applied sciences

Article

# Influence of the Slope and Gate Offset on Movement Variability and Performance in Slalom Skiing

**Carla Pérez-Chirinos Buxadé [1,2], Gerard Moras Feliu [2,*], Sílvia Tuyà Viñas [1,2], Michela Trabucchi [3], Dani Gavaldà Castet [4], Josep Maria Padullés Riu [2] and Bruno Fernández-Valdés Villa [1]**

[1] Research Group in Technology Applied to High Performance and Health, Department of Health Sciences, TecnoCampus, Universitat Pompeu Fabra (UPF), 08302 Mataró, Spain; cperezchirinosb@tecnocampus.cat (C.P.-C.B.); stuya@gencat.cat (S.T.V.); bfernandez-valdes@tecnocampus.cat (B.F.-V.V.)
[2] Institut Nacional d'Educació Física de Catalunya (INEFC), Department of Sports Performance, Universitat de Barcelona (UB), 08038 Barcelona, Spain; jmpadu@gmail.com
[3] Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya (UPC), 08034 Barcelona, Spain; michela.trabucchi@upc.edu
[4] Val d'Aran School of Sports Technicians (ETEVA), 25598 Lleida, Spain; dgavalda@maladetastudio.com
* Correspondence: gmoras@gencat.cat

**Abstract:** Adaptability to all types of terrain changes, slopes, and course settings is a key aspect related to the coordinative ability that elite skiers possess. In recent years, several studies have analyzed coordinative aspects of different motor actions via the assessment of movement variability (MV), an indicator of the motor control that assesses movement regularity. The aims of this study were (a) to evaluate the influence of different slopes and slalom (SL) gate offsets on MV and performance and (b) to assess the relationship between MV and performance. Four SL courses were set: a flat-turned (FT), a steep-turned (ST), a flat-straighter (FS), and a steep-straighter (SS). Five elite alpine skiers (21.2 ± 3.3 years, 180.2 ± 5.6 cm, 72.8 ± 6.6 kg) completed several runs at maximum speed for each SL course. A total of 77 runs were obtained. The use of an IMU accelerometer attached to the lower back of skiers measured MV through entropy. The skiers' performance was evaluated with the total time of each run. The one-way repeated measures analysis revealed that the steepness of the slope significantly increases skiers' MV, concretely between FS and ST courses ($p = 0.004$). Differences at the 10% level have been found between FS and SS and FT and ST courses ($p = 0.055$ and $p = 0.078$, respectively). For a given slope, turned courses (FT and ST) tend to produce a higher MV. In addition, faster times correlate with lower MV ($r = 0.587$, $p = 0.01$). It has been observed that both steeper and turned courses produce greater MV and that the best performing skiers have lower MV. Determining MV through entropy can be used to assess skiers' expertise regarding different types of slopes and gate offsets.

**Keywords:** steepness of the slope; gate offset; slalom course setting; movement variability; inertial measurement unit; entropy; performance; alpine skiing; elite alpine skiers; elite athletes

check for updates

**Citation:** Pérez-Chirinos Buxadé, C.; Moras Feliu, G.; Tuyà Viñas, S.; Trabucchi, M.; Gavaldà Castet, D.; Padullés Riu, J.M.; Fernández-Valdés Villa, B. Influence of the Slope and Gate Offset on Movement Variability and Performance in Slalom Skiing. *Appl. Sci.* **2024**, *14*, 1427. https://doi.org/10.3390/app14041427

Academic Editor: Alfonso Penichet-Tomás

Received: 11 January 2024
Revised: 2 February 2024
Accepted: 6 February 2024
Published: 9 February 2024



## 1. Introduction

Alpine ski racing is a technical sport, which requires great coordinative ability from the skiers [1]. One of the main challenges of alpine skiing is the unpredictability of the descents. This is due to the high degree of uncertainty that arises when interacting with the environment at high speed [2]. When competing, the skier must be prepared to deal with variations in the terrain such as the steepness of the slope [3–5], and with variations in the course setting, such as the horizontal gate offset, that will regulate the amount that a course will be turned [6,7]. Therefore, in order to adjust to all types of terrain changes and course configurations, the central and peripheral nervous system of alpine skiers must work quickly and efficiently at every moment of the race [2,8]. Adaptability to the unpredictable and changing environments is clearly a key aspect that elite skiers possess.

In recent years, several studies have analyzed the coordinative aspects of different motor actions via the assessment of human movement variability (MV) [9–13]. MV is inherent within all biological systems and can be defined as the natural variations that typically occur during the execution of motor tasks when repeated multiple times [14–18], also known as execution variability [19] that assesses movement reproducibility [17].

In that context, research suggests that MV might be reduced as a function of practice [20,21] and experience [22,23]. The degree of mastery or adaptation to a task decreases the system's degrees of freedom and makes it highly predictable. Thus, experienced athletes are able to reproduce more consistently the same technical gesture, even in changing circumstances [10,17,24,25]. However, when athletes face new or complex situations, a technical gesture becomes less reproducible. The central nervous system of athletes is forced to find an optimized motor solution and must explore the full range of movement possibilities, which causes an increase in the degrees of freedom and thus in MV [26]. This increase in MV is what enables motor adaptation to a changing environment. Thus, MV should be considered a tool to stimulate learning [27–29].

In this regard, to ensure that exercise continues to provide an optimal stimulus for athlete development, it would be desirable to introduce different variations to the tasks that induce an increase in MV [10]. These variations become important in sports, especially in situation sports, such as alpine skiing, characterized by unpredictable and changing environments [30]. These athletes must continuously perceive and interpret external and internal information to adjust their actions and obtain effective and efficient solutions [31]. In addition, the application of different stimulus on-snow training such as a different steepness of the slope and variations in course settings, such as a different gate offset between gates, could produce a destabilizing effect on the body that would cause an increase in MV.

MV could be measured through the use of linear measurements such as standard deviation in the time evolution of a variable [32]. The standard deviation is useful to characterize the amount of variability present in the perceptual-motor system, as it quantifies the mean amount of dispersion around an averaged value. However, in some cases, different time series can exhibit the same standard deviation even if they do not share the same structure in time [33,34]. This limitation can be addressed with the use of non-linear tools, such as entropy, since it quantifies the amount of regularity and unpredictability of point-to-point fluctuations in large sets of time-series data and it is suitable for dealing with the complexity of biological systems [34–37]. Sample entropy (SampEn), Multiscale entropy (MSE), and Approximate entropy (ApEn) are the most popular methods for assessing data regularity in health and sports sciences [9,35,38,39]. SampEn is more robust to variations in time series length and can provide meaningful insights even with shorter data [40], and is one of the most widely used entropies in sports and health sciences [9–12,35,41,42].

