

RELIABILITY OF CENTER OF PRESSURE MEASURES DURING SUCCESSIVE SKI-SIMULATED SQUAT TASKS

Stephanie R. Moore¹, Sarah Breen¹, Josef Kröll², Gerda Strutzenberger², and Randall L. Jensen¹

Northern Michigan University, Marquette, Michigan, USA¹
Department of Sport and Exercise Science, University of Salzburg, Austria²

Laboratory assessments of alpine ski tasks have the potential to be an effective initial investigation method prior to more intensive on-snow testing. Research questions involving acute changes elicited by sport-essential equipment would be an ideal application for such investigations. The purpose of the current study was to determine the reliability of a ski-simulated squat task on centre of pressure indices. Successive squat tasks were performed in skis at a ski-simulated rhythm and analysed during four experimental conditions. Reliability analysis via repeated measures ANOVAs and intraclass correlation coefficients resulted in good to excellent reliability of centre of pressure outputs. The current study proposes a laboratory test that is reliable and encompasses biomechanical challenges presented by the alpine ski boot-binding complex.

KEYWORDS: alpine skiing, bindings, excursion, area, geometric entropy

INTRODUCTION: The kinetic characteristics such as timing, magnitude, and location of ground reaction forces, affects skier performance by impacting a ski's translation across the snow (Hébert-Losier, Supej, & Holmberg, 2014; Professional Ski Instructors of America, 2014). Thus, the measurement of kinetic indices in a laboratory setting appear to be an important initial step when investigating the biomechanical influence of alpine ski equipment. Previous works have included measurements of CoP area and velocity (Noé, García-Massó, Delaygue, Melon, & Paillard, 2018), stabilometer area profiles (Tchórzewski, Bujas, & Jankowicz-Szymańska, 2013) and plantar pressure scans in the field (Kröll, Birklbauer, Stricker, & Müller, 2006), to name a few. When investigating effects of equipment as these studies have, the greatest challenge is in simulating sport specific movements.

Currently used ski task simulations in a laboratory setting range greatly in methodology, making reported findings very difficult to compare. Because dynamic extension and flexion movements are essential during an alpine ski turn (Müller & Schwameder, 2003; Professional Ski Instructors of America, 2014), a ski-booted squat task may be comparable and cost-effective in the laboratory assessment of ski kinetics. The development of a reliable test protocol would allow researchers to record the kinetic responses to equipment alterations such as binding ramp angle, boot stiffness, boot fit (etc.) (Moore, Kröll, Breen, Strutzenberger, & Jensen, 2018). Therefore, the purpose of this study was to determine if successive ski-booted squats (used as a skiing simulation) are reliably estimating the kinetic properties of ski tasks when the skiers were introduced to varying boot-binding ramp angles.

METHODS: Squat tasks were measured using two separate laboratories (laboratory 1 = Austria, laboratory 2 = USA) utilizing a within-subjects repeated measures design. Participants (male = 11, female = 8; 27 ± 5 yrs, 1.76 ± 0.11 m, 73.9 ± 14.7 kg) performed 10 successive squats under four experimental conditions: barefoot (BF; consequently, a 0° ramp angle) and ski booting, attached to ski-mounted bindings with a posterior to anterior ramp angle of 0° , 1° , and 2° (R0, R1, R2, respectively). Squats were performed at a metronome-controlled rhythm of 36 bpm to simulate the tempo of skiing (Seifert, Kröll, & Müller, 2009). Barefoot control conditions were performed first, and ski-booted ramped conditions were then performed in a randomized, counterbalanced order. Ramp angles were accomplished utilizing the see-saw mechanism of the SensoWip binding (Kröll et al., 2006). All participants used the same skis during the tasks, with ground contact area controlled to 1.2 m in length by the measured hip width of the participant.

Advance Medical Technologies Inc. (AMTI; Watertown, MA, USA) force platforms (laboratory 1: two AMTI OR6-7-2000, laboratory 2: one AMTI BP6001200) recorded ground reaction forces at a sampling frequency of 250 Hz (Panjan, Supej, Rosker, & Sarabon, 2016). Kinetic data were filtered using a 40 Hz Butterworth bidirectional cutoff (Fransz, Huurnink, de Boode, Kingma, & van Dieën, 2015). The “transition points” where the pelvis segment assumed a resultant velocity of zero were determined using Visual 3D x64 Professional (v6.01.18; Germantown, MD USA). A squat phase was thus defined by two successive transition point maxima (marking the beginning and end of the squat). Each squat phase was then normalized to 200%, with squat down-phase being 1-100% and up-phase being 101-200%. Center of pressure (CoP) was assessed via the global coordinates of Mx and My moments. At laboratory 1, this required the merging of two force plate outputs via the calculations supported by Exell, Gittoes, Irwin, and Kerwin (2012). From the global coordinates, the CoP length of excursion (total, sagittal, and frontal plane) and 95% confidence circle area were calculated for each squat (Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996). Geometric entropy (GeoEn) was also calculated from the global CoP coordinates during each phase, using Equation 1 (Sibella, Frosio, Schena, & Borghese, 2007):

$$GeoEn = \ln \frac{2 * CoP Path Length}{Convex Hull} \quad (\text{Equation 1})$$

