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New Technology in Education on Performance Analysis. Wearable Sensors Utility on Alpine Skiing

Sandu Razvan ENOIU [1]
Denisa Iulia BRUS [2*]
Veronica MINDRESCU [3]

[1] Department of Motor Performance, Transilvania University of Brasov, Brasov 500036, Romania, razvan.enoiu@unitbv.ro
[2] Interdisciplinary Doctoral School, Transilvania University of Brasov, Brasov 500036, Romania, denisa.brus@unitbv.ro
[3] Department of Motor Performance, Transilvania University of Brasov, Brasov 500036, Romania; mindrescu.veronica@unitbv.ro
*****corresponding author*

Abstract: *The study explains how employing sensors while alpine skiing may raise an athlete's technical proficiency. The sensors offer a reliable set of data that enables the creation of a picture of the athlete's technical dexterity. Through statistical analysis of this data, it is possible to derive the equation for multiple linear regression, which illustrates the relationship between the athlete's time recording (which is regarded as the dependent variable) and the sensor-monitored parameters (considered independent variables). In the study, two linear regression equations were developed, with the number of independent variables considered determining which one was used. The quantity of athletes being watched and their technical proficiency have an impact on how accurate multiple linear regression is. The educational utility of the study derives from the mathematical model provided. This model will enable the athlete to concentrate primarily on the technical aspects of performance improvement while also understanding how improvement in specific technical elements affects the potential time to be achieved.*

Keywords: *alpine ski; wearable sensor; performance analysis; linear regression.*

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1. Introduction

The objective of this research is to establish a link between the sensor data obtained and the athlete's test-day time recording. The primary goal of this work is to comprehend, from a statistical perspective, the significance and involvement of each parameter and sub-parameter in reducing the athlete's time. Another goal of statistical processing is to enable the equation, which theoretically determines the amount of time needed for preparation if the subject has a particular level of skills, to be fixed. The recovery the athlete requires and the technical skills to concentrate on are established by comparing the time acquired by the subject with the theoretically estimated time, but also those that will diminish the time. Specifically, alpine skiing requires that the proposed solution be accessible, acceptable and flexible. To the knowledge of the authors, this is one of the few studies conducted with insole pressure sensors during real skiing training on an outdoor slope.

Both the coach and the player want to improve their times in certain sports. Athletes' performances are now measured in tenths or hundredths of seconds rather than seconds due to the advancement of time measuring methods. The training of the athletes must alter as a result of the differentiation in outcomes at this level, and new strategies must be considered. The employment of sensors in the sport of alpine skiing offers a significant benefit in terms of increasing technique and, naturally, the times achieved. The results that have been gathered and presented in various formats can be statistically processed. Coaches and athletes are always working to improve skiing technique because by reaching an optimum (optimal) route/path, time may be cut down. A brief and user-friendly reflection of all the phenomena that affect the duration of a sample may be achieved by measuring, systematizing, aggregating, and processing the parameters acquired by the sensors. Each indicator, or component of the broader system of statistical indicators, can only define one side or a small number of sides of the examined phenomenon due to the complexity of the parameters monitored by the sensors.

2. Theoretical considerations

Several scientific domains have been reconsidered following the development of technology, used materials, and wearable smart gadgets. Recent technological developments are particularly obvious in the world of sport, where new measurement tools appeared, all of which have created a

new method for raising performance (Kim et al., 2019). Even though the great majority of these gadgets are designed to enhance athletic performance, some of them may be used by amateur athletes as a new form of sporting enjoyment or as a means of friendly competition (Snyder et al., 2021). There are differences between professionals and amateurs, especially during competitions. A competitor encounters more obstacles when competing by having less control over its trajectory (Komissarov, 2020)., and in this situation, sensors play a more significant role.