In recent years, MV has been calculated through SampEn from the acceleration time series collected at the lower back of athletes using an inertial measurement unit (IMU) [9–13]. In alpine skiing, IMUs can offer a number of advantages that go beyond the limitations of traditional or laboratory methods [43–49]: compact and lightweight, easily portable and positionable, capable of wireless operation, and with the ability to capture a substantial amount of data (i.e., several runs), instantaneous data acquisition, and the optimization of data collection due to automatic synchronization among all the built-in sensors. However, to the best of our knowledge, no research has been conducted yet to evaluate MV through IMUs in the domain of alpine skiing, nor has it been evaluated regarding how the characteristics of the terrain (flatter vs. steeper slopes) and course setting (gate offset: i.e., turned vs. straighter courses) influence skier MV. Additionally, no article has been found that relates skier performance to MV. Therefore, the aims of this study were (a) to evaluate the influence of different slopes and slalom gate offsets on MV through an IMU and (b) to assess the relationship between MV and performance of elite alpine skiers. It was hypothesized that (a) steep and turned courses would increase MV and that (b) best-performing skiers would exhibit a lower MV.

## 2. Materials and Methods

This section is similar to that reported by Pérez-Chirinos Buxadé et al. [47].

### 2.1. Participants

Five elite alpine skiers belonging to the highest national level in Andorra with less than 40 FIS points in SL (aged 21.2 ± 3.3 years, weighing 72.8 ± 6.6 kg, with a height of 180.2 ± 5.6 cm) participated in this study. Written informed consent was obtained from all participants. All the procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Ethics Committee for Clinical Sport Research of Catalonia (Study Number: 27/CEICGC/2020).

### 2.2. Procedures

#### 2.2.1. IMU Device and Location

An IMU device (WIMU, Realtrack Systems, Almeria, Spain; weight: 70 g; size: 81 mm × 45 mm × 15 mm) was used in this study. Signals from the 3-axial accelerometer (range: ±400 G; sampling frequency: 1000 Hz) and the 3-axial magnetometer (range: ±8 gauss; sampling frequency: 100 Hz) were used. Before data collection, the inertial measurement units (IMUs) underwent calibration on a level and uniform surface in accordance with the manufacturer's guidelines. The IMU was affixed to the lower back of the skiers, adhering to the instructions provided by Pérez-Chirinos Buxadé et al. [50]. Measurement system axis orientation and calibration were established as shown in Figure 1.

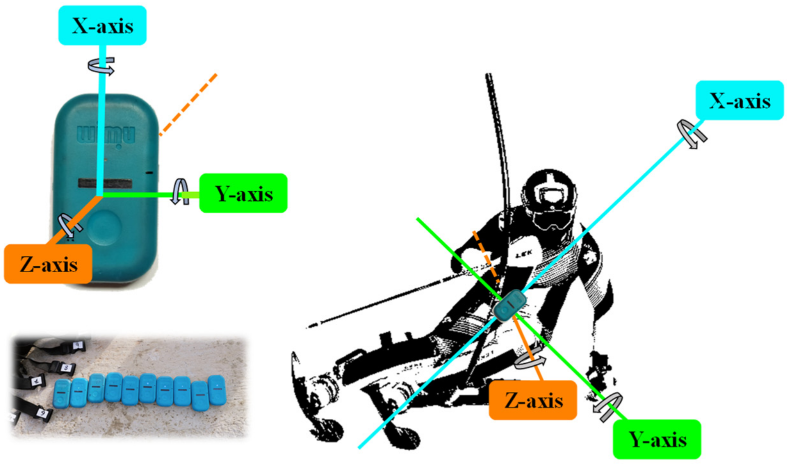


**Figure 1.** Calibration process and axis orientation. In the lower-left corner, the calibration procedure is depicted, with the Z-axis perpendicular to the surface. The X-axis (blue) represents the vertical axis, the Y-axis (green) corresponds to the lateral axis, and the Z-axis (orange) indicates the antero-posterior axis. The photo has been reproduced with permission from Nacho Casares/Comité Olímpico Español and has been edited by the authors.

#### 2.2.2. Course Setting

In order to simulate different competition scenarios, four SL course settings (Figure 2) were designed in accordance with the rules set by the International Ski Federation (FIS) [51]. The slope (12° and 21°) and gate offset (4 m and 3.25 m) were varied to replicate the conditions encountered in various competition sections. For ease of reference, each course was assigned a code based on its slope and gate offset: FT (flat-turned), ST (steep-turned), FS (flat-straighter), and SS (steep-straighter). In these codes, the first letter denotes the slope, and the second letter indicates the skier's trajectory based on the gate offset. A detailed gate analysis was performed on ten consecutive gates for each SL course. Gate placements were measured precisely using tape measures to ensure consistency across all courses. For the flatter slope courses (FT, FS), the analysis focused on gates 6 to 15, excluding gate 16. Similarly, for the steeper slope courses (ST, SS), the analysis was conducted on gates 19 to 28, excluding gate 29. The initial gate consistently required a right turn (involving the left outer leg). This approach allowed for a comprehensive analysis of gate sequences while maintaining consistency in gate numbers across course configurations. Bar magnets (measuring D33 mm × 267 mm, ND35, A.C. magnets 98, Barcelona, Spain) were positioned on ten successive gates for each SL course, adhering to the guidelines provided by Pérez-Chirinos Buxadé, et al. [50]. Prior to the trial runs, skiers were given a reconnaissance run to familiarize themselves with the SL courses. They were then instructed to perform 3 to 5 runs at maximum speed for each SL course. In total, 77 runs were collected, with 22 runs conducted on the FT course, 24 runs on the ST course, 16 runs on the FS course, and 15 runs on the SS course. Runs were distributed among five skiers: skier 1 (with counts of 4 FT, 4 ST, 0 FS, 0 SS), skier 2 (n = 4, 5, 4, 4), skier 3 (n = 5, 5, 4, 4), skier 4 (n = 4, 5, 4, 4), and skier 5 (n = 5, 5, 4, 3). Notably, skier 1 faced difficulty completing descents on the FS and SS courses due to lower back pain. To synchronize the accelerometry data with the video recordings of each run for visual validation, a portable Full HD camera (Panasonic HC-V700) recording at 30 Hz was employed. Throughout the data collection process, the snow surface was maintained in hard-packed and groomed conditions. To ensure standardization, coaches and the experimental team meticulously smoothed the course prior to each run. Air temperatures progressively increased from 1.1 °C to 1.9 °C over the course of the experiment. Relative humidity slightly decreased from 71% to 61%. The maximum recorded wind speed was 6.3 km/h, blowing from a south-westerly direction, perpendicular to the course.

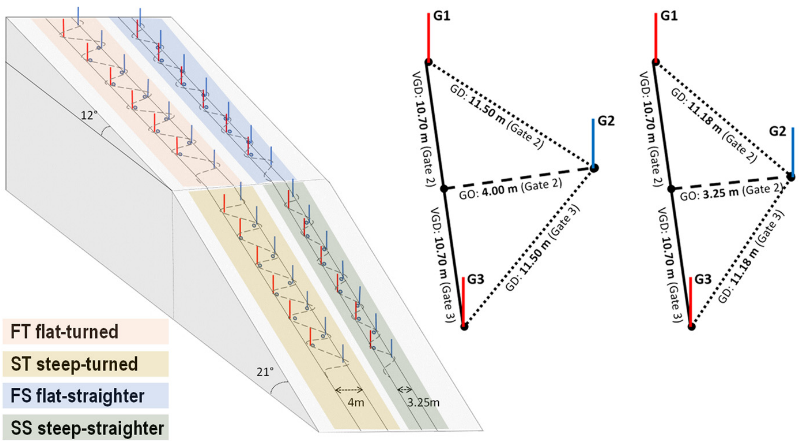


**Figure 2.** On-hill measurements. Flat-turned course (pink): 12° slope, 4 m gate offset (GO); flat-straighter course (blue): 12° slope, 3.25 m GO; steep-turned course (yellow): 21° slope, 4 m GO; steep-straighter course (green): 21° slope, 3.25 m GO.

