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Performance improvement research in alpine skiing through simulation and video analysis of trainings

ABSTRACT

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INTRODUCTION

At the beginning of the 21st century, alpine skiing has made considerable progress in terms of teaching techniques and training methods, as well as in the materials used for skis, ski boots, and all other components of the equipment. All these advancements have led to an increase in the performance of skiers.

Acknowledging the role, diversity, and overwhelming importance of the techniques used in skier training, any effort made to improve their performance is justified and deserves the attention of researchers. In this context, the doctoral thesis aims to analyze the possibilities of applying modern training techniques to athletes and their final implications on skier performance.

The presence of video techniques and sensors in the training process creates favorable premises for their application. Achieving performance within reasonable costs, while improving the quality of training, recommends the use of video recordings of training sessions and wearable sensors as an effective method to enhance alpine skiing performance.

At the same time, the doctoral thesis aims to develop a software application that contributes to improving skier performance. The main idea of the application is to compare the ideal trajectory with the trajectory taken by the skier. Another goal of the application is that proper technical training, adapted to the new conditions, could enhance the performance of Romanian skiers in both national and international competitions.

To obtain results that meet the demands of the third decade of the 21st century, wearable sensors from the XSensDOT and CARV range will be used to demonstrate that the technical parameters recorded are very important in establishing training strategies. From this, it implicitly follows that significant attention must be given to the technical and physical preparation of skiers in order to achieve outstanding results in competitions.

Furthermore, by using sensors, the goal is to monitor the most important parameters in alpine skiing. In addition, the main angles of the skier during competitions can be corrected.

Through the results obtained, the doctoral thesis makes a modest contribution to the study of the application of modern technology in training, with concrete implications in the field of improving the performance of alpine ski athletes.

PARTEA I

Chapter 1 Training Simulation in Alpine Skiing

It has been observed that as knowledge of the phenomena and processes occurring in sports practice deepens, the technology used in training no longer meets the requirements. There is a need to address situations where choosing solutions and experimenting with them directly on the athlete increasingly bears the imprint of unpredictability. In most cases, where negative changes cannot be quickly reversed, specialists in the field have turned to simulating conditions and using simulators in the training process (Nicu, 1993).

Simulation in sports emerged for two reasons:

- practical experimentation takes too long, leading to high consumption of materials and time, and the success rate is uncertain;
- it is difficult to subject the original system to study methods that may endanger its integrity (Nicu, 1993).

In recent research, technology has become essential in sports training, especially in complex sports like alpine skiing, where movements are difficult to simulate and analysis is challenging. Simulation in sports arose from the need to save time and resources and to avoid risks associated with direct experimentation on athletes. In alpine skiing, simulators and advanced technologies, such as augmented reality (AR) and virtual reality (VR), allow for constant training throughout the year, improving performance and simulating specific conditions on the slopes. These technologies, combined with sensors (IMU, GPS), help coaches analyze movements and improve technique, reducing the risks of injury. However, their use requires a deep understanding, as they can produce errors as significant as the absence of such technologies.

Chapter 2 Video Analysis of Training

The role of training is important for developing skills and perfecting the techniques necessary for the sport being practiced, and video analysis of training adds an additional dimension to the learning process as it provides athletes, as well as coaches, with the opportunity to evaluate and improve performance through a detailed visualization of movements and techniques (Rhoads, et al., 2014).

Skiing is one of the winter sports with the highest demands on measurement systems that evaluate load and performance during training. These demands are high because the athlete's speed is great, and the distance covered is likewise large, often reaching hundreds of meters or even kilometers, especially in speed events. Using video-based analysis consumes a lot of resources and is applied very rarely. In contrast, the use of sensor-based technology has increased substantially in recent years due to its efficiency and the ease with which it is used (Fasel, et al., 2018).

Currently, recordings used for motion capture represent the highest standard when referring to the three-dimensional kinematic analysis of technique and trajectory in alpine skiing. However, due to the difficulty of filming outdoors on snow with video cameras, this method of training analysis is used less and less, being replaced by other technologies that are much easier to apply.

Whether referring to alpine skiing or any other sport, video analysis has become an increasingly important tool in performance analysis and improvement. Coaches are using video analysis more and more to consolidate and refine technique and performance.

When we talk about alpine skiing, we refer to the technical details that are very important in this sport for achieving top performance. Through video analysis, athletes and coaches can observe aspects such as posture, weight distribution, entries and exits from turns, and developed angles. All this information provides a detailed picture of how the skier interacts with the snow and also indicates which elements need correction. Moreover, video analysis has become an increasingly essential tool in the development and optimization of performance, not only in skiing but also in other sports.

Chapter 3 Performance Optimization in Alpine Skiing

There is research discussing the optimization of a ski run using the Method of Moving Asymptotes (MMA). Through this method, the race time is minimized by choosing the optimal distribution of available power, where the numerical results for the race profile have provided an optimized power distribution (Sundström, et al., 2012). To optimize the trajectory, an optimal control method was applied, which was converted into an optimization problem of the parameters, later solved using sequential quadratic programming. Obtaining an optimal solution for an alpine ski course with multiple gates is very difficult due to the complexity of the nonlinear ski-skier system and the difficulty of converging the optimization model (Congying & Xiaolan, 2021).

Maximizing performance in sports goes beyond the physical aspects, involving mental, nutritional, and recovery components. By adopting a holistic approach to athletic performance and integrating the strategies mentioned above, athletes can maximize their potential and improve their performance sustainably. It is important to consider that each athlete is unique, and the approach to performance optimization should be adapted to individual needs and the specific sport discipline (Weinberg & Gould, 2018). By adapting these methods and personalizing them according to the athlete's individual needs, a personalized performance optimization plan can be created to develop the athlete's strengths and maximize their performance potential in competitions (McArdle, et al., 2014).

If we refer strictly to alpine skiing, improving performance requires a constant commitment to the aforementioned goals. These interconnected goals play a crucial role in improving athletes' performance and achieving remarkable results in this discipline, which is as challenging as it is spectacular (Müller, et al., 2015).

Chapter 4 Elements and Components of Specific Technique in Alpine Skiing

4.1. Characteristics

Alpine skiing takes place in the mountains during the winter, which implies certain adjustments in comfort for the participants in the instructional-educational process, due to factors such as altitude, atmospheric pressure, cold, fog, blizzards, and reduced visibility, etc. (Müller, et al., 2015). This sport allows movement only through sliding on a surface called a slope covered with snow (Yacenda, 1992).

Another important and specific characteristic of this discipline is the slope, which has different degrees of inclination. Therefore, approaching the slopes requires different sliding speeds, depending on the athlete's physical, technical, and psychomotor preparation level (Matei, 1988).

4.2. Content of the Specific Technique in Alpine Skiing

The specific technique of alpine skiing is based on a correct and balanced position, essential for control and safety on the slopes. The basic position involves slightly bent knees, feet placed shoulder-width apart, and a torso leaning forward to keep the center of gravity over the skis. The arms are held in front, bent at the elbows, with ski poles pointed backward, while the gaze is directed forward to anticipate the next movements (Lind & Sanders, 2004).

Turns, essential elements of alpine skiing, are executed by shifting the body's weight and using the edges of the skis. Skiers shift their weight from one leg to the other and rotate their hips and shoulders to initiate turns, while maintaining constant pressure on the edges of the skis to control their speed and direction (Lind & Sanders, 2004).

Skiing involves numerous changes in direction and speed, which translates to variations in momentum. The forces acting on the skier in alpine skiing are divided into two categories: internal and external. Internal forces are those generated by the skier through muscle contractions, used to align body segments, maneuver the skis and poles, and apply pressure on the snow to elicit a specific reaction from it. On the other hand, external forces act on the skier from outside their body, such as gravity (LeMaster, 2020).