Alpine skiing is one of the most well-known and often performed sports (Bon et al., 2021; Fromel et al., 2017). It has recently gained more fans, but it also faces considerable technical advancements. Although technology has advanced, gathering reliable data in real-world settings for an outdoor activity is still difficult. Position, acceleration, and speed are the three variables that must be gathered in the greatest quantity for performance analysis (Fasel et al.,2016; Spörri et al., 2016). The repetition of turns, which is the primary element of this sport, has an impact on the competitor's total performance or time (Nimmervoll et al., 2021; Martínez et al., 2019; Ruiz-García et al., 2021). The attention that turns in alpine skiing receive from coaches and athletes clearly demonstrates their significance, as do the numerous publications that cover this subject. Due to all of this, there is growing interest in using ski steering motion analysis to boost performance (Ruiz-García et al., 2021; Ostrek et al., 2019). In the current research we suggest a pressure sensor-based approach for assessing ski-turning performance. Performance skiers may use this insole-style sensor during practice without feeling uncomfortable. In order to better comprehend athletes' motions and provide important information for performance enhancement, sensors are frequently examined in literature in conjunction with video capture (Supej & Holmberg, 2019; Russo et al., 2022; Repnik et al., 2018). Contrary to other sports, alpine skiing has rarely used visual perception in modern times. There is evidence from studies indicating athletes have stressed the value of visual perception for peak performance. After these investigations, it was determined that the data indicated that, in athletes' eyes, the expertise in alpine skiing is determined by a strong mutual interdependence of perception and action (Schläppi et al., 2016).

In skiing, the time attained at the finish line is crucial since it influences the International Ski Federation's (FIS) ranking. As a result, there are several time analyses conducted to identify where a skier loses or wins time. Short section timings are simple for coaches and athletes to grasp, but they are not accurate measures of cornering performance (Taborri et al., 2020; Spörri et al., 2012). A quick duration per section, a high speed while

departing the section, a high-speed gain (output speed vs. input speed), or minimal energy dissipation across the section are only a few examples of what constitutes strong track performance (Neuwirth, 2020). Performance in the prior part has an impact on performance along the full trip as well. However, if the outcome is favourable, a section's lesser performance may be helpful. Regular performance identification is essential to the long-term growth of performance in terms of performance optimization, particularly in alpine skiing (Supej et al., 2020; Luchner et al., 2021; Müller et al., 2000; Camomilla et al., 2018).

The use of magneto-inertial sensors, which may monitor performance without blocking it, without space restrictions or laborious configuration processes, is an alternative to standard training techniques. The plantar pressure platform system or foot detection system are standard detection systems for these measures in sports performance monitoring. Plantar pressure measurement is significant in areas like walking phase detection or sprint acceleration performance. The sock liner is more appealing than the platform system, according to the research that have been done so far. They are preferred more frequently because their built-in pressure sensors can monitor the pressures generated by the user (Zhang et al., 2019). These sensors are also extremely accurate and represent a growing number of systems in footwear (Tan et al., 2015). It should be mentioned that one of the insoles' major benefits is that they have little impact on a skier's performance, in addition to the fact that the patient may use his own gear (Nakazato et al., 2011). Other sports, such as ski jumping, benefit from the use of sensors in addition to alpine skiing since sensors can monitor the landing and preparation for this phase (Bessone et al., 2018). Additionally, several studies have examined the use of insole-type sensors in football to track movement (Stoeve et al., 2021) or gauge changes in the ground's vertical response forces (Keshvari et al., 2022). The sock liner sensors is used in a different sport, basketball.to improve performance by studying shooting posture and foot recognition (Qi, 2021; Umek & Kos, 2020). In almost all sports, sensors of any type have influenced the further development of the respective sport.

It is commonly established that human performance and athletic performance are intertwined. An athlete's gait, stride, leap, or other movement patterns all affect their speed, power, efficiency, and effectiveness. Coaches and athletes can use the data provided and collected by pressure sensors to help them perform better (XSENSOR Marketing, 2022). From the above, it appears that the insole pressure sensors have the ability to collect the data provided by the plantar pressure, and based on the

analysis of the foot area it is possible to assess the characteristics that are of interest to each individual.

The Carv X2.2 sensor was selected since it offers all of the data relating to ski technique in a single unit. While skiing with the Carv gadget, the sensor recognizes the pressure the foot applies to the insole despite the close proximity of the foot to the boot. There are undoubtedly many other types of sensors, such as the Xsens Dot for tracking human activity, but they cannot offer ski information without additional processing and harmonization of the data gathered. The Carv X2.2 is a collection of sensors built into a pad or sole that translates the force applied by the skier's foot into knowledge of his skiing prowess. Thus, the position of the skier (the inclination of the lower limbs on two axes) and even the position of the skier's complete body are determined according on the pressure applied by the sole to the apparatus (via the 36 pressure sensors). Only those data that are relevant to ski technique are processed from all the data acquired by the Carv X2.2 sensor and made available to the user in a clear and understandable format.