Terrain characteristics, such as the slope, were determined by generating a digital elevation model using high-resolution images obtained through a drone (DJI Mavic Air, SZ DJI Technology Co., Hong Kong, China) and several photogrammetry software (Agisoft Metashape Professional® 1.5.2 version, Agisoft LLC., St. Petersburg, Russia, and ArcGIS free software version 10.3, Environmental Systems Research Institute, Inc., Redlands, CA, USA).

### *2.3. Data Analysis*

#### 2.3.1. Skiers' Performance

The skiers' performance was evaluated with the descent time of each run defined as the time elapsed between the first and tenth gates and was calculated through a validated Magnet-Based Timing System (M-BTS) [50].

#### 2.3.2. Skier's MV

MV was evaluated through SampEn from the acceleration time series collected with an IMU at the lower back of the skiers. The acceleration was the magnitude of the vector formed by adding the acceleration vectors in each axis (x, y, z). Taking advantage of the synchronization of all the sensors, the peaks recorded in the magnetometer signal were used to delimit the start and end of each run [50]. The SPRO software (version, 987, Realtrack Systems, Almeria, Spain) was used to segment the acceleration signals of each run and export the data to Excel. Then, the calculation of SampEn entropy was performed according to Goldberger et al. [52], following a routine programmed in MatLab® (version R2020a, The MathWorks, Natick, MA, USA).

#### 2.3.3. Statistical Analysis

The analysis encompassed a total of 77 runs for a sample of five skiers. In this sense, the runs from each skier were considered as repeated measures. To assess the influence of different slopes and slalom gate offsets on MV and total descent time, a one-way repeated measures analysis of variance (ANOVA) was implemented. If a significant result was obtained, post hoc comparisons were performed and *p*-values were adjusted considering Tuckey correction for multiplicity of contrasts. To show the differences more visually, bar plots depicting the mean SampEn for each SL course and the distribution of skiers were used. Additionally, the total descent times for each SL were also plotted. Additionally, a two-way ANOVA was employed to determine the significance of the explanatory variables, specifically the steepness of the slope and gate offset. Partial eta squared was used to determine the effect size as small ($\eta^2 p$ = 0.01), medium ($\eta^2 p$ = 0.06), and large ($\eta^2 p$ = 0.14) [53]. To assess the relationship between MV and performance, a Pearson's linear correlation coefficient was used to calculate the correlation between SampEn and total descent time. A scatter plot was created with each point representing the average of each skier's runs for each SL course. All database management tasks and statistical analyses were performed using R v4.0.4 software [54]. The significance level for all statistical tests was set at 5% ($p < 0.05$) and 10% ($p < 0.1$) [55].

## 3. Results

The effect of different slopes and gate offsets on MV was investigated using SampEn, as shown in Figure 3. SampEn was higher on the steeper slope (21°: ST and SS courses) than on the flatter slope (12°: FT and FS courses). Concretely, differences at the 5% level were found between ST and FS courses (ST: 0.094 ± 0.015 a.u. vs. FS: 0.074 ± 0.008 a.u.). Differences at the 10% level were found between ST and FT (ST: 0.094 ± 0.015 a.u. vs. FT: 0.082 ± 0.007 a.u.) and between SS and FS courses (SS: 0.088 ± 0.008 a.u. vs. FS: 0.074 ± 0.008 a.u.) (Table 1). Additionally, a trend was observed in which turned courses had greater SampEn values than straight courses, consistent across all comparisons, i.e., ST had higher entropy values than SS and FT had higher entropy values than FS. Figure 3 also shows the deviation of each skier from the mean SampEn in each SL course. On the FT course, skiers 1, 4, and 5 exceeded the mean entropy (0.082) by 1.83%, 1.62%, and 1.97%, respectively. The mean SampEn on the FS course was 0.074, and all skiers had a lower entropy on this run except skier 4, who had exceeded this value by 6.55%. The ST course had the highest mean SampEn (0.094), and skiers 2 and 5 had even higher entropies on this course, exceeding the mean by 8.29% and 7.85%, respectively. The mean SampEn on the SS course was 0.088, and skier 5 exceeded the mean on this SL by 4.72%.

Differences in descent times between SLs were also plotted (Figure 4). Turned courses (gate offset of 4 m: FT and ST) had the longest descent times (7.712 ± 0.245 s and 7.857 ± 0.146 s, respectively). The FS course had been the one with the shortest descent time (6.934 ± 0.168 s), followed by the SS course (7.335 ± 0.145 s). There were differences at the 5% level between all the SL courses, except for FT vs. ST courses (Table 1). Figure 4 also illustrates the deviation of each skier's descent time from the mean for each SL course. Skiers 4 and 5 consistently exceeded the mean descent time on all course settings. On the

FT course, skiers 4 and 5 were 4.39% and 1.58% slower than the mean group, respectively. Similarly, on the FS course, skier 4 exceeded the mean descent time by 3.13%, and skier 5 by 0.32%. This trend repeated on the ST course, where skier 4 exceeded the mean time by 2.30% and skier 5 by 1.64%. Finally, on the SS course, skier 4 surpassed the mean descent time by 1.78%, and skier 5 by 1.52%.

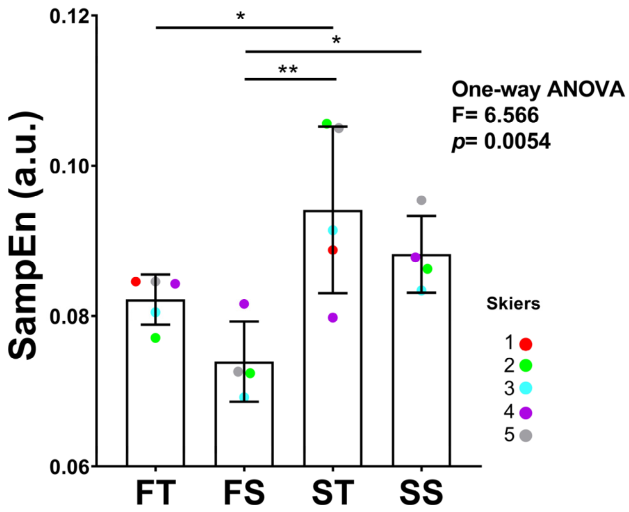


**Figure 3.** Bar plots illustrating the Sample entropy (SampEn) for individual skiers on each SL. The bar values indicate group means ± SD. Statistical comparisons were conducted using a one-way ANOVA for repeated measures. The course abbreviations are as follows: FT (flat-turned course), FS (flat-straighter course), ST (steep-turned course), and SS (steep-straighter course). Different colors on the graphs correspond to different skiers. Significance levels are denoted as ** $p < 0.05$ and * $p < 0.1$.