Chapter 6 Somatic, Functional, and Neuropsychological Aspects at the Age of 14 – 16 Years

Winter sports, and alpine skiing in particular, are generally practiced at an average altitude that does not exceed 3000 meters, and they are practiced for a few months each year. Considering the harsh climatic conditions (cold, fog, wind, snowfall), the uneven terrain with bumps where training takes place, coaches must be very familiar with the characteristics of this age group, as well as the specific rules regarding the growth and development processes of the body (Coyle, 1995).

6.1. Somatic-Functional Particularities

The totality of morphological parameters that define the human body represents the somatic type. However, since the somatic type cannot be strictly defined morphologically without considering its functionality, the concept of somatophysiology is introduced. The totality of the morphological and physiological parameters in the composition of the human body forms the somatophysiological type (Ifrim, 1986).

At the age of 14-16 years, the respiratory system develops significantly, adapting to the needs of a growing organism. The lungs increase in size, which enhances total lung capacity and improves blood oxygenation (Polgar & Weng, 1979). The respiratory muscles, including the diaphragm and intercostal muscles, become stronger and more efficient, which increases the volume of air inspired and expired in each breathing cycle. Additionally, the resting respiratory rate tends to decrease, approaching adult values, with an average of 12-20 breaths per minute (Cotes, et al., 2006).

6.2. Motor Particularities

From a motor perspective, the late adolescence period is favorable for progressive improvement in the ability to execute motor tasks, with a significant increase in motor quality indices, especially in boys, who show superior availability. Regarding speed, its development is limited by physiological support, especially in the case of basic speed (pure speed), although a slight increase in its parameters is observed. At the same time, there is a notable improvement in coordination abilities, which implicitly leads to an increase in skill level. Until around the age of 17, there are no significant differences between girls and boys regarding skill; however, after this age, girls become more skilled, having a more precise ability to limit effort on specific muscle segments and groups, due to a much more efficient differential inhibition (Ifrim, 1986). Additionally, joint mobility begins to decrease, a phenomenon more pronounced in boys, while endurance efforts are optimally managed at this stage. Muscular strength, supported by more pronounced muscular hypertrophy in boys, can be developed in all its forms of manifestation.

6.3. Neuropsychological Particularities

It should be noted from the outset that the central nervous system is the one under whose control motor activity, as well as the entire morphofunctionality of the human body, falls. This means that skill, viewed from a psychoneuromotor perspective, as well as the entire formation of motor skills, are conditioned by the morphofunctionality of the brain (Ifrim, 1986). It is also important to know that it is not the locomotor system that leads to victory in sports, but intelligence.

Adolescence is the period of significant experiences and essential experiments initiated and experienced by the adolescent for the first time in life. This stage is marked by existential and identity crises, and overcoming them is crucial for preparing the adolescent to assume future adult roles and statuses. In this context, the adolescent shapes their perception of the environment in which they live, makes decisions about their actions, the people they interact with, and the places they frequent, often without considering the consequences or risks of such experiences.

PART II

Chapter 7 Premises, Objectives, Purpose, Tasks of Preliminary Research, Hypotheses of Preliminary Research, Research Stages, Period, Place, and Subjects of the Research

7.1. Premises of the Preliminary Research

The age category of 14-16 years in alpine skiing represents the intermediate level of training leading up to the youth and senior categories.

The specificity of training for juniors aged 14-16 years is reflected in achieving specific objectives that focus both on physical preparation and technical preparation. The content of the training is aligned with these objectives, developing/including means for strengthening and perfecting the technical skills specific to the age and training level.

By analyzing national and international performances at this age, we observe that there is a certain gap between their values. Evaluating the level of these performances, we find that a possible motivation for this discrepancy could be the different technical levels between Romanian juniors and those from other countries. As also highlighted by the analysis of the specialized literature, the degree of mastering technical skills requires a qualitative leap for juniors in our country as well.

Training at the age of 14-16 years is based on several specific characteristics outlined below:

- consolidation and improvement of the technical elements and procedures based on the use of specific action tools in training;
- continuous correction of the individual technique of athletes based on training the sense of balance;
- approaching the comprehensive training specific to this age group, focusing on training all factors of preparation;
- utilizing modern tools in training, both for recording athletes' parameters and for algorithmizing their preparation;
- training the desire for self-improvement in juniors and increasing the level of seriousness in both training and competition.

7.2. Objectives of the Preliminary Research

The preliminary research aims to achieve the following concrete objectives in the proposed experimental approach:

- understanding the opinion of specialists regarding: the importance of technical training at this age and the need to use video analysis in the training process;
- utilizing a specific system of alpine skiing tools in the training of 14-16-year-old juniors, aiming to optimize their technical performance;
- using information technology in the training process of 14-16-year-old juniors to record their parameters and correct the level of technical execution;
- validating the tools used in the research (questionnaire, experimental program).

7.3. Purpose of the Preliminary Research

The purpose of the preliminary research focuses on four aspects:

- highlighting the coaches' opinion on the importance of technical training at this age;
- the importance/necessity of using video analysis in technical training at this age;
- highlighting the improvement of the technical level of juniors aged 14-16;
- optimizing technical performance through the improvement of specific alpine skiing technical elements using modern technologies.

7.4. Tasks of the Preliminary Research

The tasks proposed in the preliminary research reflect the research topic and the need for its theoretical-methodological justification. These tasks are:

- identifying the subjects who will be tested;
- organizing the necessary framework for applying the tests;
- selecting the control samples proposed in the preliminary research;
- applying the control samples under standard conditions;
- designing a questionnaire regarding the opinions of coaches working in alpine skiing, especially with juniors aged 14-16;
- applying the questionnaire, analyzing, and interpreting the responses obtained;
- validating the questionnaire by calculating the Alpha-Cronbach coefficient on a sample of 90 coaches;
- identifying specific parameters used for analysis and interpretation of results;
- establishing preliminary conclusions and proposals that arise from the preliminary testing.

7.5. Hypotheses of the Preliminary Research

Hypothesis 1: We assume that by applying a series of specific means for developing the physical factor, we will achieve an increase in the indices of motor qualities (physical tests).

Hypothesis 2: If we use training systems designed to consolidate the technical elements specific to skiing, we will achieve superior performance indices in technical tests.

Hypothesis 3: We assume that by using information technology in the training process, we will identify the basic parameters specific to the technique of alpine skiing (balance, edges, pressure, and rotation).

7.7. Period, Location, and Subjects of the Preliminary Research

The preliminary research took place between November 2021 and April 2022. The location of the preliminary experiment was the Poiana Brașov resort.

The preliminary research involved testing the group of subjects at the beginning and at the end of the experimental period. The initial testing was conducted in January 2022 and aimed to record the baseline values from which the preliminary research began. The final testing took place in February 2022, and it recorded the progress made in the control tests to which the subjects were subjected during the experiment.

The research subjects consisted of 15 juniors, aged 14-16 years, registered at CSM Corona Brașov.

During the period between the two tests, the experimental mesocycle designed to optimize alpine skiing performance was applied. In this mesocycle, the specific means were selected and used to accomplish the proposed tasks and meet the objectives of the preliminary research.

Chapter 8 Research Methods

For the study of the proposed topic, the following methods were used:

- the method of literature review;
- the scientific experiment method, in which the subjects were measured/evaluated through control tests;
- the survey-questionnaire method;
- the mathematical-statistical method.

8.2. The scientific experiment method

In this method, the proposed preliminary research activity was conducted to fulfill the tasks of the research. At the beginning of the experimental period, initial testing was applied to the subject group to assess the initial levels of the indices obtained in the control tests at the start of the preliminary experiment. During the months of January and February, the preliminary experimental program designed for training junior skiers aged 14-16 years was implemented. The experimental program included specific alpine skiing methods selected to achieve the tasks and objectives set forth in the research. In this regard, the responses recorded in the questionnaire addressed to specialists were interpreted and correlated with the conclusions derived from the study of the specialized literature. The experimental program consisted of 4 microcycles of training, organized over the course of a macrocycle of preparation. Each microcycle contained 4 training plans in which the themes and objectives of the training sessions were aligned with the goals and objectives pursued in the research.

