%)				.								
M	.85	1.39	.73	.79	.84	.74	.75	.79	.89	.75	.75	.83
SD	±.31	±.27	±.35	±.47	±.31	±.28	±.38	±.25	±.51	±.42	±.44	±.30
RS(N*/kg$^{.67}$)												
M	226.09	184.09	232.65	188.42	244.74	200.34	238.27	196.33	243.45	188.18	228.93	192.53
SD	±18.53	±16.59	±21.51	±14.42	±20.12	±18.79	±21.41	±17.19	±23.02	±25.58	±23.62	±25.32

*N: Newtons

Abbreviations: Oly/WC = Olympic/World Cup, M = mean, SD = standard deviation

Results

LSI data did not meet the assumption for normality according to a Shapiro-Wilk test ($p < .001$). Histograms showed positively skewed data. Square root transformation of LSI data (Transforming variable to normality for parametric statistics, 2020) was performed, resulting in a normal distribution ($p = 0.646$). A Levene's test revealed LSI met the assumption of homogeneity of variance (p = 0.283). A 2x2x3 factorial ANOVA revealed no significant main effect of sport type ($p = 0.194$), competitive level ($p = 0.061$), or sex ($p = 0.260$) for LSI. There were no significant interactions between independent variables for LSI.

RS data met the assumption of normality according to a Shapiro-Wilk test ($p = 0.354$), and homogeneity of variance according a Levene's test ($p = 0.956$). The main effects of sport type ($p = 0.041$) and sex ($p < 0.001$) were significant for RS. The main effect of competitive level was not significant ($p = 0.695$) for RS. There were no significant interaction effects between independent variables for RS. Post hoc analyses revealed that alpine RS was significantly different than ariels ($p = 0.001$) and moguls ($p = 0.002$), and male and female RS was significantly different ($p < 0.001$). Alpine competitors ($M = 227.89 \pm 27.93$ N) were stronger than aerials ($M = 211.77 \pm 27.38$ N) and moguls ($M = 214.95 \pm 33.45$ N) competitors. Males RS ($M = 238.23 \pm 21.58$ N) was significantly greater than female RS ($M = 222.34 \pm 29.89$ N).

Discussion

Limb Symmetry

The current results indicate that strength LSI in the bilateral isometric squat is not different among the ski disciplines. However, asymmetry was low in this sample ($M = 0.80 \pm 0.36\%$) and varied little, making it difficult to observe a difference. It is possible that the maximum bilateral effort encourages a bilateral coordination between limbs and limits the amount of asymmetry that can be observed. Sabaron, Kozinc, Bishop, and Maffiuletti (2020) suggest that there is very little interlimb variation in strength during a maximum voluntary contraction due to full neuromuscular activation of both limbs. Steidl-Müller et al. (2018) recorded a mean LSI of 7.4 ± 6.4% in Austrian World Cup alpine ski racers (n = 84) using a unilateral isokinetic leg press. Although a squat is more similar in position to skiing than a leg press, the data used in the present study was from a bilateral squat. Patterson, Raschner, and Platser (2009) demonstrated that force difference between legs decreased rather than increased as loads were increased in a loaded bilateral countermovement jump. In Kobayashi, Kubo, Matsudo, Matsubayashi, Kobayashi, and Ishii (2010), long jumpers had no difference in force between takeoff leg and non-takeoff leg in various loads of a back squat despite showing significantly greater joint angles and torques in the takeoff leg. Additionally, kinematics between dominant and non-dominant legs have been found to be significantly different in a unilateral squat variation compared to a bilateral squat (Moore, Mulloy, Bridle, & Mullineaux, 2016). The differences in kinematics between limbs in both bilateral and unilateral exercises could contribute to force production differences in a unilateral task. Future research should compare the abilities of unilateral and bilateral maximum strength tests to expose asymmetry.

Asymmetry in the leg press has been shown to predict injury in alpine ski racing and other strength measurements such as knee flexion, extension, and the ratio of the two (HQ), have had less success in injury prediction (Sporri et al., 2017). This may be because the application of force and the coordinated contraction of knee flexors and extensors are more similar to skiing in the leg press than in isolated knee flexion or extension. If this is the case, then it may be more beneficial to measure strength in a way that is even more like skiing, such as in a unilateral squat. However, a squat primarily produces force vertically. Research has shown that alpine ski injuries primarily occur while an athlete is turning or landing (Bere et al., 2014). Turning while skiing, asymmetrically loads the lower extremities, with the outside leg taking most of the force not only vertically but laterally as well (Hintermeister, O'Connor, Dillman, Suplizio, Lange, & Steadman, 1995). Maddy (2020) found that a laterally resisted split squat was significantly more similar to the ground reaction force angle in change of direction activities than a traditional split squat. This may be good option for specific unilateral strength testing and strength training in alpine skiers.