**Table 1.** Differences between SL course settings in SampEn and Time.

| | Conditions | | Mean Differences | *p* | 95% CI | |
|---|---|---|---|---|---|---|
| | | | | | Lower | Upper |
| SampEn (a.u.) | FT | FS | 0.008 | 0.339 | −0.006 | 0.022 |
| | | ST | −0.012 | 0.078 * | −0.025 | 0.001 |
| | | SS | −0.006 | 0.598 | −0.020 | 0.008 |
| | FS | ST | −0.020 | 0.004 ** | −0.034 | −0.006 |
| | | SS | −0.014 | 0.055 * | −0.029 | 0.000 |
| | ST | SS | 0.006 | 0.611 | −0.008 | 0.020 |
| Time (s) | FT | FS | 0.778 | 0.0001 ** | 0.419 | 1.136 |
| | | ST | −0.146 | 0.605 | −0.484 | 0.192 |
| | | SS | 0.377 | 0.038 ** | 0.018 | 0.735 |
| | FS | ST | −0.923 | <0.0001 ** | −1.282 | −0.565 |
| | | SS | −0.401 | 0.036 ** | −0.779 | −0.023 |
| | ST | SS | 0.522 | 0.004 ** | 0.164 | 0.880 |

FT, flat-turned course; FS, flat-straighter course; ST, steep-turned course; SS, steep-straighter course. ** $p < 0.05$; * $p < 0.1$. CI, 95% confidence interval. Comparisons used a one-way ANOVA for repeated measures.

Additionally, in Table 2, a two-way ANOVA was employed to evaluate the significance of two key explanatory variables: the steepness of the slope and the gate offset. Both had a significant impact on MV and performance of the skiers with large ($\eta^2p > 0.14$) effects. There was no interaction between the explanatory variables in any of the response variables.

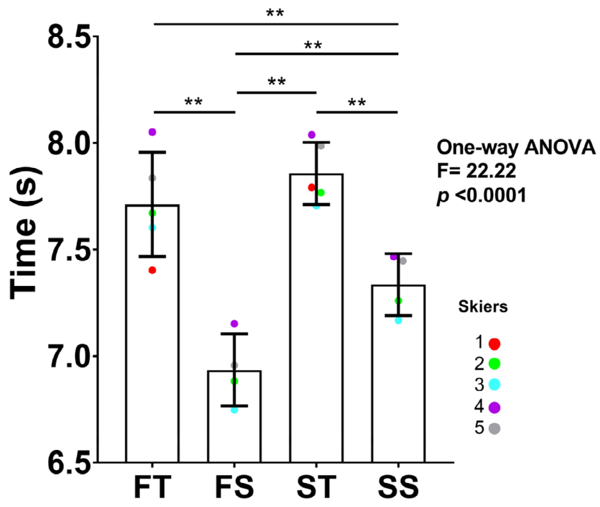


**Figure 4.** Bar plots illustrating the descent time for individual skiers on each SL. The bar values indicate group means ± SD. Statistical comparisons were conducted using a one-way ANOVA for repeated measures. The course abbreviations are as follows: FT (flat-turned course), FS (flat-straighter course), ST (steep-turned course), and SS (steep-straighter course). Different colors on the graphs correspond to different skiers. Significance levels are denoted as ** $p < 0.05$.

**Table 2.** Influence of the steepness of the slope and gate offset on SampEn and descent time.

| | Steepness of the Slope (12°) | | Steepness of the Slope (21°) | | Steepness Effect | $\eta^2p$ | Gate Offset Effect | $\eta^2p$ | Steepness x Gate Offset | $\eta^2p$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gate Offset (4 m) | Gate Offset (3.25 m) | Gate Offset (4 m) | Gate Offset (3.25 m) | | | | | | |
| SampEn (a.u.) | 0.082 ± 0.003 | 0.074 ± 0.005 | 0.094 ± 0.011 | 0.088 ± 0.005 | 0.002 ** | 0.521 | 0.053 ** | 0.242 | 0.729 | 0.009 |
| Time (s) | 7.712 ± 0.245 | 6.934 ± 0.168 | 7.857 ± 0.146 | 7.335 ± 0.145 | 0.007 ** | 0.413 | <0.0001 ** | 0.799 | 0.165 | 0.133 |

Values are means ± SD. ** $p < 0.05$. Comparisons used a two-way ANOVA. $\eta^2p$, partial eta squared.

To assess the relationship between MV and performance of elite alpine skiers, a Pearson's linear correlation coefficient was used (Figure 5). A moderate positive correlation was observed between SampEn and descent time; thus, as SampEn decreases, descent time also decreases ($r = 0.587$, $p < 0.01$).

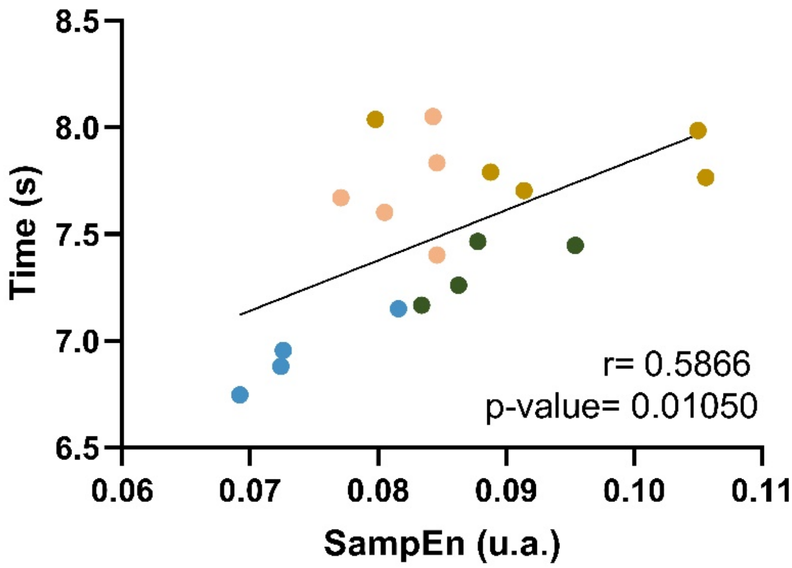


**Figure 5.** Correlation between descent time and SampEn. Different colors on the graphs represent the SL courses: flat-turned course (pink), flat-straighter course (blue), steep-turned course (yellow), steep-straighter course (green); r, coefficient of correlation. Significance levels are denoted as $p < 0.05$.

## 4. Discussion and Conclusions

This study aimed to (a) evaluate the influence of different slopes and slalom gate offsets on MV through an IMU and to (b) assess the relationship between MV and performance of elite alpine skiers. To the best of our understanding, this study represents the initial attempt to investigate the impact of terrain features, such as the steepness of the slope (flatter and steeper), and course settings, involving gate offset variations (turned and straighter courses), on skier's MV. Also, it is the first that relates skiers' performance to MV in the field of alpine skiing. The main findings corroborated the hypotheses and pointed out that (a) steep and turned courses increased skier's MV and that (b) best-performing skiers exhibited a lower MV.