3. Experimental setup

A sensor of the support type (sole/pad) Carv X2.2 was utilized in the testing. Such a sensor is included in every ski boot, and it is fixed between the liner and housing of the ski boot (case). The sensor's foundation is the recording of the pressure and motion the skier (or athlete) exerts during practice or competition. The sensor gives a thorough examination of the subject's skiing technique. The mobile phone application that has been installed gathers the data. It is possible to enhance skiing skill so that the athlete's performance improves by observing how it was skied and analysing the improper parts. The information utilized in the research was gathered during the giant slalom test for alpine skiing, the subjects (athletes-girls) being adolescents who have the same level of skiing and the age between 14 and 16 years. The individuals ranged in weight from 63 to 70 kg and in height from 1.66 to 1.79 m. The circuit was 100 meters long, with 10 gates (five on the left and five on the right), and had nine direction changes. The test was conducted at an altitude of 1,546 meters, and its arrival was at 1,517 meters. The temperature of the snow layer and the ambient air remained constant during the test. The sensor in use keeps track of the four primary variables of balance, edging, pressure, and rotation. The primary parameters each have two to four sub-parameters that they keep an eye on. There is a value that must be satisfied for each sub-parameter in order for the skier to be classified in a certain technical level (4 levels).

Basically, the values show whether or not the subject masters the technique of skiing and what technical elements must improve, during training. Table 1 shows the values of the sub-parameters allocated for the four levels of skiing technique (skills).

Table 1. Assignment of sub-parameter values to skiing technique level

No.	Sub-parameter	Skiing technique (Skill) level			
		OK	Good	Great	Expert
1	Start of turn [%]	37	55	71	93
2	End of turn [%]	30	57	67	93
3	Topple [%]	37	48	58	84
4	Similarity [%]	10	59	82	93
5	Angle [%]	23	37	56	77
6	Early edging [%]	17	61	81	94
7	Smoothness [%]	26	57	81	93
8	Outside ski pressure [%]	60	70	80	88
9	Pressure smoothness [%]	38	61	86	99
10	Parallel ski [%]	41	61	75	89
11	Turn shape	28	53	71	88

The sensor maker selected the numbers for OK, Good, Great, and Expert levels after consulting with players in this sport (athletes, coaches). Sub-parameters with percentage values are used to convey the information. Ideal is when the skier achieves 100% for each of the sub-parameters. The sensor was made specifically for ski boots and is a sole (pad) type with 36 pressure sensors and motion sensors inside. Additionally, the sole is connected to a program that was created to evaluate and instruct a variety of skiers in the principles of skiing (Carv, accessed on 05.06.2022). Additionally, in order to ensure the identification of the tiniest differences, the values presented by the program have been produced with the assistance of ski instructors, performance skiers, as well as intermediate skiers. A personal profile is created for each user, as stated by the sensors' creator, and it is via this process that the program may inform skiers of the most crucial ability to master next. According to the creator of these sensors, a personal profile is created for each user, and as a result, the program may tell the skier which ability is the most crucial to work on next. Everyone may develop their technique more quickly by according to the advice given by the application. The idea behind the application is also that the top ski instructors not only explain how the skier may improve their technique but also the fundamental ideas behind it, so you know why they need to be improved as it is said by the developers (Carv, accessed on 05.06.2022). In

order for the skier to comprehend what to do on the snow in order to reach the next objective, it will be feasible to deconstruct the essential ideas behind each Carv value using the CARV application. Additionally, one of the benefits of this sensor is that it will explain to the user why each idea is crucial to skiing and what makes the best skiers as skilled as they are.

Given the challenging skiing circumstances, the gadget is installed inside the boot, and all sensors are made to endure as long as feasible. Carv may also be used for custom boots because it goes underneath the lining of the boot. Additionally, if the skier wears insoles, it also functions. All of these addresses (addresses) the issue of performance skiers needing unique footwear. The insole is lightweight and small, with a thickness of less than 3 mm and a weight of 296 g per insole. Elite skiers have also been involved in the development of this application's value to ensure that the developers can accurately identify even the tiniest technical distinctions between each skier. Another benefit of the program is that it gives users access to trainings that aid skiers in improving their technique while also assisting coaches in creating personalized workouts depending on the needs of the sport. Although the data are gathered during the training, analysis is done after it is complete. It may be used by skiers at all skill levels, from novice to expert. Athletes will be able to adapt their workouts thanks to the information because certain incorrect techniques can only be addressed through activities that are specifically designed to do so.