Injury prediction from strength LSI has only been demonstrated in youth alpine ski racers. It has not been attempted for adult elite ski racers. Steidl-Müller et al. (2018) showed that youth display larger asymmetries in strength and strength LSI decreases with age and experience. It would be more difficult to observe a relationship between strength LSI and injuries in elite adult skiers. A possible reason for this difference is the emphasis and experience with bilateral maximal strength training in adult competitors. Bilateral maximum strength training has been shown to reduce strength asymmetry (Bazyler, Bailey, Chiang, Sato, & Stone, 2014). Youth strength training is focused more on coordination and stability than on maximal strength (Steidl-Müller et al., 2018). The strength training experience in the population for the present study may have also contributed to the low asymmetry found.

Relative Strength

The results from this study indicate that alpine ski racers have significantly greater RS than moguls and aerials competitors. This may be due to the greater emphasis on speed in alpine racing compared to the two other disciplines. The reliance on speed in racing may subject racers to greater forces and may require, as well as stimulate, greater strength (Turnbull, Kilding, & Keogh 2009). Greater strength is needed at greater speeds to eccentrically absorb the terrain during transitions and turning (Hydren, Volek, Maresh, Comstock, & Kraemer 2013). Moguls and aerials are freestyle events that rely on complexity and accurate performance of skills to achieve a high score (FIS, 2014). Depending on the alpine racing discipline, racers reach speeds ranging from 20 to 65 mph and experience forces between 1- and 3- times gravity while turning (Hydren et al., 2013).

While it did not reach significance, mean RS showed a trend of being greater in moguls than in aerials competitors. This may be due to the partial reliance on speed for scoring in moguls. Moguls competitors can receive a higher score by increasing speed through the course while aerials competitors are wholly reliant on execution of technique for scoring (FIS, 2014). The partial emphasis on speed during the moguls may explain the slight difference in strength between competitors of these two events.

RS was significantly greater in males than females among all three sport types. While it is well documented that males tend to have greater absolute strength than females, some studies have shown little to no difference when strength values are normalized to body mass (Frontera, Hughes, Lutz, & Evans, 1991; Hedt, Pearson, Lambert, McCulloch, & Harris, 2019). It may be that females in this study are lacking in strength, however, when comparing sex differences in strength with equally trained athletes, Bishop, Cureton, and Collins (1987) found that fat-free mass, and forearm and thigh cross-sectional area accounted for 97% of sex-related strength differences. In the present study, the only available anthropometric measurement was body mass. It may be that similar measurements of body composition and cross-sectional area would explain sex-related strength differences in this population as well.

Men and women in this study show similar differences in strength among sport types relative to their sex. In a recent meta-analysis, Roberts, Nuckols, and Kriegor (2020) found males and females adapted similarly when participating in identical resistance training programs. The similar differences in strength among sports indicate that males and females of the same sport may have underwent similar resistance training programs.

Conclusion

The strength training experience in elite adult athletes combined with the use of a bilateral maximum strength test might minimize the amount of strength asymmetry that can be observed. Use of unilateral strength tests using a movement pattern specific to the sport is recommended for future investigations into strength asymmetry in ski athletes.

Strength differences among sports may exist due to exposure to forces associated with speed. Increased reliance on speed in ski events may require increases in maximum lower extremity strength. Coaches and athletes should place an emphasis on maximum strength when speed is a vital component for competitive success.

RS was significantly greater in males even though RS has been shown vary little between males and females with similar training experience. It may be that less training emphasis is placed on strength in female ski athletes. Coaches of female ski athletes should strive to close the gap in RS between males and females or to explain the variation by other anthropometric variables.

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Vita

Author:	Benjamin Adams
Place of Birth:	Kennewick, Washington
Undergraduate Schools Attended:	Eastern Washington University
Degrees Awarded:	Bachelor of Science/Exercise Science, 2018, Eastern Washington University
Honors and Awards:	Graduate Assistantship, Wellness and Movement Sciences Department, 2018-2020, Eastern Washington University
Professional Experience:	Graduate Assistant for Wellness and Movement Sciences Department, Eastern Washington University, Cheney, Washington, 2018-2020 Revolution Fitness Coach/Personal Trainer, Spokane Fitness Center, Spokane, Washington, 2016-2020 Strength and Conditioning Coach, Eastern Washington University, Cheney, Washington, 2018-2019 Strength and Conditioning Intern, Eastern Washington University, Cheney, Washington, 2018 Avionics Electrical Technician/Flight Mechanic/Rescue Hoist Operator, United States Coast Guard, North Bend, Oregon, 2005-2012