The results of this study indicated that skier's MV increased with slope steepness. Thus, the steepness of the slope can be considered a conditioning factor that increases the difficulty of the task of descending an SL [56]. This is supported from a biomechanical perspective. Supej et al. [3] reported significant kinematic and kinetic variations in ski turn execution when comparing turns performed on slopes with different inclinations: 25.2° (≈47%) and 19.8° (≈36%). On the steeper slope, skiers initiated their turns earlier, with the apex located before the gate; turns were sharper with a tighter radius and lateral knee and hip angles were more pronounced, suggesting a heightened focus on controlling speed and edge engagement. The increased potential energy available on steeper slopes demands greater energy dissipation and, consequently, higher accelerations and forces [57]. This dynamic necessitates alterations in the skier's coordination patterns to maintain equilibrium throughout the turn, reducing speed across all turn phases. This observation aligns with our findings since skiers exhibited the longest descent times on steeper slopes, further supporting the notion of increased task difficulty. Furthermore, slope inclination has been shown to induce a greater activation of lower limb muscles [58], which play a crucial role in powering turns and maintaining stability. These findings collectively indicate that slope variations significantly modulate task difficulty, prompting skiers to adapt their movement patterns and muscle activation strategies to successfully navigate the varying terrain.

Concerning course settings, changing the distance between gates modifies the characteristics of the course and, therefore, the trajectories that skiers must follow. Although the FIS establishes regulations [51], considerable flexibility remains in determining course setting features. For instance, manipulating the horizontal distance between gates, known as the gate offset, can alter the turning demands of the course. In the present study, two different gate offsets (3.25 m and 4 m) were set, and it was observed that there was a tendency for skier MV to increase with the gate offset, particularly on courses with higher turning demands (FT and ST). These findings align with those of previous biomechanical studies that have examined the impact of increasing the gate offset in giant slalom and super-giant slalom [59,60]. Spörri et al. [59] demonstrated that increasing the horizontal gate offset in giant slalom led to a decrease in speed during the steering out of the turn, a prolonged centripetal force duration, which significantly doubled at turn completion, and a predominance of backward skier positions (weight shifted toward the ski tails) and lateral inclinations (toward turn, inwards). These factors contributed to the adoption of more critical postures that may heighten the risk of out-of-balance situations. Notably, high standard deviations of speed, centripetal force, and front–back positions were observed at the end of the turn on the more turned course, indicating that skiers exhibited increased variability in their movement patterns when the horizontal gate offset was widened. Similarly, Gilgien et al. [60] reported that increasing the horizontal gate offset in super-giant slalom reduced turn speed, forced skiers to execute sharper turns with a decreased radius of curvature, and increased peak snow reaction forces and their duration (greater impulse) [61,62], consequently increasing physical exertion and fatigue [7]. In this context, studies investigating the impact of the horizontal gate offset on kinematic and kinetic variables have primarily focused on giant slalom and super-giant events [59,60,63]. Limited research has been conducted on the effects of the gate offset in slalom [8,47]. Pérez-Chirinos Buxadé et al. [47] reported a decrease in turn initiation time and an increase in turn steering time with an increasing gate offset. Reid [8] modified both the gate offset and distance between gates, making it difficult to isolate the influence of each factor on ski turn biomechanics. While the distance between gates is the distance regulated by the FIS [51] and the most practical for coaches to use on a daily basis, it is linearly independent of the gate offset. Therefore, the gate offset and vertical distances accurately represent course configuration, although they are also the most complex to determine in practice [64].

The present study also investigated the relationship between MV and performance and it was found that skiers that obtained better descent times, hereinafter skilled skiers, had a lower MV than skiers with greater descent times. MV would be expected to be lower in the skilled skiers, due to their greater ability to control the degrees of freedom of the task [21,23,27]. Learning is explained through synaptic reorganization, which makes movement patterns more stable and reduces MV [21,27]. As a result, experienced athletes can reproduce the same technical gesture more similarly, even when circumstances change [10,11,17,24,25]. An example of this is a study investigating the MV of volleyball players during the spike. The MV of the spike decreased as players progressed from the youth to the cadet category, demonstrating a reduction in MV among more experienced athletes. Similarly, spikers, who use this technical gesture most frequently, exhibited a lower MV than other players [65]. Another similar example to highlight this idea is that of Fernández-Valdés et al. [11], who conducted a study in a rugby league to examine changes in MV between positions (forwards vs. backs) during cumulative tackle event training. Their findings revealed that forwards consistently exhibited lower MV values compared to backs across all training blocks. Previous research suggests that MV can be reduced by various factors including practice and experience [66]. Given that forwards engage in more collisions throughout a match, this suggests that they may possess a heightened ability to adapt to tackle actions effectively. Additionally, the study observed a progressive reduction in MV with increasing tackle events, particularly among backs and during the defensive role.

The closest approach to this idea in the field of alpine skiing was a study conducted by Müller et al. in 1998 [67], in which the turn technique was compared between expert and intermediate skiers. They found that intermediate skiers had much higher standard deviations for all biomechanical variables analyzed, while they were reduced in experts. Along the same lines, Yamagiwa et al. [48] also analyzed variability during the skiers' descents. In this case, they developed a simple system based on a single IMU mounted on the trunk of a skier to assess skiing quality based on turning tempo (turn frequency). The algorithm assessed the turning tempo during a run to differentiate between high- and low-skill skiers. They found that high-skill skiers were those who showed greater regularity, demonstrating the ability to maintain a constant tempo during descents. In contrast, the low-skill skiers had greater tempo variability, who could be considered as athletes who are improving their motor adaptations, as they explore more of the task space [27]. Unlike previous research that employed linear statistical measures such as standard deviation and tempo calculation, this study introduces non-linear tools like SampEn in the field of alpine skiing, offering a novel approach to explore the nature of human movement and its connection to coordination development [18]. In this sense, a skier's MV must be understood and perceived during the execution of the task, within the other biomechanical variables of the process [68].

The conclusion of this study is that determining MV through entropy can be used to assess the skier's ability to adapt to changing conditions. Introducing variations in on-snow training, such as different slopes and gate offsets, can increase MV, suggesting that skiers are adapting to the new stimuli. Best-performing skiers exhibit lower MV, indicating greater consistency of movement patterns. Skiers with higher MV may be in the process of developing their motor adaptations, as they explore new movement options.

## 5. Practical Application

The availability of good training conditions (snow) will determine the number of on-snow training days in a competitive season. A study conducted in 2018 on the training of Olympic skiers [2] found that, in a competitive season of 130–150 days, the effective training time does not exceed 9.2 h in the case of technical disciplines (slalom and giant slalom), and does not exceed 7.1 h in the case of speed disciplines (super-giant slalom and downhill). This is due to the nature of the sport, in which descents have a very short duration (between 30 and 60 s), what represents a 6 min training for a morning's training where an average of eight runs are made. In this context, it is necessary to carry out a thorough analysis of the skiers' coordinative level to make informed decisions about which aspects need to be prioritized in on-snow training. To optimize this training time, it is necessary to know which stimuli represent a greater challenge for our group of skiers (i.e., higher entropies) to give them preference in our training. As an example, in the current study, with the use of a single IMU device placed on the lower back of the skiers, it is possible to analyze that the FT course is more challenging for skiers 1, 4, and 5, as they are the skiers who have presented an above-average entropy value. In the same way, the FS course has been more challenging for skier 4. The ST course has been more difficult for skiers 2 and 5 and the SS course has been a greater challenge for skier 5. This study demonstrates that if skiers consistently train under the same conditions (slopes and course settings), their coordination may stagnate. It is essential to carry out tests to obtain objective data on our skiers' coordination level to propose sufficiently stimulating training sessions and to optimize the very limited training time available on the slopes.

