Edging Velocity: The Crucial Role of Edge Engagement in Alpine Skiing

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Abstract: In alpine skiing, the way a ski engages with the snow surface – particularly at the beginning of a turn – plays a key role in determining performance. This study introduces Edging Velocity (EV) as a novel metric to quantify how quickly the ski is tipped onto its edge during turn initiation. Building upon sensor-based motion analysis using the “Connected Boot” system, we investigated three distinct skiing techniques: race carving, moderate carving, and parallel ski steering. An expert skier performed multiple turns for each technique, and EV was computed from edge angle progression. Results show that EV was highest during race carving, followed by moderate carving, and lowest during parallel ski steering. All pairwise differences were statistically significant ($p < 0.001$ or $p < 0.01$). These findings highlight EV’s potential as a performance-relevant parameter for optimizing edge engagement. Integrated into real-time feedback systems, EV may support learning and refinement of skiing technique, particularly in the critical early phase of a turn.

1 INTRODUCTION

A skier continually strives to place the ski on its edge, carefully adjusting edge angles and body positioning to navigate tight radii without lateral skidding, allowing gravity to guide them through the turn (Jo, 2020). This effect typically occurs during carving turns and is primarily utilized by experienced skiers. It refers to the technique in which the ski's tip forms a groove in the snow that the entire length of the ski edge follows, thereby producing a self-steering effect, where the ski naturally follows a curved path dictated by its edge angle and deflection characteristics, minimizing lateral skidding and enhancing dynamic stability throughout the turn (LeMaster, 2009; Federolf, Roos, Lüthi, & Dual, 2010). In contrast, parallel ski steering creates additional braking forces, which make the turns feel less smooth and continuous. Most of the literature focuses on parallel ski steering or carving, but these are not rigidly separate and can occur simultaneously along different segments of the ski (Reid, Haugen, Gilgien, Kipp, & Smith, 2020; Thorwartl et al., 2023).

Attaining competence in the carving technique is fundamental. Motor learning theory emphasizes the need for immediate and precise feedback in the form of knowledge of performance (KP) to support technical refinement and skill acquisition (Schmidt & Young, 1991; Oppici, Dix, & Narciss, 2024). Recent evidence highlights that KP may outperform

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knowledge of results (KR) in certain skill-learning contexts, especially when complex movement patterns or spatial–temporal precision are involved. In alpine skiing, where technique relies heavily on kinematic subtleties, KP-based real-time feedback may provide greater value than outcome-focused cues alone (Künzell, Knoblich, & Stippler, 2025).

A key challenge in skiing is identifying sensitive, learn-efficient parameters that can guide technique refinement. It has been demonstrated that the edge angle (EA) is a key metric in determining carving performance, as a higher EA leads to a smaller turn radius (Jentschura & Fahrbach, 2004). Furthermore, it has been shown that the EA is closely related to both the radial force and the deflection of the ski, factors which also play a crucial role in discriminating performance (Thorwartl et al., 2023). Therefore, proper edging of the ski serves as a fundamental requirement for achieving the desired carving experience. To further analyze and enhance skiing performance, a "Connected Boot" has been developed alongside the accompanying "Atomic Connected" app. This system evaluates performance by generating a "motion quality score" (ranging from 1 to 10) based on key metrics such as EA, EA symmetry, g-force, and speed (Martínez et al., 2019a; Martínez et al., 2019b; Snyder, Martínez, Jahnel, Roe, & Stöggl, 2021; Snyder, Martínez, Strutzenberger, & Stöggl, 2022). Recently, the system was utilized to (a) analyze effects of physical stress in alpine skiing (Finkenzeller et al., 2022), (b) detect big air jumps and jumps during skiing (Kranzinger, Kranzinger, Martinez Alvarez, & Stöggl, 2024a) and (c) analyze skiing quality of recreational skiers (Kranzinger, Kranzinger, Hollauf, Rieser, & Stöggl, 2024b).

Building on this framework of the "Connected Boot", the importance of precise edging techniques becomes evident, particularly during the initiation phase of a turn. Based on prior findings, it is hypothesized that initiating edging earlier in the initiation phase of a turn positively impacts performance and the entire movement chain leading to the self-steering effect. The authors propose early edging, defined by a high edging velocity (EV), as a potential additional metric to measure motion quality during skiing and for providing real-time feedback.

However, no study has yet validated EV as a performance metric. Thus, the objective of this paper is to compare race carving, moderate carving, and parallel ski steering turns to evaluate whether these techniques differ in terms of EV, assess its potential integration into the "Atomic Connected" app, and explore its potential for real-time feedback that could optimize skiing technique.

2 METHOD

2.1 Experimental Setup

An expert skier performed race carving, moderate carving, and parallel ski steering turns with long radii on a uniform slope under consistent soft snow conditions. The skier wore Atomic Hawx 130 CTD Ultra ski boots equipped with a strap, on which each one IMU (Suunto, Vantaa, Finland) was mounted, and skied using an Atomic Redster G7 with a length of 1.82 m and a sidecut radius of 19.6 m. The IMU data was transmitted to the phone and recorded with the "Atomic Connected" app (Fig. 1).

Figure 1: Experimental Setup.