At the end of the preliminary experimental period, after the subjects completed the experimental program, final testing was applied. The aim of the final testing was to record the indices obtained in the final control tests and compare them with the indices obtained during the initial testing, in order to confirm the methodological approach of the experiment.

During the initial and final testing, a total of 10 control tests were used, divided into 2 groups: one group of general tests and one group of specific tests. The tests included 5 general tests and 5 specific tests, which are presented below.

8.2.2. Specific Tests

8.2.2.5. Giant Slalom

Each athlete will complete the course with a sensor mounted in the ski boots, the CARV X2.2 insole. The athlete must complete the course in the shortest time possible. During this test, the athlete's technique will be analyzed based on the data provided by the sensor. By analyzing the data from the sensor, execution errors will be identified, and corrective actions will be taken. The stopwatch is started upon the first movement of the subject.

The CARV X2.2 sensor is based on recording the pressure and movement exerted by the skier (athlete) during training or the sport test. The sensor provides a detailed analysis of how the subject skied. The data is collected through an app installed on a mobile phone. By monitoring how the skiing was performed and analyzing the improper aspects, the skier's skills can be improved, thus enhancing their performance.

With the help of the app, the user can refine the following elements:

- parallel turns;
- correct posture on skis;
- edge control and pressure management

Fig. 10 Sistemul CARV (CARV – How it works, 2021)

The quicker and better the fundamental elements are understood, the more effectively the user of the app will be able to improve their technique. The developers of the CARV app have based their design on the concept of detailed analysis of movements and athletes' performance using technology and real-time data collection. Coaches also explain key concepts so that they can be improved. What results is that through the app, the key concepts behind each CARV value will be detailed, allowing the skier to understand what to do on the snow to reach the next goal, called Ski:IQ in the app. Furthermore, CARV explains the importance of each skiing-specific parameter and provides a path to improve each one (CARV – How it works, 2021).

The sensor used monitors the following main parameters: balance, edging, pressure, and rotation. Each of these main parameters has two to four sub-parameters that are monitored. For each sub-parameter, there is a target value that must be achieved for the skier to be classified at a certain technical level. The app divides the technical level into four categories: satisfactory (the lowest level), good, very good, and expert (the highest level). Each value defined in the table for every technical level for each sub-parameter was taken from CARV and transposed into the table so that all sub-parameters are defined in the same place.

The sensor manufacturer selected the values corresponding to the Satisfactory, Good, Very Good, and Expert levels after consultation with specialists in the sport (skiers, coaches), and the sub-parameters with percentage values are used to convey the necessary information. Ideally, a skier should reach 100% for each of the sub-parameters.

The sensor used is an insole containing 36 pressure and motion sensors inside, specifically designed for ski boots. Moreover, the sensor connects to an app that was created to measure and train the fundamental elements of skiing for a wide range of skiers (CARV – How it works, 2021).

The device is placed between the textile material of the boot and the plastic material, built to withstand the harsh skiing conditions over time. Since the CARV insole is used beneath the lining of the boot, it can also be used with custom ski boots. Additionally, it works when the skier uses their personal insoles, as performance skiers often have boots made specifically for them.

The data provided by the app for each subject (skier) was analyzed to determine which of the four values (main parameters) are the most important for achieving the best performance. Identifying the most important data will guide more intense training of those values during the summer, so that when returning to the snow, those values will be improved, and performance will increase. The sensor size is E and can be used for ski boots sized 40-42 (CARV – How it works, 2021).

8.3. Survey Method – Questionnaire

The survey method refers to the application of various techniques aimed at observing regularities regarding the subject of investigation, measuring and describing them (PƒÉunescu, 2013). Survey methods can be used independently or in combination with other research methods, with the particularity that they replace the observation of real conditions with the mental experience of the subject (Turcu, 2007).

According to the evolution of alpine skiing teaching methods in all its forms, continuous improvement of coaches is also necessary through the accumulation of new knowledge and new skills. With progress, the development of equipment and technique, the training themes used by coaches have fundamentally changed.

For the selection of the group of coaches included in the research, the following requirements were considered:

- choosing respondents from coaches who train groups of children aged 14-16 years;
- when selecting the sample, the time given by respondents to complete the questionnaire was taken into account, with those who did not have enough time to answer the questionnaire being eliminated;
- the persons surveyed have held the position of coach for at least 5 years;
- selection of the 14-16 year age group.

8.4. Mathematical-Statistical Method

The use of the mathematical method is closely related to the quantitative study of phenomena, but also to the qualitative study, due to the objective relationship that exists between their quantitative and qualitative variations.

The correct interpretation of reality is conditioned by the accuracy of measurement, data collection, and data recording. In the field of sports science, when studying the progress of subjects through tests, a series of measurements regarding the technology of their application, as well as the conditions that must be met for the accuracy of measurement, are required (Zlate, 1980).

In addition to descriptive statistics, we used statistical tests to verify the validity of hypotheses and statistical interactions.

Furthermore, we also used non-parametric tests, such as the t-test for two dependent data sets. A dependent t-test means that the two data sets are related to each other in some way. If the value obtained from the t-test is greater than the one in Fisher's table (a table used for degrees of freedom), it means that the difference obtained between the two data sets is significant (Fleancu, 2007).

For the slalom test, the variables X and Y are considered, represented by the value sequences xi and yi, i=1, 2, ..., n, sequences obtained by performing measurements under simultaneous and similar conditions. In statistics, it can be verified if there is a relationship of dependency between two random variables or two data sets (X and Y). The study of the dependency between two variables is done by analyzing the correlation. The correlation analysis shows the degree of dependency between the considered variables. If the variables studied (analyzed) are correlated, the points will follow a line or curve. To determine the strength (intensity) of the correlation, the correlation coefficient is calculated, which shows the magnitude of the linear dependency between the independent variable X and the dependent variable Y. The correlation coefficient r (or R) is calculated using the formula:

$$r = \frac{\sum (X_i - \overline{X}) \cdot (Y_i - \overline{Y})}{\sqrt{\sum (X_i - \overline{X})^2 \cdot \sum (Y_i - \overline{Y})^2}}, \qquad (1)$$

where,

X – the values of the independent variable;

Y – the values of the dependent variable;

$\overline{X}$ – the mean of the X values;

$\overline{Y}$ – the mean of the Y values;

Σ– sum.

The value is identical whether X is correlated with Y or Y with X. When there is a linear relationship between the variables of interest, we can identify a simple regression equation to determine the value of the dependent variable based on the value of the independent variable (Enoiu et al., 2023). The regression equation is:

$$Y = a + b \cdot X \quad (2)$$

where,

a – intercept (intercept);

b – slope coefficient (slope) or regression coefficient;

X – independent variable.

X and Y are the variables of the equation, while a and b are the constants of the equation. The linear regression method can be extended from two variables to multiple variables using the method of multiple linear regression. In this case, there is one dependent variable and multiple independent variables. The purpose of multiple regression is to establish the relationship between one dependent (outcome) variable and a set of independent (predictor) variables. Consider a set of n independent random variablesX_1, X_2, ...X_n which probabilistically represent the variables influencing a process. These variables act independently of each other. Another random variable, denoted as Y, is the dependent variable whose values will be estimated based on the multiple linear regression. The multiple linear regression equation is in the form:

$$Y = a + b_1 \cdot X_1 + b_2 \cdot X_2 + \ldots + b_n \cdot X_n \quad (3)$$

unde,

a – intercept (intercept);

b_1, b_2, ... b_n – regression coefficients.

The variables involved in regression must meet the following conditions:

- the relationship between the dependent variable and the independent variable must be linear;
- the effects of each variable are, in principle, independent of the others.

Multiple linear regression allows, in some cases, for the hierarchical ranking of the influence of independent variables on the dependent variable. The analysis is conducted to retain only the variables that have a significant influence on the dependent variable, discarding those that are insignificant (Enoiu, et al., 2023). For this ranking, the significance level p is studied, and it should be less than 5%.