Where GeoEn = Geometric entropy

CoP = center of pressure

Convex hull = the smallest envelope encompassing all data points

Reliability analysis for the final three squats (8, 9, and 10) during each experimental condition was performed utilizing SPSS Statistics v.24. Comparison of squat means were analysed with a within subjects repeated measures ANOVA ($\alpha = 0.05$). The intraclass correlation coefficient (ICC) was reported as an indicator of variance for each reported kinetic variable. ICC level of reliability was assessed on an interpretive scale of poor to excellent (< 0.50 = poor, $0.50 - 0.74$ = moderate, $0.75 - 0.9$ = good, ≥ 0.90 = excellent; Koo & Li, 2016).

RESULTS: The repeated measures ANOVAs indicated that there were no significant differences between the three squat trials for any experimental condition or kinetic measure (p

Table 1. Reliability analysis of three squat trials is displayed for five centre of pressure measurements (area, total excursion, sagittal and frontal plane excursion, and geometric entropy). F-Statistic, significance = ANOVA results; ICC = intraclass correlation coefficient; CI 95% = 95% confidence interval of the ICC.

	Total Excursion				Area			
	BF	R0	R1+	R2	BF	R0	R1+	R2
F-Statistic	0.249	1.365	1.307	0.513	0.279	1.560	1.919	0.520
Significance	0.781	0.268	0.284	0.603	0.758	0.224	0.162	0.599
ICC	0.865**	0.949**	0.931**	0.922**	0.822**	0.941**	0.963**	0.909**
Low CI 95%	0.709	0.891	0.848	0.833	0.618	0.873	0.919	0.804
High CI 95%	0.944	0.979	0.972	0.968	0.926	0.975	0.985	0.962
	Sagittal Excursion				Geometric Entropy			
	BF	R0	R1+	R2	BF	R0	R1+	R2
F-Statistic	0.558	1.361	1.239	0.521	4.141	3.941	0.076	1.881
Significance	0.577	0.269	0.302	0.598	0.051	0.063	0.927	0.167
ICC	0.911**	0.948**	0.932**	0.921**	0.982**	0.987**	0.993**	0.992**
Low CI 95%	0.808	0.889	0.851	0.831	0.962	0.973	0.984	0.983
High CI 95%	0.963	0.979	0.972	0.967	0.993	0.995	0.997	0.997
	Frontal Excursion							
	BF	R0	R1+	R2	BF	R0	R1+	R2
F-Statistic	0.014	2.166	3.562	0.834				
Significance	0.986	0.129	0.062	0.442				
ICC	0.469	0.808**	0.674*	0.803**				
Low CI 95%	-0.140	0.587	0.285	0.576				
High CI 95%	0.799	0.920	0.868	0.918				

*Significant at $p < 0.05$, **Significant at $p < 0.001$, + = sample size was reduced ($n = 18$) due to insufficient data.

= 0.051 – 0.986; Table 1). Further, significant ICCs were found for 19 of the 20 tests, with the exception being frontal plane excursion in the BF condition ($p = 0.052$; Table 1). Of these 19 significant ICCs, 18 of them explained greater than 64% of the variability in the samples ($ICC > 0.80$). With respect to the ICCs, 13 of the 20 tests can be interpreted as “excellent,” while four were classified as “good.” The final three ICCs were less than 0.75 (one “moderate”, two “poor”).

DISCUSSION: The lack of significant differences in repeated measures ANOVAs suggests that the three squat trials analysed are measuring consistent CoP profiles. Importantly, when ramp angles were changed, thus presenting unfamiliar conditions, the repeatability of these test results were unchanged. Several measures (R1 frontal plane excursion and BF and R0 geometric entropy; Table 1) had near statistically significant differences in mean comparisons. For these measures especially, a larger sample size would help minimize the conclusions of the current study being at risk for type two errors.