In order to establish which of the four variables (primary parameters) is most crucial for getting the highest performance, the value supplied by the application for each subject (athlete) was examined. By identifying the most crucial values, training for those values will be intensified throughout the summer, improving them with the return of the snow and enhancing performance. The sensor has an E size and may be used with ski boots that measure 40 to 42. Even though the number of insole systems is growing, the most of them are commercially available, including the F-scan and Pedar Sensole System, but they are extremely expensive and primarily utilized for medical or research purposes. Due to the poor resolution and few sensors on the less expensive models, such as the Moticon, XSensor, and FSR-12, it may be difficult to capture all of the necessary details. Although these sensors are less expensive than the competition, they may not be accessible to the general public (Yu et al., 2016). Considering the aforementioned factors, Carv was selected among other insole sensors since it was specifically developed by specialists for alpine skiing and offers recommendations on how technique and all other skills may be improved. It is also the most sophisticated ski wearable in the

world and a reasonably priced gadget. The usage of a 9-axis 3D motion, accelerometer, gyroscope, and magnetometer is also a significant benefit.

4. Results and discussions

The results collected by the sensors applied in the boots were transferred to the application installed on the phone. The acquired information was processed in such a way that the results (test times) that did not fall within the established confidence interval (95%) were not taken into consideration. In many sports, the winner is the athlete who gets the shortest time. Table 2 shows the data provided by the sensors used.

Table 2. Values of the sub-parameters collected by sensors

Subject	Balance			Edging				Pressure		Rotation		Time [s]
	1 [%]	2 [%]	3 [%]	4 [%]	5 [%]	6 [%]	7 [%]	8 [%]	9 [%]	10 [%]	11 [%]	
1	82	78	68	69	45	79	78	70	72	54	50	16.73
2	95	86	80	73	49	91	79	70	88	62	64	14.76
3	83	74	58	74	42	71	68	69	68	48	40	18.89
4	79	78	73	78	46	84	88	67	95	70	69	15.00
5	85	70	60	60	38	69	67	68	71	47	42	20.00
6	74	63	63	87	48	72	89	63	74	54	52	18.78
7	81	76	72	84	46	74	84	59	73	60	48	17.56
8	67	53	52	79	42	63	73	63	61	51	44	18.00
9	80	70	72	71	36	61	70	62	30	61	39	19.00
10	66	64	61	58	38	49	62	64	75	43	32	20.58
11	73	68	67	52	37	54	60	58	70	41	24	20.95
12	82	86	58	78	38	72	84	63	50	43	35	19.60
13	80	65	71	80	49	73	68	66	82	74	51	15.70

The significances (names) of the second row (sub-parameters, column 2…12) of Table 2 were presented in Table 1, second column (Sub-parameter.). Of the times obtained by the subjects, in Figure 1 only the first six are presented.

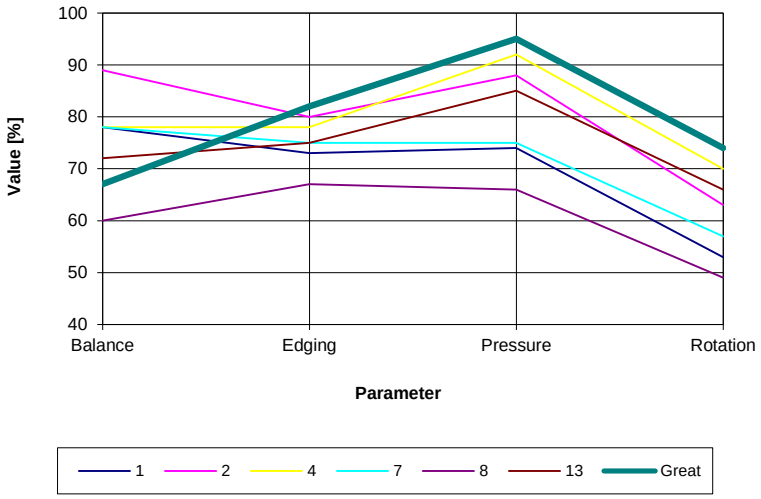


Figure 1. Comparison between Great level and main parameters recorded by subjects

To make the figure easier to grasp, this choice was chosen. It was determined that the trend is to achieve the Great level minimum since all test results indicate that participants are above the OK level, with some of them reaching the Good level. The decision of the subjects wasn't determined by an algorithm. Only two topics have values that are near to the Great Technical Level ideal line (bold line), and they also have the best timings. According to the analysis, the participants that have major parameters that are close to the limits established by the sensor manufacturer would achieve the best results. It should be mentioned that the linked application determined the values of the primary parameters for each topic associated with the sensors. But, for the skiing technique levels, the application does not indicate values for the main parameters.