Chapter 9 Results of the Preliminary Research and Their Interpretation

The preliminary study included 10 tests applied to subjects in the experimental group, grouped into two categories: general tests and specific tests. The general tests include: 50m speed run, squats, single-leg squats, abdominal strength from a hanging position on the horizontal bar, and spinal mobility. The specific tests are divided into: serpentine running between flags, maintaining a specific position on the balance board, dry land slalom, lateral jumps, and giant slalom.

9.1 General Tests

The preliminary study included 5 general tests applied to subjects in the experimental group. The general tests are: 50m speed run, squats, single-leg squats, abdominal strength from a hanging position on the horizontal bar, and spinal mobility. Each test involved 15 athletes, with both initial and final tests conducted for each.

9.2. Specific Tests

The preliminary study included 5 specific tests applied to subjects in the experimental group. The specific tests are: serpentine running between flags, maintaining a specific position on the balance board, dry land slalom, lateral jumps, and giant slalom. Each test involved 15 athletes, with both initial and final tests conducted for each.

9.2.5 Giant Slalom

The results collected by the sensors applied to the skiers' boots were transferred to the application installed on the phone. The information obtained was processed in such a way that results (testing times) that did not fall within the established confidence interval (95%) were excluded, as this was a necessary condition for successfully performing the multiple linear regression equations, which were used to determine the time required for the subjects' technical level.

Table 23 presents the data provided by the sensors used. The meanings (names) of the second row (sub-parameters, columns 2…12) in Table 23 are presented in Table 4, the first column (No.). Of the times obtained by the subjects, only the first six are shown in Figure 22. This selection was made to facilitate the understanding of the figure. Compared to the ideal line for a high technical level (the bold line), only two subjects have values close to it and achieved the best times.

Table 23 Values of the sub-parameters collected by the sensors (Enoiu, et al., 2023)

Subject	Balance			Edging			Pressure			Rotation		Time
	P1 [%]	P2[%]	P3[%]	P4[%]	P5[%]	P6[%]	P7[%]	P8[%]	P9 [%]	P10 [%]	P11 [%]	[s]
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

The analysis shows that subjects whose main parameters are close to the values established by the sensor manufacturer will achieve the best times. It is worth mentioning that for each subject, the values of the main parameters were calculated by the application associated with the sensors. However, for ski technique levels, the application does not indicate values for the main parameters. (Enoiu, et al., 2023).

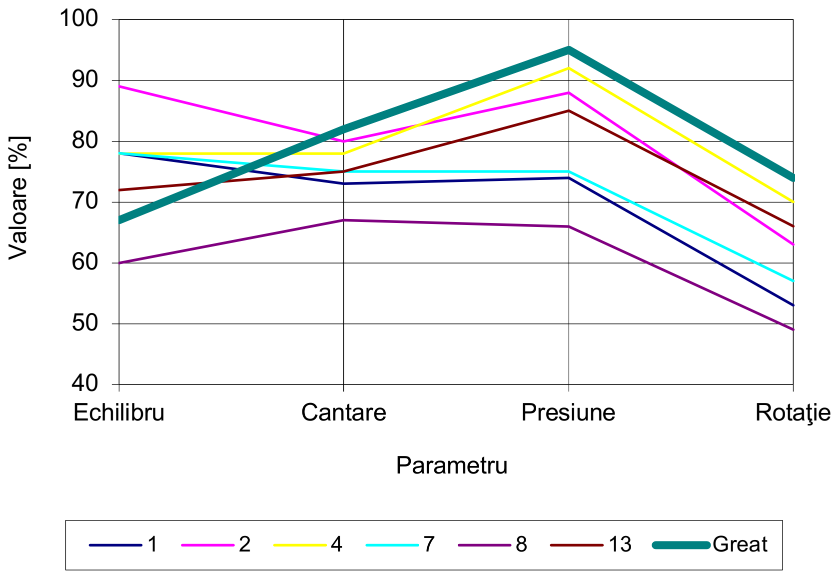

Fig. 22 Comparison between the "Great" Level and the Main Parameters Recorded by the Subjects (Enoiu, et al., 2023)

The next step in data analysis is determining the correlation coefficient between the main parameters and the time achieved. Since Table 23 presents 11 sub-parameters and it is more difficult to establish and track the influence of each on the final time, a simplified form was used (Table 24), where the main parameters considered are selected (balance, weight, pressure, rotation). Given that the main parameters do not have values associated with the ski technique level, a mathematical algorithm was developed that allowed us to calculate these values based on the recorded values by the application, as well as the skiing technique and the skill level of the sub-parameters. The correlation coefficient values for the main parameters are:

- balance - 0.58068;
- edging - 0.85019;
- pressure - 0.67264;
- rotation - 0.9266 (Enoiu, et al., 2023).

The analysis of the correlation coefficients shows that rotation and weight have the best correlation coefficients (the highest values); therefore, both factors decisively influence the time achieved by the subject.

Figures 23 and 24 demonstrate that there is a linear regression relationship between weight and the skier's time, as well as between rotation and the skier's time, with the correlation being very high according to the classification presented. The diamonds present in the figures below represent the value from Table 24 corresponding to the weight parameter and its correlation with the time achieved.

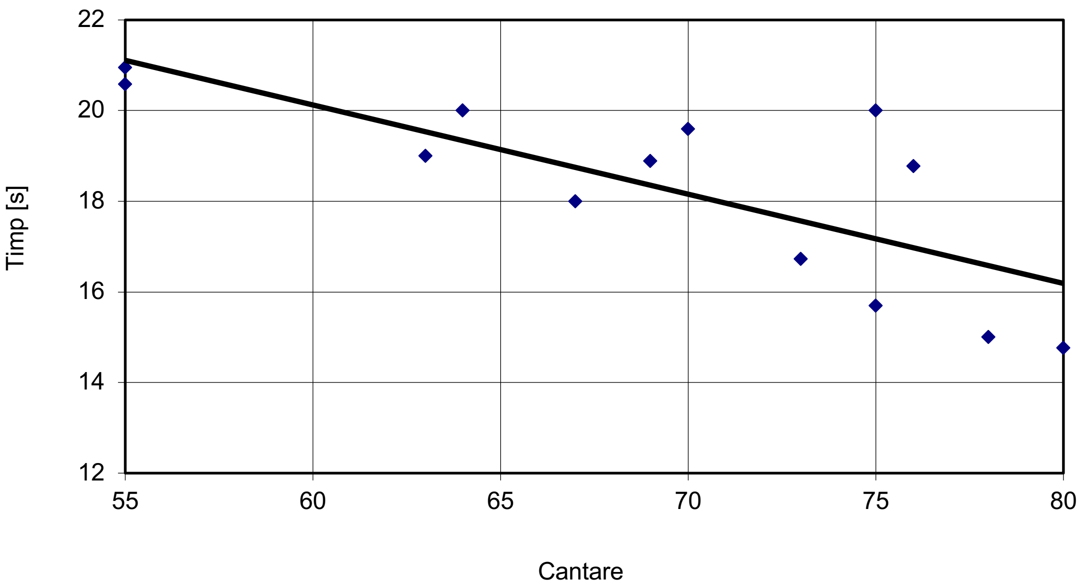

Fig. 23 The Linear Relationship Between Weight and Time (Enoiu, et al., 2023)