The reliability of the squat tasks is further supported by the strength of the ICCs. Good to excellent ICC interpretations were recorded for 18 of the 20 tests. Interestingly, the lowest ICCs were reported for frontal plane excursions. This is likely because the average excursions in the frontal plane were at most 5.5% of the CoP total excursion, sagittal excursion, and area measurements. Again, a greater number of participants may help to increase the relationship of the ICC in the frontal plane, especially considering one participant was excluded from the R1 measures (R1 frontal plane excursion: $ICC = \text{moderate}$, $ANOVA = 0.062$). However, because the small frontal plane excursions had the poorest repeatability, it is a parameter that should be forgone or reported with limitations in ski-booted squat research. Ultimately, the squat tasks performed in the current study report most kinetic variables in a laboratory setting with generally good to excellent reliability, though a larger number of samples would bolster the confidence of these results.

Although a reliable task protocol is supported in the current study, further investigation into the validity of the task is the necessary next step. Importantly, the applicability of laboratory tasks is limited in nature: if CoP measures vary in a dynamic laboratory ski task with equipment alterations but are unaffected or inconsequential when applied to the more intricate on-snow skiing tasks, the validity of the tests may be questionable. Thus, associating simple and reliable laboratory assessment results (as provided in the current study) to on snow performance would encourage the consistency of ski task methodology.

CONCLUSION: The development of a reliable and prevailing laboratory assessment of ski tasks is imperative for the comparison of research findings. The use of task performance in a laboratory setting helps researchers investigate the effects of equipment on indices like CoP movement without the high expense, logistics, and commitment of a field study. The current study proposes a reliable ski-simulated squat task that encompasses some primary characteristics of alpine ski turns: bipedal dynamic flexion and extension movements, limited ankle range of motion, and a large base of support. Importantly, the repeatability of frontal plane deviations is not supported in the current study, and thus should not be considered a reliable outcome parameter for ski-booted squat tasks.

REFERENCES

- Exell, T. A., Gittoes, M. J. R., Irwin, G., & Kerwin, D. G. (2012). Considerations of force plate transitions on centre of pressure calculation for maximal velocity sprint running. *Sports Biomechanics*, *11*(4), 532–541.
- Fransz, D. P., Huurnink, A., de Boode, V. A., Kingma, I., & van Dieën, J. H. (2015). Time to stabilization in single leg drop jump landings: An examination of calculation methods and assessment of differences in sample rate, filter settings and trial length on outcome values. *Gait & Posture*, *41*(1), 63–69.
- Hébert-Losier, K., Supej, M., & Holmberg, H.-C. (2014). Biomechanical Factors Influencing the Performance of Elite Alpine Ski Racers. *Sports Medicine*, *44*(4), 519–533.
- Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163.

- Kröll, J., Birklbauer, J., Stricker, G., & Müller, E. (2006). Technique training in alpine ski racing: forced movement changes by a specific device. In *ISBS-Conference Proceedings Archive* (Vol. 1).
- Moore, S.R., Kröll, J., Breen, S., Strutzenberger, G., & Jensen, R. L. (2018). Joint coordination adaptations to an implemented ramp angle in recreational alpine skiers. Presented at the International Society of Biomechanics in Sports.
- Müller, E., & Schwameder, H. (2003). Biomechanical aspects of new techniques in alpine skiing and ski-jumping. *Journal of Sports Sciences*, 21(9), 679–692.
- Noé, F., García-Massó, X., Delaygue, P., Melon, A., & Paillard, T. (2018). The influence of wearing ski-boots with different rigidity characteristics on postural control. *Sports Biomechanics*, 1–11.
- Panjan, A., Supej, M., Rosker, J., & Sarabon, N. (2016). Reliability and sensitivity of a novel dynamic balance test for alpine skiers. *Measurement*, 85, 13–19.
- Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., & Myklebust, B. M. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Transactions on Biomedical Engineering*, 43(9), 956–966.
- Professional Ski Instructors of America. (2014). *Alpine technical manual*. [Lakewood, CO]: American Snowsports Education Association, Inc.
- Seifert, J., Kröll, J., & Müller, E. (2009). The relationship of heart rate and lactate to cumulative muscle fatigue during recreational alpine skiing. *The Journal of Strength & Conditioning Research*, 23(3), 698–704.
- Sibella, F., Frosio, I., Schena, F., & Borghese, N. A. (2007). 3D analysis of the body center of mass in rock climbing. *Human Movement Science*, 26(6), 841–852.
- Tchórzewski, D., Bujas, P., & Jankowicz-Szymańska, A. (2013). Body posture stability in ski boots under conditions of unstable supporting surface. *Journal of Human Kinetics*, 38, 33–44.

ACKNOWLEDGEMENTS: This project was funded in part by an Excellence in Education Award (2017; Northern Michigan University; NMU), an International Society of Biomechanics in Sports (ISBS) Student Mini Research Grant (2017; ISBS), and an ISBS Internship Grant (2017; ISBS). The research was further supported via facility use in the Exercise Science Laboratory at NMU and the Biomechanical Lab at the University of Salzburg.