3 DATA PROCESSING AND ANALYSIS

The analysis included 32 turns per technique, and the data were segmented using an automatic turn detection algorithm (Martínez et al., 2019a; Martínez et al., 2019b). Specific features, including EA, EA symmetry, g-force, and velocity, were calculated based on established methods (Snyder et al., 2021). Additionally, the EV during the initiation phase was calculated using (1)

$$EV = abs(EA_{90} - EA_0)/\Delta t \quad (1)$$

and incorporated into the app's metrics (see Fig. 1). EA_{90} represents the point at which EA first reaches 90% of its maximum value, while EA_0 denotes the initial EA value at the start of the turn. Δt is the time from the start of the turn to reaching EA_{90}. EV therefore represents the difference quotient in °/s (Fig. 2). For each turn, only data from the dominant outside leg were used for analysis, while data from the inside leg were excluded. An ANOVA was used to compare the mean EV across the three situations race carving, moderate carving, and parallel ski steering.

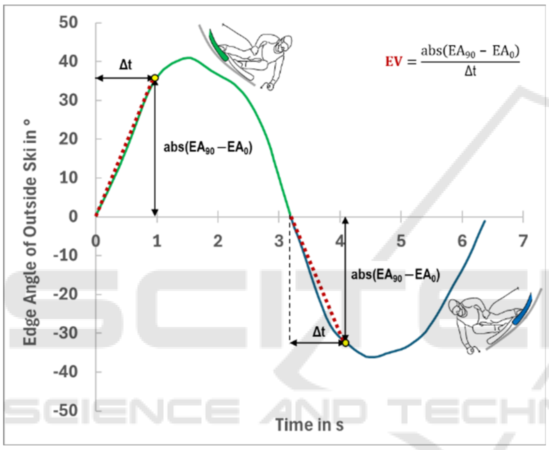

Figure 2: Calculation of Edging Velocity (EV) based on the time required to reach 90% of the maximum edge angle (EA) from the beginning of a turn. The figure shows EA progression over time and highlights EA_0, EA_{90}, and the resulting time interval Δt.

4 RESULTS

EV differed across the three skiing techniques. The mean EV was 41.4 ± 16.4 °/s for parallel ski steering, 69.4 ± 16.7 °/s for moderate carving, and 81.5 ± 20.4 °/s for race carving. The differences were statistically significant, with $p < 0.001$ for carving vs. parallel ski steering and $p < 0.01$ for moderate vs. race carving (Fig. 3). Similarly, the maximum EA was 34.8 ± 3.8° for parallel ski steering, 54.1 ± 5.9° for moderate carving, and 62.4 ± 5.1° for race carving (all $p < 0.001$).

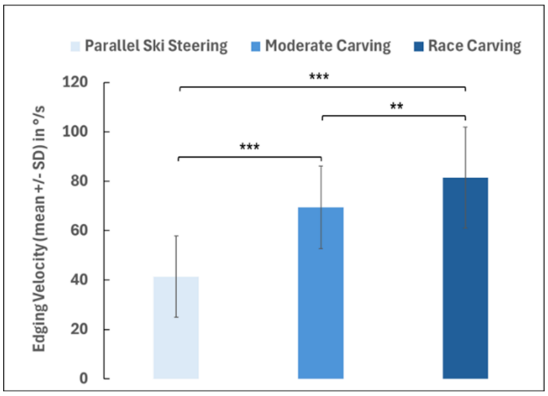

Figure 3: Comparison of edging velocity (mean +/- SD) for different performance levels. ** denotes $p < 0.01$, *** denotes $p < 0.001$.

5 DISCUSSION

This study investigates EV as a novel metric for skiing performance using the connected boot, focusing on its significance during the initiation of a turn. The results indicate that in carving turns, the edges are engaged significantly faster compared to parallel skiing, which aligns with the hypothesis that proper edge engagement plays a crucial role in optimizing performance. This early edge engagement likely contributes to the self-steering effect (LeMaster, 2009; Federolf et al., 2010), enhancing stability and control during the turn. The maximum EA is also significantly different; therefore, EV is explained by a higher EA range of motion. The findings related to EV highlight differences in technique; however, larger sample sizes may be necessary to reach more definitive conclusions. The aim of this exploratory study of one expert skier was to investigate whether EV is a potential indicator of different turn techniques. Further studies should replicate the analysis with more participants to confirm robustness and inter-individual applicability.

In the future, EV could provide real-time feedback to support recreational alpine skiers in learning and competitive alpine skiers in refining their carving technique. It is possible to get near real-time feedback from the EV using the sonification method. Sonification has recently been identified as an intuitive and effective method for delivering continuous knowledge of performance in dynamic sports (Effenberg & Hwang, 2024). Integrating EV into auditory feedback may thus facilitate earlier perception–action coupling and support implicit learning processes.

6 CONCLUSIONS

This study highlights EV as a meaningful and performance-relevant metric for optimizing edge engagement, particularly during the early phase of alpine ski turns. By integrating EV into real-time feedback systems – particularly during the early turn phase – motor learning processes can be supported and technique refinement accelerated.

Real-time feedback is a key factor for effective motor learning (Geisen & Klatt, 2021; Baca & Kornfeind, 2006). However, only one existing system in alpine skiing currently utilizes lateral skidding as a feedback parameter (Kirby, 2009). To address this gap, a novel system has been developed to sonify the EA in near real-time (latency: 28 ms), using pitch-modulated audio signals via helmet-integrated speakers. The system, along with a proof-of-concept field approach, will be presented at the congress.

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