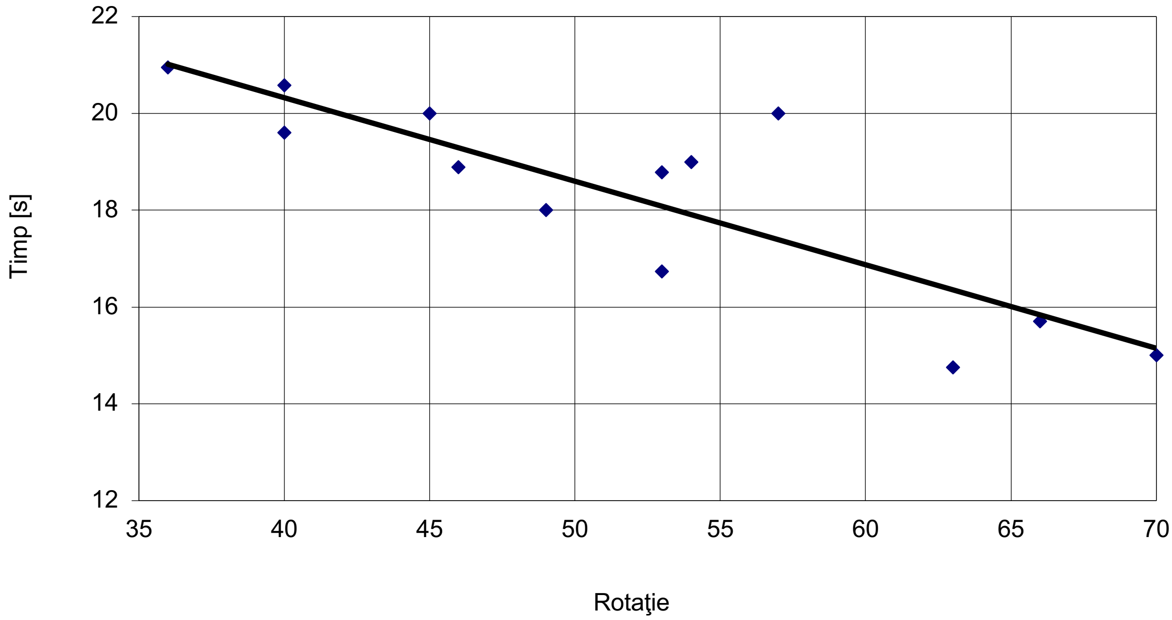

Fig. 24 The Linear Relationship Between Rotation and Time (Enoiu, et al., 2023)

Linear regression is also valid for the other two main parameters (balance and pressure), but the correlation coefficients do not have very high values. They can be classified as having a high level of correlation. The relationship between the time achieved by the subjects and the main parameters is of the multiple linear regression type, allowing for the determination of the regression coefficients and the intercept value. Based on the values of the main parameters from Table 24, it is possible to write the equation that estimates the time, based on the main parameters (Enoiu, et al., 2023). The multiple linear regression equation based on the 4 main parameters (R_4V) is:

$$R\_4V = 31.56934 - 0.02401X1 - 0.05005X2 - 0.02411X3 - 0.12532X4 , \quad (4)$$

where:

R_4V – the possible time to be achieved;

X_1 – the value for balance;

X_2 – the value for weight;

X_3 – the value for pressure;

X_4 – the value for rotation.

Thus, for each subject, depending on the technical level achieved, the theoretically possible time that could be achieved in the test was determined based on the relationship (4). Additionally, the time a subject would achieve, who is at the "Very Good," "Expert," or another skill level in terms of skiing technique, can be calculated (Enoiu, et al., 2023). Figure 25 presents a comparison between the times recorded by the subjects during the test and those calculated based on the multiple linear regression. In other words, for each subject, the time they achieved is shown in red (square) using equation (4), while the time they would have achieved is presented in orange (triangle) using equation (5). The time achieved by the subject is represented in blue (diamond).

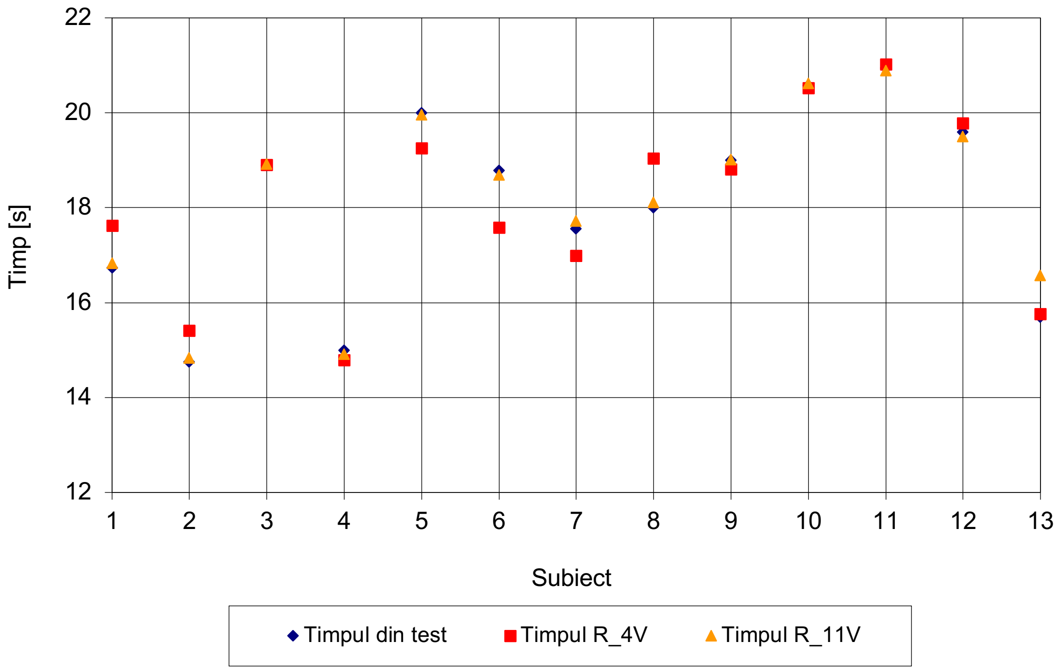

Fig. 25 Comparison between the test times and those calculated based on multiple linear regression with 4 (R_4V) and 11 (R_11V) independent variables (Enoiu, et al., 2023)

Similarly, multiple linear regression was determined, but considering the 11 sub-parameters as independent variables. Equation (5) was written based on the multiple linear regression coefficients, established using the values from Table 23 (Enoiu, et al., 2023).

$$R\_11V = -0.39824 + 0.168502X_1 - 0.19029X_2 + 0.144939X_3 + 0.101063X_4 - 0.3893X_5 - 0.08883X_6 + 0.187593X_7 + + 0.274781X_8 + 0.090394X_9 - 0.02933X_{10} - 0.25661X_{11}, \quad (5)$$

where:

R_11V – the possible time that can be achieved;

X_1 – the value for the start of the turn;

X_2 –the value for the end of the turn;

X_3 – the value for Topple;

X_4 – the value for similarity;

X_5 – the value for angle;

X_6 – the value for early weight transfer;

X_7 – the value for finesse;

X_8 – the value for the pressure of the outer ski;

X_9 – the value for the finesse of the pressure;

X_{10} – the value for parallel skis;

X_{11} – the value for the shape of the turn.

In the case of multiple linear regression with 4 variables, the ANOVA analysis shows that the F significance indicator is 0.000345, which is lower than the significance threshold set (0.05). Additionally, the significance level indicator (the P-value), which allows for determining the hierarchy of importance of the variables (predictors), is 1.85E-06 for the intercept and 0.00884 for the main parameter, Rotation. Since this has the lowest P-value of the 4 independent variables, it means it has the greatest influence on reducing the testing time. The value of this indicator increases for pressure, weight, and balance, in the order shown. Based on the order of importance of the main parameters in reducing the time, training for each athlete can be personalized. Each athlete will prioritize those skills that have not reached the desired technical level. Furthermore, within each main parameter, the athlete can focus on the sub-parameter(s) where they have not reached the desired level. In the case of multiple linear regression with 11 variables, the F significance indicator is 0.1227, which is greater than 0.05. This shows that the regression can lead to significant errors. The reason for the large errors is the small number of attempts (tests). For 11 variables, 30-35 tests would be required, but performing this number of tests is impossible under the same conditions (air and snow temperature, boot size, and therefore the same sensors in terms of size).

If the subjects are close in terms of technical level, the mathematical model might provide values close to those obtained in the tests. Also, for each subject, the achieved time can be compared to the time calculated for the four ski technique levels, based on equations 4 or 5 (see Table 25).

9.2.6. Interpretation of Questionnaire Data

As part of the preliminary research, one of the objectives was to obtain the coaches' opinions on the use of information technology in training, which led us to apply a questionnaire. Given that the questionnaire was not standardized, we conducted a pretest to assess its validity, using the Cronbach's Alpha coefficient, on a sample of 90 coaches from various clubs across the country, with the goal of determining the reliability of the questionnaire.