The significances of the main parameters are:

- *balance* is a fundamental element for excellent skiing; sensor shows if the skier is balanced on his skis and offers exercises to improve it;
- *edging* (both in the turn and after it) shows a smooth control of the skis and gives the skier an excellent control.
- *pressure* – the pressure that is put on the outdoor ski is a fundamental one for an excellent ski.
- *rotation* – with this value, the application measures the parallel movement and the left/right symmetry; by eliminating these mistakes the skier can reach an increased efficiency and a good skiing style (Carv, accessed on 05.06.2022).

The angle of the edge, which describes how much the ski is tilted "on the edge" in relation to the local snow surface, is a crucial aspect of skiing (XSENSOR Marketing (May 30, 2022); Umek & Kos, 2020). It is the angle between the plane of the local snow surface and the sliding surface of the ski.

Table 2 has been shifted to a simpler version (Table 3), where only the essential parameters (4) are taken into consideration, as it is more difficult to work with and observe the effect of each in the final time. Additionally, they must be calculated because the primary parameters do not contain values corresponding to the various degrees of ski technique. Since the values of the parameters and sub-parameters for each subject are known, it was feasible to establish the coefficients (weights) by which each sub-parameter contributes to the construction of the value of the primary parameter. Establishing the correlation coefficient between the primary parameters and the time acquired is the next phase in the data analysis.

Table 3. Value recorded by subjects for main parameters

Subject	Balance [%]	Edging [%]	Pressure [%]	Rotation [%]	Time [s]
1	78	73	74	53	16.73
2	89	80	88	63	14.76
3	75	69	68	46	18.89
4	78	78	92	70	15.00
5	75	64	69	45	20.00
6	69	76	78	53	18.78
7	78	75	75	57	17.56
8	60	67	66	49	18.00
9	76	63	42	54	19.00
10	64	55	72	40	20.58
11	70	55	66	36	20.95
12	71	70	65	40	19.60
13	72	75	85	66	15.70

The values of the correlation coefficients for the main parameters are: balance–0.58068, edging–0.85019, pressure–0.67264 and rotation–0.9266. The analysis of the correlation coefficients shows that rotation and edging have the best correlation coefficients (the highest values), so their values decisively influence the time obtained by the subject. Figures 2 and 3 show that there is a linear regression type link between Edging and time, as well as between Rotation and time, the correlation being very high depending on the classification presented.