**Author Contributions:** Conceptualization, C.P.-C.B., B.F.-V.V. and G.M.F.; methodology, C.P.-C.B., J.M.P.R. and G.M.F.; software, C.P.-C.B., D.G.C., M.T., B.F.-V.V. and G.M.F.; validation, C.P.-C.B., B.F.-V.V. and G.M.F.; formal analysis, C.P.-C.B., J.M.P.R., B.F.-V.V., S.T.V. and G.M.F.; investigation, C.P.-C.B., J.M.P.R., D.G.C., B.F.-V.V., S.T.V. and G.M.F.; resources, C.P.-C.B., J.M.P.R., D.G.C., M.T., B.F.-V.V. and G.M.F.; data curation, C.P.-C.B., J.M.P.R., D.G.C., M.T., B.F.-V.V. and G.M.F.; writing—original draft preparation, C.P.-C.B.; writing—review and editing, J.M.P.R., D.G.C., M.T., B.F.-V.V., S.T.V. and G.M.F.; visualization, C.P.-C.B., J.M.P.R., D.G.C., M.T., B.F.-V.V., S.T.V. and G.M.F.; supervision, J.M.P.R. and G.M.F.; project administration, C.P.-C.B., B.F.-V.V. and G.M.F.; funding acquisition, C.P.-C.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by The Ministry of Education, Culture and Sport; the first author (C.P.-C.H.B.) was the recipient of a predoctoral fellowship (FPU18/04647). This paper also received the support of the National Institute of Physical Education of Catalonia (INEFC), University of Barcelona (UB), the Research Group in Physical Activity and Health (GRAFiS, Generalitat de Catalunya 2017SGR/741), and the Research Group in Technology Applied to High Performance and Health, TecnoCampus, Universitat Pompeu Fabra, Barcelona (Spain).

**Institutional Review Board Statement:** This study was conducted according to the guidelines of the Declaration of Helsinki and approved by Ethics Committee for Clinical Sport Research of Catalonia (Study Number: 27/CEICGC/2020).

**Informed Consent Statement:** Written informed consent was obtained from all subjects involved in this study.

**Data Availability Statement:** The raw data supporting the conclusions of this article will be made available by the authors on request.

**Acknowledgments:** The authors would like to thank the participating skiers as well as the Andorran ski federation (FAE) for the technical support, and, lastly, the Servei d'Estadística Aplicada of the Autonomous University of Barcelona (UAB), especially Anabel Blasco-Moreno.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Raschner, C.; Hildebrandt, C.; Mohr, J.; Müller, L. Sex Differences in Balance among Alpine Ski Racers: Cross-Sectional Age Comparisons. *Percept. Mot. Skills* **2017**, *124*, 1134–1150. [CrossRef]

2. Gilgien, M.; Reid, R.; Raschner, C.; Supej, M.; Holmberg, H.-C. The Training of Olympic Alpine Ski Racers. *Front. Physiol.* **2018**, *9*, 1772. [CrossRef]
3. Supej, M.; Hébert-losier, K.; Holmberg, H. Impact of the Steepness of the Slope on the Biomechanics of World Cup Slalom Skiers. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 361–368. [CrossRef] [PubMed]
4. Bruhin, B.; Janssen, R.J.F.; Guillaume, S.; Gander, M.; Oberle, F.; Lorenzetti, S.; Romann, M. Giant Slalom: Analysis of Course Setting, Steepness and Performance of Different Age Groups—A Pilot Study. *Front. Sport. Act. Living* **2020**, *2*, 107. [CrossRef] [PubMed]
5. Falda-Buscaiot, T.; Hintzy, F.; Rougier, P.; Lacouture, P.; Coulmy, N. Influence of Slope Steepness, Foot Position and Turn Phase on Plantar Pressure Distribution during Giant Slalom Alpine Ski Racing. *PLoS ONE* **2017**, *12*, e0176975. [CrossRef]
6. Spörri, J.; Kröll, J.; Gilgien, M.; Müller, E. How to Prevent Injuries in Alpine Ski Racing: What Do We Know and Where Do We Go from Here? *Sport. Med.* **2017**, *47*, 599–614. [CrossRef] [PubMed]
7. Gilgien, M.; Crivelli, P.; Kröll, J.; Luteberget, L.S.; Müller, E.; Spörri, J. Preventing Injuries in Alpine Skiing Giant Slalom by Shortening the Vertical Distance between the Gates Rather than Increasing the Horizontal Gate Offset to Control Speed. *Br. J. Sports Med.* **2020**, *54*, 1042–1046. [CrossRef]
8. Reid, R.C. A Kinematic and Kinetic Study of Alpine Skiing Technique in Slalom. Ph.D. Thesis, Norwegian School of Sport Sciences, Oslo, Norway, 2010.
9. Moras, G.; Fernández-valdés, B.; Vázquez-guerrero, J.; Tous-fajardo, J.; Exel, J.; Sampaio, J. Entropy Measures Detect Increased Movement Variability in Resistance Training When Elite Rugby Players Use the Ball. *J. Sci. Med. Sport* **2018**, *21*, 1286–1292. [CrossRef]
10. Fernández-Valdés, B.; Sampaio, J.; Exel, J.; González, J.; Tous-Fajardo, J.; Jones, B.; Moras, G. The Influence of Functional Flywheel Resistance Training on Movement Variability and Movement Velocity in Elite Rugby Players. *Front. Psychol.* **2020**, *11*, 1205. [CrossRef]
11. Fernández-valdés, A.B.; Jones, B.; Hendricks, S.; Weaving, D. A Novel Application of Entropy Analysis for Assessing Changes in Movement Variability during Cumulative Tackles in Young Elite Rugby League Players. *Biol. Sport* **2022**, *39*, 3–12. [CrossRef]
12. Tuyà Viñas, S.; Fernández-Valdés, B.; Pérez-Chirinos Buxadé, C.; Morral-Yepes, M.; Del Campo Montoliu, L.; Moras Feliu, G. Adding Mechanical Vibration to a Half Squat with Different Ballasts and Rhythms Increases Movement Variability. *PLoS ONE* **2023**, *18*, e0284863. [CrossRef]
13. Morral Yepes, M.; Gonzalo-Skok, O.; Fernández-Valdés, B.; Bishop, C.; Tuyà, S.; Moras Feliu, G. Assessment of Movement Variability and Time in a Football Reactive Agility Task Depending on Constraints. *Sport. Biomech.* **2023**. [CrossRef]
14. Dias, G.; Couceiro, M.S.; Barreiros, J.; Clemente, F.M.; Mendes, R.; Martins, F.M.L. Distance and Slope Constraints: Adaptation and Variability in Golf Putting. *Mot. Control.* **2014**, *18*, 221–243. [CrossRef] [PubMed]
15. Stergiou, N.; Yu, Y.; Kyvelidou, A. A Perspective on Human Movement Variability with Applications in Infancy Motor Development. *Kinesiol. Rev.* **2016**, *2*, 93–102. [CrossRef]
16. Stergiou, N.; Harbourne, R.T.; Cavanaugh, J.T. Optimal Movement Variability: A New Theoretical Perspective for Neurologic Physical Therapy. *J. Neurol. Phys. Ther.* **2006**, *30*, 120–129. [CrossRef] [PubMed]
17. Davids, K.; Glazier, P.; Araújo, D.; Bartlett, R. Movement Systems as Dynamical Systems: The Functional Role of Variability and Its Implications for Sports Medicine. *Sport. Med.* **2003**, *33*, 245–260. [CrossRef] [PubMed]
18. Preatoni, E.; Hamill, J.; Harrison, A.J.; Hayes, K.; van Emmerik, R.E.A.; Wilson, C.; Rodano, R. Movement Variability and Skills Monitoring in Sports. *Sport. Biomech.* **2013**, *12*, 69–92. [CrossRef] [PubMed]
19. Cowin, J.; Nimphius, S.; Fell, J.; Culhane, P.; Schmidt, M. A Proposed Framework to Describe Movement Variability within Sporting Tasks: A Scoping Review. *Sport. Med. Open* **2022**, *8*, 85. [CrossRef]
20. Newell, K.M.; Vaillancourt, D.E. Dimensional Change in Motor Learning. *Hum. Mov. Sci.* **2001**, *20*, 695–715. [CrossRef]
21. Wu, H.G.; Miyamoto, Y.R.; Castro, L.N.G.; Ölveczky, B.P.; Smith, M.A. Temporal Structure of Motor Variability Is Dynamically Regulated and Predicts Motor Learning Ability. *Nat. Neurosci.* **2014**, *17*, 312–321. [CrossRef]
22. Ko, J.-H.; Newell, K.M. Organization of Postural Coordination Patterns as a Function of Scaling the Surface of Support Dynamics. *J. Mot. Behav.* **2015**, *47*, 415–426. [CrossRef]
23. Williams, G.K.R.; Irwin, G.; Kerwin, D.G.; Hamill, J.; Van Emmerik, R.E.A.; Newell, K.M. Coordination as a Function of Skill Level in the Gymnastics Longswing. *J. Sports Sci.* **2016**, *34*, 429–439. [CrossRef]
24. Bernstein, N.A. *The Coordination and Regulation of Movements*; Pergamon Press: Oxford, UK, 1967.
25. Davids, K.W.; Button, C.; Bennett, S.J. *Dynamics of Skill Acquisition: A Constraints-Led*; Human kinetics: Champaign, IL, USA, 2008; pp. 1–27.
26. Schoellhorn, W.I. Applications of Systems Dynamic Principles to Technique and Strength Training. *Acta Acad. Olymp. Est.* **2000**, *8*, 67–85.
27. Dhawale, A.K.; Smith, M.A.; Ölveczky, B.P. The Role of Variability in Motor Learning. *Annu. Rev. Neurosci.* **2017**, *40*, 479–498. [CrossRef]
28. Moreno, F.J.; Caballero, C.; Barbado, D. Editorial: The Role of Movement Variability in Motor Control and Learning, Analysis Methods and Practical Applications. *Front. Physiol.* **2023**, *14*, 1260878. [CrossRef] [PubMed]
29. Caballero, C.; Moreno, F.J.; Reina, R.; Roldán, A.; Coves, Á.; Barbado, D. The Role of Motor Variability in Motor Control and Learning Depends on the Nature of the Task and the Individual' s Capabilities. *Eur. J. Hum. Mov.* **2017**, *38*, 12–26.