After analyzing the responses from the 90 coaches, we extracted their opinions. It is worth mentioning that all participants completed all the questions in the questionnaire. Once the data was centralized and collected, we calculated the internal consistency of the questionnaire using the Cronbach's Alpha coefficient, and the result confirmed both the consistency of the items and the overall validity of the questionnaire.

Chapter 10 Conclusions of the Preliminary Research

Optimizing the alpine skiing training process involves an objective analysis of both the theoretical and practical-methodical aspects involved in improving performance, particularly the influence some of these aspects have on the general training framework.

Alpine skiing, like many other sports, has benefited or continues to benefit from the contribution of other sciences and disciplines to allow athletes or practitioners to improve their technique or performance.

The use of various types of sensors was one of the first steps in implementing new techniques in mountain sports. The use of sensors by athletes (subjects) during training allowed coaches to better visualize the technical elements that the athlete master's and also indicated the technical level at which the athlete is. The shift from analyzing images recorded during training (obtained with cameras) to using sensors increased the accuracy and quality of the analyses performed. This paper highlights the technical elements that significantly influence time, which is why training sessions should prioritize making significant progress in this regard.

Determining the equation of the main parameters. The most significant results were obtained during the giant slalom test, where the design of the test included determining the main parameters (balance, weight, pressure, rotation) involved in the test, confirming the third hypothesis of the preliminary research. In this sense, the values of these parameters were introduced into mathematical equations, which provided, for the first time, both data specific to each subject and exact data that allowed the calculation of the multiple linear regression equation. Through this equation, a number of 11 sub-parameters were used, based on which, for greater accuracy regarding the level of mastery of the alpine skiing technique, the equation of the main parameters was developed, referring to the 4 main independent variables (weight, balance, pressure, rotation). This offers efficiency and precision in determining and identifying weak technical aspects and accuracy in determining the technical elements that require further training, with a high degree of precision in determining performance.

PART III

Chapter 11 Premises, objectives, purpose, tasks, hypotheses, stages, period, location, and subjects of the final experimental research

11.1. Premises of the final research

The premises of the final research are based on identifying an experimental methodology aimed at optimizing performance in alpine skiing through video analysis of training sessions. In this context, the final research aims to develop an application that will stand out through its ability to analyze skiers' tracks in real-time, providing coaches and athletes with essential information about deviations from the optimal course. It will utilize video technology, artificial intelligence, and machine learning to capture and compare the movements of the skiers with predefined ideal tracks, thus facilitating the identification and correction of errors. By providing a clear visual analysis, the application will contribute to improving technique and reducing the time needed to achieve top-level performance.

In addition to the video application that will be developed, the research aims to integrate the use of XSensDOT sensors, which will measure and monitor various biomechanical parameters during training sessions. These sensors will provide precise data on posture, angles, and accelerations generated by skiers, essential information for adjusting training sessions according to the specific needs of each athlete. The integration of these technologies will allow for a comprehensive and personalized approach, thus improving the efficiency and effectiveness of training programs.

The final research aims to highlight the importance of using advanced technologies in training junior athletes in alpine skiing. By combining the track analysis application with biomechanical sensors, the goal is to significantly optimize training sessions, providing young athletes with the best tools to reach their maximum potential. This innovative approach will not only improve individual performance but will also contribute to the development of more precise and effective training methods for the future.

11.2. Objectives of the final research

The final research aims to achieve the following concrete objectives in the proposed experimental approach:

- to determine how the use of the OptiPath application influences athletes' performance;

- to monitor how the biomechanical data provided by XSensDOT sensors can contribute to improving athletes' technique and posture;
- to identify correlations between the measured parameters and the achieved performance, thus facilitating personalized training adjustments;
- to develop a training plan that integrates the use of the OptiPath application and XSensDOT sensors;
- to improve existing training methodologies by incorporating modern technologies;
- to analyze to what extent these technologies can be integrated into daily training sessions and how they can be adapted for different skill levels and learning styles.

11.3. The purpose of the final research

The purpose of the final research focuses on three aspects:

- developing an application that compares the skier's trajectory with the ideal one;
- utilizing video analysis;
- optimizing technical performance based on the improvement of specific alpine skiing techniques through the use of modern technologies.

11.4. The tasks of the final research

The tasks proposed within the final research reflect the research theme and the need for its theoretical-methodological justification. These tasks are:

- identifying the subjects who will undergo testing;
- organizing the framework necessary for conducting the tests;
- selecting the control samples proposed in the preliminary research;
- applying the control samples under standard conditions;
- developing an application that compares the skier's trajectory with the ideal trajectory;
- using XSensDOT sensors to measure the angles developed by the skiers;
- identifying the specific parameters used for analyzing and interpreting the results;
- establishing preliminary conclusions and proposals based on the results of the preliminary testing

11.5. The hypotheses of the final research

Hypothesis 1: We assume that by using specific methods for balance development, we will achieve both a correct skiing position and a better time in the competition event.

Hypothesis 2: By using XSensDOT sensors in the giant slalom event, we will measure the acceleration (descent) speed and the angles at the knee joint level of the skiers.

Hypothesis 3: The development of an innovative application (OptiPath) and its use in the final experimental research will lead to the identification of the skier's ideal trajectory, as well as its customization for each athlete.

11.7. The period, location, and subjects of the final research

The period during which the final research was conducted was between June 2022 and April 2023. The experiment took place in the tourist resorts of Poiana Brașov and Predeal.

The final research consisted of testing the group of subjects at the beginning and at the end of the experimental period. The initial testing took place in January 2023 and aimed to record the starting values of the indices for the preliminary research. The final testing took place in March 2023, and through this, the progress achieved in the control tests to which the subjects were subjected was recorded.

The subjects of the research included 30 juniors, aged between 14 and 16 years. Of these, 15 are athletes from the CSM Corona Brașov club, 9 are athletes from the CS Edelweiss club, 3 are athletes from the CS Dinamo club, and 3 are athletes from the Toro Racing Team club.

Between the two testing periods, an experimental mesocycle aimed at optimizing performance in alpine skiing was applied. Within this mesocycle, specific methods were selected and used to achieve the proposed tasks and meet the objectives of the preliminary research.

Chapter 12 Research methods

For the study of the proposed topic, the following methods were used:

- the method of literature review;
- the scientific experimental method;
- the video analysis method;
- the mathematical-statistical method.

12.2. The scientific experiment method

In the framework of this method, the proposed final research activity was carried out to fulfill the tasks of the research. At the beginning of the final research period, an initial test was applied to the subject group to assess the starting values of the indices from the control tests at the beginning of the final experiment. During the months of January and February, the final experimental program designed for the preparation of junior skiers aged 14-16 years was implemented. The final experimental program included specific alpine skiing methods selected to achieve the tasks and objectives proposed in the research.

At the end of the final experimental period, after the subjects completed the final experimental program, a final test was conducted to record the indices obtained from the final control tests and compare them with the indices from the initial testing, in order to confirm the methodological approach of the experiment.

The initial and final tests included five control tests without the use of modern technology. The sixth control test, the giant slalom, consisted of three main elements based on the use of modern technology: the use of XSensDOT/Movella sensors, the video analysis method, and the use of the OptiPath application.

12.2.1. The experimental intervention plan

The design of the final experimental program included two experimental mesocycles of training carried out during the snow training/competition period. Each mesocycle consisted of 4 microcycles of training, with each microcycle structured to include 4 training sessions per week.

The implementation of the final experimental program was carried out by following two major training objectives: the first was the development of the specific motor qualities of alpine skiers (Theme 1 of the experimental training) and the second was video analysis of the training sessions (Theme 2 of the experimental training), aimed at correcting individual technical executions, raising awareness of the main technical errors, and identifying methods/tools for their correction (ideomotor training).