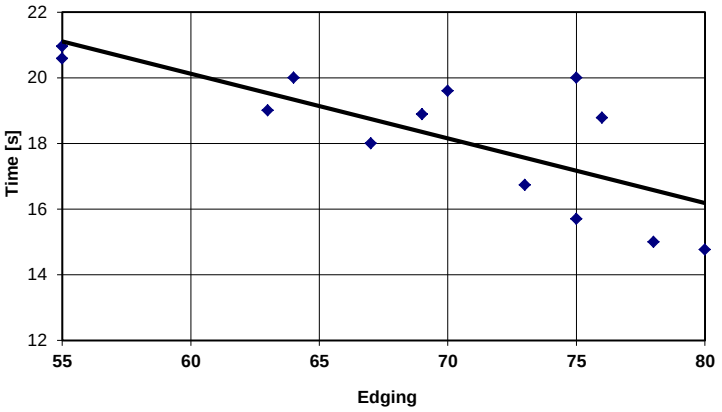


Figure 2. Linear connection between edging and time

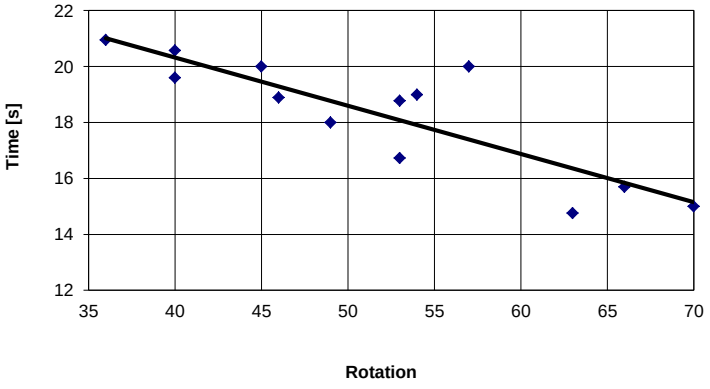


Figure 3. Linear connection between rotation and time

Linear regression is also valid for the other two main parameters, but the correlation coefficients do not have very high values. They can be framed in the high correlation level. The relationship between the time obtained by the subjects and the main parameters being of the type of multiple linear regression, the values of the regression coefficients and the value of the interceptor can be determined. Based on the main parameter values from Table 3, it is possible to write the equation that estimates the time, based on the main parameters. The multiple linear regression equation based on the 4 main parameters (R_4V) is:

$$R_4V = 31.56934 - 0.02401X_1 - 0.05005X_2 - 0.02411X_3 - 0.12532X_4, \quad (3)$$

were:

R_4V – possible time to be obtained;
X_1 – value for Balance;
X_2 – value for Edging;
X_3 – value for Pressure;
X_4 – value for Rotation.

Thus, for each subject, depending on the technical level reached, it was possible to determine from a theoretical point of view based on the relation (3) the possible time to be obtained in the performed test. It is also possible to calculate the time that would be obtained by a subject, which from the point of view of the skiing technique is at the Great, Expert or other level. Figure 4 shows a comparison between the times recorded by the subjects during the test and those calculated based on multiple linear regression.

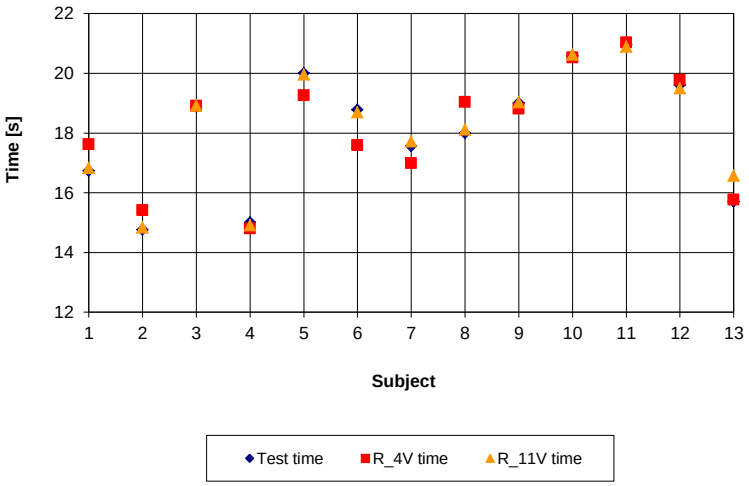


Figure 4. Comparison between test times and those calculated based on multiple linear regression with 4 (R_4V) and 11 (R_11V) independent variables

Similarly, multiple linear regression was determined, but taking into account the 11 sub-parameters as independent variables. Equation (4) was determined on the basis of the values from Table 2.

$$R_11V = -0.39824 + 0.168502X_1 - 0.19029X_2 + 0.144939X_3 + 0.101063X_4 - 0.3893X_5 - 0.08883X_6 + 0.187593X_7 + + 0.274781X_8 + 0.090394X_9 - 0.02933X_{10} - 0.25661\ X_{11}\ , \quad (4)$$

were:

R_11V – possible time to be obtained;

X_1 – value for Start of turn;
X_2 – value for End of turn;
X_3 – value for Topple;
X_4 – value for Similarity.
X_5 – value for Angle;
X_6 – value for Early edging;
X_7 – value for Smoothness;
X_8 – value for Outside ski pressure.
X_9 – value for Pressure smoothness;
X_{10} – value for Parallel ski;
X_{11} – value for Turn shape.

The time calculations performed with equation (4) for each subject are shown in Figure 4. The analysis of the figure shows that the times calculated with the established equations are close to those obtained by the subjects during the test.