30. Hristovski, R. Sport Performance as a Domain of Creative Problem Solving for Self-Organizing Performer-Environment Systems. *Open Sports Sci. J.* **2012**, *5*, 26–35. [CrossRef]
31. Araújo, D.; Davids, K.; Hristovski, R. The Ecological Dynamics of Decision Making in Sport. *Psychol. Sport Exerc.* **2006**, *7*, 653–676. [CrossRef]
32. Bashford, L.; Kobak, D.; Diedrichsen, J.; Mehring, C. Motor Skill Learning Decreases Movement Variability and Increases Planning Horizon. *J. Neurophysiol.* **2022**, *127*, 995–1006. [CrossRef] [PubMed]
33. Caballero, C.; Barbado, F.; Moreno, F.J. Non-Linear Tools and Methodological Concerns Measuring Human Movement Variability: An Overview. *Eur. J. Hum. Mov.* **2014**, *32*, 61–81.
34. Harbourne, R.T.; Stergiou, N. Movement Variability and the Use of Nonlinear Tools: Principles to Guide Physical Therapist Practice. *Phys. Ther.* **2009**, *89*, 267–282. [CrossRef] [PubMed]
35. Richman, J.S.; Moorman, J.R. Physiological Time-Series Analysis Using Approximate Entropy and Sample Entropy. *Am. J. Physiol. Heart Circ. Physiol.* **2000**, *278*, H2039–H2049. [CrossRef] [PubMed]
36. Stergiou, N. *Nonlinear Analysis for Human Movement Variability*; CRC Press; Taylor & Francis Group: Boca Raton, FL, USA, 2016; ISBN 9781498703383.
37. García-Aguilar, F.; Caballero, C.; Sabido, R.; Moreno, F.J. The Use of Non-Linear Tools to Analyze the Variability of Force Production as an Index of Fatigue: A Systematic Review. *Front. Physiol.* **2022**, *13*, 1074652. [CrossRef] [PubMed]
38. Busa, M.A.; van Emmerik, R.E.A. Multiscale Entropy: A Tool for Understanding the Complexity of Postural Control. *J. Sport Heal. Sci.* **2016**, *5*, 44–51. [CrossRef] [PubMed]
39. Costa, M.; Goldberger, A.L.; Peng, C.K. Multiscale Entropy Analysis of Complex Physiologic Time Series. *Phys. Rev. Lett.* **2002**, *89*, 6–9. [CrossRef]
40. Pincus, S.M. Approximate Entropy as a Measure of System Complexity. *Proc. Natl. Acad. Sci. USA* **1991**, *88*, 2297–2301. [CrossRef]
41. Murray, A.M.; Ryu, J.H.; Sproule, J.; Turner, A.P.; Graham-Smith, P.; Cardinale, M. A Pilot Study Using Entropy as a Noninvasive Assessment of Running. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 1119–1122. [CrossRef]
42. González-Millán, S.; Caparrós, T.; Toro-Román, V.; Illera-Domínguez, V.; Albesa-Albiol, L.; Moras, G.; Pérez-Chirinos Buxadé, C.; Fernández-Valdés, B. Effect of Ball Inclusion in Drop Vertical Jump Test on Performance and Movement Variability in Basketball Players. *Appl. Sci.* **2024**, *14*, 505. [CrossRef]
43. Supej, M.; Holmberg, H.-C. Monitoring the Performance of Alpine Skiers with Inertial Motion Units: Practical and Methodological Considerations. *J. Sci. Sport Exerc.* **2021**, *3*, 249–256. [CrossRef]
44. Snyder, C.; Martínez, A.; Jahnel, R.; Roe, J.; Stöggl, T. Connected Skiing: Motion Quality Quantification in Alpine Skiing. *Sensors* **2021**, *21*, 3779. [CrossRef] [PubMed]
45. Fasel, B.; Gilgien, M.; Spörri, J.; Aminian, K. A New Training Assessment Method for Alpine Ski Racing: Estimating Center of Mass Trajectory by Fusing Inertial Sensors with Periodically Available Position Anchor Points. *Front. Physiol.* **2018**, *9*, 1203. [CrossRef] [PubMed]
46. Yu, G.; Jae Jang, Y.; Kim, J.; Kim, J.H.; Kim, H.Y.; Kim, K.; Panday, S.B. Potential of IMU Sensors in Performance Analysis of Professional Alpine Skiers. *Sensors* **2016**, *16*, 463. [CrossRef] [PubMed]
47. Pérez-Chirinos Buxadé, C.; Padullés Riu, J.M.; Gavaldà Castet, D.; Trabucchi, M.; Fernández-Valdés, B.; Tuyà Viñas, S.; Moras Feliu, G. Influence of Turn Cycle Structure on Performance of Elite Alpine Skiers Assessed through an IMU in Different Slalom Course Settings. *Sensors* **2022**, *22*, 902. [CrossRef] [PubMed]
48. Yamagiwa, S.; Ohshima, H.; Shirakawa, K. Skill Scoring System for Ski's Parallel Turns. In Proceedings of the icSPORTS 2014—Proceedings of the 2nd International Congress on Sports Sciences Research and Technology Support, Rome, Italy, 24–26 October 2014; pp. 121–128.
49. Martínez, A.; Jahnel, R.; Buchecker, M.; Snyder, C.; Brunauer, R.; Stöggl, T. Development of an Automatic Alpine Skiing Turn Detection Algorithm Based on a Simple Sensor Setup. *Sensors* **2019**, *19*, 902. [CrossRef] [PubMed]
50. Pérez-Chirinos Buxadé, C.; Fernández-Valdés, B.; Morral-Yepes, M.; Tuyà Viñas, S.; Padullés Riu, J.M.; Moras Feliu, G. Validity of a Magnet-Based Timing System Using the Magnetometer Built into an IMU. *Sensors* **2021**, *21*, 5773. [CrossRef] [PubMed]
51. International Ski Federation. *The International Ski Competition Rules (ICR) Book IV Joint Regulations for Alpine Skiing*; International Ski Federation FIS: Oberhofen, Switzerland, 2019.
52. Goldberger, A.L.; Amaral, L.A.N.; Glass, L.; Hausdorff, J.M.; Ivanov, P.C.; Mark, R.G.; Mietus, J.E.; Moody, G.B.; Peng, C.-K.; Stanley, H.E. PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals. *Circulation* **2000**, *101*, 215–220. [CrossRef] [PubMed]
53. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Routledge Academic: New York, NY, USA, 1988; ISBN 0805802835.
54. R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Available online: https://www.r-project.org/ (accessed on 20 May 2022).
55. Thiese, M.S.; Ronna, B.; Ott, U. P Value Interpretations and Considerations. *J. Thorac. Dis.* **2016**, *8*, E928–E931. [CrossRef]
56. Newell, K.M. Constraints on the Development of Coordination. In *Motor Development in Children: Aspects of Coordination and Control*; Wade, M.G., Whiting, H.T.A., Eds.; Martinus Nijhoff: Leiden, The Netherlands, 1986; pp. 341–360.
57. Supej, M. Differential Specific Mechanical Energy as a Quality Parameter in Racing Alpine Skiing. *J. Appl. Biomech.* **2008**, *24*, 121–129. [CrossRef]