The training for the development of the main motor qualities included 32 training sessions carried out during the two experimental mesocycles, totaling 1,760 minutes, representing an average of 220 minutes per microcycle, approximately 60 minutes per training session.

The ideomotor training, based on the video analysis of the training sessions, included 32 training sessions during the two experimental mesocycles, totaling 395 minutes, with an average of almost 50 minutes per microcycle, approximately 12-15 minutes per training session.

Based on the ideomotor training sequence, the main technical errors exhibited by the research subjects in the giant slalom event were visualized, explained, and corrected. The focus of this training was primarily on improving the entry into turns, skier posture, gate attack, and the exit from turns, with all these elements contributing to the identification of the ideal trajectory for each subject involved in the research. By visualizing and understanding these concepts, the aim was to improve the performance of the research subjects, leading to the correction of technique specific to the giant slalom event and achieving better times in control/competition tests.

The experimental program aimed to efficiently combine the development of the main motor qualities specific to the giant slalom event with video-based (ideomotor) training for refining the technique of the research subjects. Additionally, information technology was used, represented by the XSensDOT (Movella) sensors, which were used to measure the angles of the subjects' lower limbs at the knee joint level.

12.2.2. Specific tests

12.2.2.6. Giant slalom

Each athlete will complete the course with an XSensDOT sensor mounted on their shin and thigh, and they will be filmed using a mobile phone to later upload the video into the OptiPath application. The athlete must complete the course in the shortest time possible. During this test, the angles developed by the skier, including the knee angle, will be analyzed based on the data provided by the sensor. Additionally, the video recording will be used for a visual analysis of the course traversal. In practice, the application will compare the athlete's trajectory with the ideal trajectory. After analyzing the two components, execution errors will be identified, and corrective actions will be taken. The stopwatch will start when the subject makes the first movement. The time will be recorded in seconds and hundredths of a second. Each athlete will have two attempts, and the best time achieved will be recorded as the final result.

12.2.2.6.1. XSensDOT/ Movella DOT

The XSensDOT, or as it is more recently renamed Movella DOT, is a motion sensor that allows for the collection of precise and reliable data. Such a sensor, which measures movement, is an example of a micro-electromechanical system (MEMS). In other words, the XSensDOT is an Inertial Measurement Unit (IMU) consisting of an accelerometer to measure acceleration, a gyroscope to measure rotational speed or turning speed, and a magnetometer to measure the magnetic field, similar to a compass needle pointing north (Movella Dot, 2022). Each of the components mentioned above collects its own data, which can later be used for analysis. Together, they can be utilized to calculate orientation through a process called sensor fusion.

Movella has patented the sensor-based technology, which is centered around sensor fusion algorithms that guarantee performance in orientation measurements. The sensor can be used in various fields such as health and rehabilitation, sports and physical exercise, and ergonomics.

It is important to note that motion sensors require specific calibrations to successfully measure human body movement. Several sensor fusion profiles are used to ensure that dynamic movements can be tracked by the user

The ability to measure joint angles of the body becomes crucial in the analysis of human motion. A strong point of the sensors provided by Movella is their ability to measure joint angles compared to other wearable devices that only contain a single motion tracker.

The sports performance technologies developed by Movella have contributed to and made the work of many coaches, elite teams, and international athletes easier by transforming the collected data into useful information that helps optimize health and sports performance (Movella Performance, 2022).

12.2.2.6.2. OptiPath application – personal contribution

In this subsection, I will describe in detail the conception, design, and development of the OptiPath application, which represents my personal contribution to the final experimental research.

12.2.2.6.2.1. Application description

Title: OptiPath

Category: Desktop application[1]

Based on the skills acquired through my graduation from the Faculty of Mathematics and Computer Science, I developed an innovative experiment that we will apply in testing, focusing on the ideal path.

OptiPath is a desktop application with a complete set of functionalities to meet the needs of users in the field of alpine skiing. It is designed to be installed and used on personal computers, providing an intuitive and efficient experience. Furthermore, OptiPath comes with a wide range of features and functionalities tailored to the needs of alpine skiing users. It is developed and designed with an emphasis on performance, reliability, and ease of use, offering an intuitive and user-friendly interface.

Whether the user is an individual or a professional in alpine skiing, OptiPath provides the tools and features necessary to efficiently and organizedly visualize the optimal path. With this application, users will experience increased productivity and better management of training sessions, enabling coaches and skiers to focus on other more important aspects of training.

This newly created application offers a comprehensive tool and a comfortable environment for calculating a skier's path and comparing it with the ideal path they should ski on.

The overall design of the application makes user interaction easier by facilitating convenient window manipulation, which is advantageous for performing the desired tasks.

The development tools used to write the code are state-of-the-art, providing several advantages, such as:

- enhanced performance;
- innovative functionality;
- increased ability to customize the application according to the user's preferences.

Additionally, the application offers excellent compatibility with existing IT infrastructures, as well as unbeatable flexibility and ease of use.

12.2.2.6.2.2. The algorithm and mathematical model used in the development of the application

In the OptiPath application, a video of an athlete skiing between gates is loaded. As soon as the video starts, the application identifies the gates and analyzes the skier's path frame by frame.

[1] A desktop application is a software program designed to run on a computer operating system, such as Windows, macOS, or Linux, and is installed locally on the user's device. These applications interact directly with the computer's hardware resources and can operate without an internet connection, often providing a faster and more efficient experience compared to web applications.

Based on the position and coordinates of the gates, the application calculates the optimal path. The application analyzes not only the position of the gates but also the skier's movements to analyze the path.

Once the video begins, the underlying algorithm starts tracking the skier's movement. Once the video finishes, the application detects the gates and then the path the skier has taken. The application marks the skier's path with a line. However, in order to compare the skier's path to the optimal path, the gate coordinates must be loaded. Only after the coordinates are uploaded can the application display the comparison between the two paths.

OptiPath was developed using the Python programming language. Thanks to the libraries available in Python, the gates were detected, and the model was able to detect the gates using the algorithms provided by Python. Furthermore, the gate detection structure is based on an object detection model, and with the help of image processing, the application detects the gate. Once the gate is detected, the application sends this information to the backend, where the detected gate is stored. Afterward, OptiPath processes the detection of the skier's movement using image processing algorithms and machine learning (ML) techniques. These techniques detect the skier's movement, and based on this detection, the skier's path is calculated and drawn on the video.

In addition, the application uses AI models that, together with the gate coordinates and the skier's path, draw the two paths. When the skier moves, the AI models are triggered, working together with the machine learning models and image processing algorithms, detecting the movement in the video and capturing it. It is important to note that the AI model keeps track of the skier's path information, and later, a mathematical model is used to compare the two paths. The AI model refers to the personalization server that the AI runs, along with the backend.

For the application to find both the optimal path and the skier's path, it needs the gate coordinates. The application relies on these coordinates to calculate the paths. The coordinates are uploaded by the user into the application, and based on this data, OptiPath draws the optimal path and then compares it to the skier's path.

In conclusion, Python is used to detect the gates, machine learning is used to detect the skier's path, and artificial intelligence is used to determine the ideal path based on the gate coordinates

To develop this application, a mathematical model was needed to calculate the optimal path and, in turn, enable the comparison between the skier's path and the optimal path.

To determine the mathematical model to be used in the application, it is necessary to understand how a perfect turn works and what are the necessary steps to execute it:

1. **beginning of the turn –** this is the first phase of the turn, where the inside ski begins to take on the skier's force.
2. **Apex of the curve –** the hips are slightly rotated and leaned towards the snow until a slight counter-rotation, depending on the skier's flexibility, in order to build the centrifugal force. In this phase, the ski is completely unloaded, and the outside ski takes 90% of the skier's weight. In an ideal turn, the snow left behind is minimal.

3. **End of the turn** – in the final part of the turn, the energy reaches its peak, is released, and directed toward the next turn.

The equation for the ideal turn has already been studied and analyzed by other researchers, which has made it much easier to define and implement the ideal path using this equation.