To determine if differences between sets of data are statistically significant, the ANOVA approach is utilized. The technique also considers sample size and variations in sample means. The ANOVA analysis reveals that the significance-F indicator in the case of multiple linear regression with four variables is 0.000345, which is less than the predetermined significances level (0.05). Additionally, the interceptor's significant level indicator (P value), which allows for constructing the importance hierarchy of the variables (predictors), is 1.85E-06, and the Rotation major parameter's is 0.00884. The fact that this has the lowest P value out of the four independent factors indicates that it has a significant impact on test time reduction. This indicator's value rises for Pressure, Edging, and Balance in the indicated order. Each athlete's training may be tailored based on the primary parameter's relevance in relation to one another throughout the fading time. The talents that fall short of the necessary technical level will be given priority by each athlete. The athlete will also be able to concentrate on the sub-parameter(s) inside each primary parameter(s) where she/he fell short of the mark. The significance-F indicator is 0.1227 in the instance of multiple linear regression involving 11 variables, which is higher than 0.05. This demonstrates that regression may produce important inaccuracies. The little number of trials is what causes the significant mistakes (tests). 30-35 tests would be needed for 11 variables, but these are impossible to perform in the same conditions (air and snow temperature, boot size and same sensors). The regression function was used to acquire the values that were mentioned.

The mathematical model could produce results that are comparable to those found in the tests if the individuals are near to a particular degree of technique in their skiing. Additionally, based on equations 3 or 4, each subject can compare their time to that computed for the four degrees of skiing technique (see Table 4).

Table 4. Calculated time for skiing technique level established based on multiple linear regression

Skiing technique level	R_4V time [s]	R_11V time [s]
OK	23.69	12.45
Good	18.27	11.17
Great	14.29	11.05
Expert	10.87	4.59

5. Discussions and Conclusions

The study of Tables 2, 3, and 4 reveals that every subject is proficient enough to ski at an acceptable level. According to R 4V, none of them achieve the Great or Expert level. Practically, all athletes may be classified as having technique levels between OK and Great. In comparison to timings computed using 11 factors, those based on regression using 4 variables are far more reasonable. Because 4.59 seconds at the Expert level corresponds to a speed of 21.78 m/s (78 km/h), which is extremely high for a slalom giant sample, the time predicted using R 11V is unrealistic. Despite the fact that a review of the values in Figure 4 would suggest that equation (4) is significantly more closely related to the time values recorded by the subjects. For example, if it is determined based on the relation R 4V by how much the time acquired is improved when any sub-parameter out of 11 would rise by 10% for subject 7 (recorded time 17.56 s - close to average time), the following values are produced. The time recorded during the timed lap decreases for Parallel ski (sub-parameter 10), Turn shape (sub-parameter 11), Smoothness (sub-parameter 7) and Topple (sub-parameter 3) by 0.5 seconds, 0.22 seconds, 0.04 seconds, and 0.03 seconds, respectively (sub-parameter 3). The other sub-parameter values fell within the range of those timeframes. The illustration demonstrates that training any sub-parameter with 10% improvement does not have the same effect on reducing the time (on the time reduction). Auxiliary parameter Topple has the least impact, whereas Parallel Ski is the most significant. When the proposed values for the sub-parameters captured by the sensors are reached, the mathematical model enables for the athlete's performance to be predicted.

Like many other sports, alpine skiing has profited from or continues to benefit from the contributions of various sciences and disciplines to enable athletes or practitioners to enhance their performance. One of the initial stages in the use of new technology in mountain sports was the use of various types of sensors. The usage of sensors by athletes (subjects) during training has improved trainers' ability to see the technical elements that the athlete is proficient in or not. It also reveals the athlete's technical level. The use of wearable sensors has improved the accuracy and quality of the analyses performed, replacing the usage of image analysis during training (obtained using cameras or other devices). the information gathered by the training's sensors allowed their statistical processing. Statistical data processing has shown which technical elements in-fluence the time. In alpine skiing, time is regarded as the primary metric and the factor that distinguishes competitors. The technical aspects that have a big impact on time are highlighted in the article, therefore training must insist on making considerable progress in that area as a top priority throughout preparations. The coaches receive genuine help when the equations connecting independent and dependent variables are established. It is feasible to identify the technical factors contributing to the subjects' separation by comparing the collected data. Additionally, the technical level (out of four) in which the athlete can be included is determined by theoretically calculating the time using the stated equations. The established mathematical model can also be altered for each training. In other words, the equation will have different coefficients depending on the geometry, length, and configuration of the run (route). Given that the subjects record comparable timings and that the athletes are technically at similar levels, the equation for multiple linear regression will be much more precise. Higher errors are produced by the multiple linear regression set based on the 11 sub-parameters (11 independent variables) than by the set based on the primary parameters (4 independent variables).

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