58. Clarys, J.P.; Alewaeters, K.; Zinzen, E. The Influence of Geographic Variations on the Muscular Activity in Selected Sports Movements. *J. Electromyogr. Kinesiol.* **2001**, *11*, 451–457. [CrossRef]
59. Spörri, J.; Kröll, J.; Schwameder, H.; Schiefermüller, C.; Müller, E. Course Setting and Selected Biomechanical Variables Related to Injury Risk in Alpine Ski Racing: An Explorative Case Study. *Br. J. Sports Med.* **2012**, *46*, 1072–1077. [CrossRef]
60. Gilgien, M.; Crivelli, P.; Kröll, J.; Luteberget, L.S.; Müller, E.; Spörri, J. Injury Prevention in Super-G Alpine Ski Racing through Course Design. *Sci. Rep.* **2021**, *11*, 3637. [CrossRef] [PubMed]
61. Gilgien, M.; Spörri, J.; Kröll, J.; Crivelli, P.; Müller, E. Mechanics of Turning and Jumping and Skier Speed Are Associated with Injury Risk in Men's World Cup Alpine Skiing: A Comparison between the Competition Disciplines. *Br. J. Sports Med.* **2014**, *48*, 742–747. [CrossRef] [PubMed]
62. Gilgien, M.; Kröll, J.; Spörri, J.; Crivelli, P.; Müller, E. Application of DGNSS in Alpine Ski Racing: Basis for Evaluating Physical Demands and Safety. *Front. Physiol.* **2018**, *9*, 145. [CrossRef]
63. Spörri, J.; Kröll, J.; Schwameder, H.; Müller, E. Turn Characteristics of a Top World Class Athlete in Giant Slalom: A Case Study Assessing Current Performance Prediction Concepts. *Int. J. Sport. Sci. Coach.* **2012**, *7*, 647–659. [CrossRef]
64. Gilgien, M.; Crivelli, P.; Spörri, J.; Kröll, J.; Müller, E. Characterization of Course and Terrain and Their Effect on Skier Speed in World Cup Alpine Ski Racing. *PLoS ONE* **2015**, *10*, e0118119. [CrossRef]
65. Català Antúnez, J. *La Variabilidad de Movimiento En La Carrera Batida de Remate En Jugadoras de Voleibol de Distintas Categorías*; University of Barcelona: Barcelona, Spain, 2021.
66. Newell, K.M.; Broderick, M.P.; Deutsch, K.M.; Slifkin, A.B. Task Goals and Change in Dynamical Degrees of Freedom with Motor Learning. *J. Exp. Psychol. Hum. Percept. Perform.* **2003**, *29*, 379–387. [CrossRef]
67. Müller, E.; Bartlett, R.; Raschner, C.; Schwameder, H.; Benko-Bernwick, U.; Lindinger, S. Comparisons of the Ski Turn Techniques of Experienced and Intermediate Skiers. *J. Sports Sci.* **1998**, *16*, 545–559. [CrossRef]
68. Couceiro, M.; Clemente, F.; Dias, G.; Mendes, P.; Martins, F.; Mendes, R. On an Entropy-Based Performance Analysis in Sports. In Proceedings of the 1st International Electronic Conference on Entropy and Its Applications, Internet, 3–21 November 2014. [CrossRef]