The following equations determine the arc of a turn and the skier's motion along the arc. The main improvement brought by Jeukendrup and Fahrbach's work *"Physics of Skiing: The Ideal-CARVing Equation and its Applications"* is that there is no longer a distinction between the end of one turn and the beginning of the next. Additionally, in slalom and giant slalom races, the turn radius is smaller than the ski's radius of curvature. The work mentioned above is not the only one where an equation for the ideal path is presented, but the equation in this study is the most effective and easiest to implement in an application (Jentschura & Fahrbach, 2004).

Based on these equations, the equation of the optimal path can be determined, which is:

$$\sqrt{\frac{R_{SC}^2}{R^2}-1} = \frac{v^2}{gRcos\alpha} - tan\alpha\ cos\beta$$

Given the equation of the optimal path, the variables of this equation are the skier's speed v, the angle β of the skier's trajectory with the horizontal, and the radius RR of the skier's trajectory. The parameters of the equation for the optimal path include the slope inclination α, the gravitational acceleration gg, and the ski radius cut R_{SC}. Furthermore, the equation of the optimal path also defines a function for the optimal trajectory, which is in accordance with Jentschura and Fahrbach.

$$f(v, R, \beta) = \frac{v^2}{gRcos\alpha} - tan\alpha\ cos\beta - \sqrt{\frac{R_{SC}^2}{R^2}-1}$$

12.3. Video method

Through the video analysis method used during training, coaches have the opportunity to view the athlete's training frame by frame, as well as the option to analyze the training in slow-motion or accelerated modes (Lees, 2002).

The evolution of technology has also allowed sports researchers to process information rapidly from different aspects. This evolution can be described as follows: it starts with the "analog translation" of data, followed by converting characteristics into digital signals, which are then analyzed on a computer (Bartlett, 2007). Moreover, a significant advantage for researchers has been the continuous improvement of technological resources, such as the reduction in sensor size and the development of smaller and more portable installations, making them usable in any conditions and transportable to hard-to-reach places.

In the modern era, the most important fundamental components of movement studies are:

- sensors;

- laptop/desktop;
- a software system/a research project.

12.4. Mathematical-statistical method

The statistical-mathematical method is a scientific approach that combines mathematical and statistical techniques to analyze data and solve complex problems. It involves collecting relevant data through various means, organizing and presenting it in an easily analyzable form, such as tables or graphs.

Within the statistical-mathematical method, we performed descriptive statistics to calculate the following statistical indicators: the arithmetic mean, standard deviation, and coefficient of variability. In addition to descriptive statistics, we also used the following statistical tests: effect size (Cohen's d), the t-test between two dependent data sets, t value, and effect size.

Chapter 13 The results of the final research and their interpretation

The final study included 5 control trials without the use of modern technology and one giant slalom trial that incorporated several elements, namely: the use of XSensDOT sensors, the video analysis method, and the use of the OptiPath application, all of these tests being applied to the subjects undergoing testing. The specific trials are divided into: serpentine running between flags, maintaining a specific position on the balance board, dry slalom, lateral jumps, and maintaining balance on the Bossu ball with weight shifting.

13.6. Giant slalom

The application developed to improve the performance of skiers must meet the following principles (aspects):

- it should be easy to use by the people involved in skier training;
- it should not require many steps or long times for collecting the necessary information before the training begins;
- it should be usable on any ski slope or training location;
- the devices necessary for the application to function should be common and accessible to the technical staff;
- errors generated during the processing of input information should not distort the events taking place in reality.

Considering that in alpine skiing, technical events require a number of 40-50 gates (flags), depending on the type of event (giant slalom or special slalom), determining the GPS coordinates of each flag using topographic stations would require a very long time, which is not available before the event. Additionally, the slopes on which the competitions take place are not mapped, which is why interested parties or the general public do not have access to certain technical data regarding the surface where the competition is held. The GPS coordinates provided by a mobile phone are not as accurate as those provided by a topographic station.

In the images generated by the developed application (see Fig. 55), it can be observed that the arrangement of the flags (their setup) is not the same, and it is found that the two courses are different. This is due to the fact that the arrangement of the flags was done according to several flag placement schemes, in order to verify how the application generates the analyzed courses and if they are in accordance with the actual flag setup on the slope. Furthermore, by looking at Figure 55, it can be seen that in certain places there is no clear difference between the skier's actual course and the ideal course. To address this, passes were made at clearly established distances from the mounted flags along the course. The chosen distances were 0.5 m, 1 m, 1.5 m, and 2 m. These distances were marked on the snow, and the skier passed at the respective distance from each flag. In Figure 55, the 2-meter course was obtained by moving the skier 2 meters away from each flag of the course (the ski tracks were 2 meters apart). For the 0.5-meter course, the skier passed each flag at a distance of 0.5 meters. In the case of the 0.5-meter distance, the difference between the two courses is much more blurred.

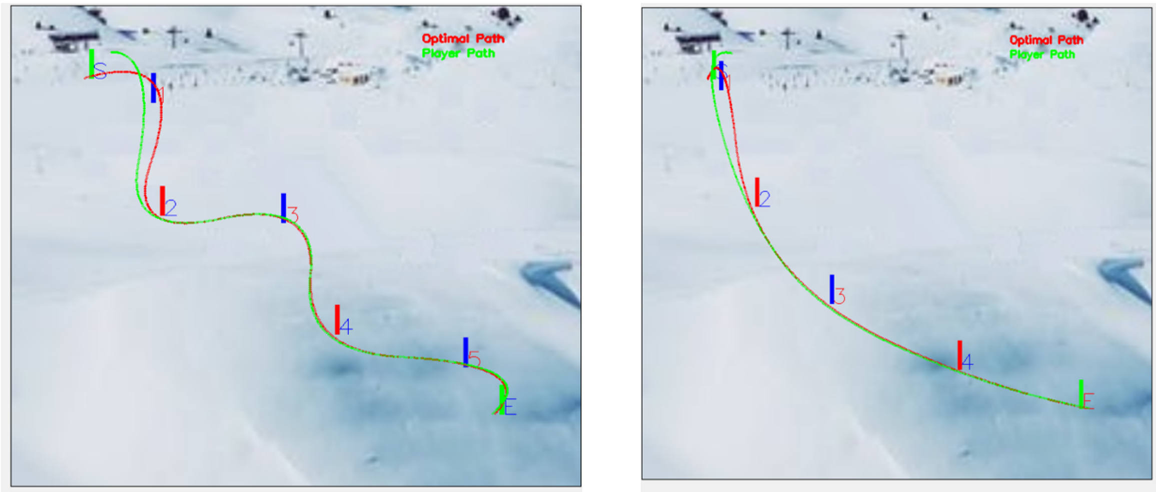

Fig. 55 The ideal and real course of the skier for 2 m (left) and 0.5 m (right)

It is known from geometry that the shortest path between two points is a straight line. As a result, in order to finish the course in the shortest time, the skier should move between the gates in a straight line and as close as possible to them. Any deviation from this ideal path will increase the distance covered by the skier and, implicitly, the time taken. Another important aspect is that the approach to the ideal path (correcting the trajectory) must be made without sudden changes in trajectory, which would result in a reduction in the skier's speed. Figure 61 shows how the results provided by the application are used in the analysis of the skier's performance. Knowing the distance between each gate on the course and the skier, the extra distance covered by the skier can be calculated. By following the same procedure for each gate, the additional path covered by the skier can be determined, thus practically measuring the time loss recorded by the athlete. Furthermore, the areas where the skier passes a significant distance from the gate are identified. Additionally, a comparison can be made between the way different skiers navigate the same course.

$$tj_i = 2\,\pi\, r_i\, \alpha_i / 360 = \pi\, r_i\, \alpha_i / 180 \quad (4)$$

where:

tj_i – the extra path for gate i;

r_i – the radius of the path for gate i;

α_i – the angle of the arc of the circle traveled by the skier at gate i.

Similarly to how the distance from the gate was determined, the skier's movement along the entire course can also be assessed, including the space between the gates, where the trajectory is generally made up of a straight line and circular arcs (or an arc of a circle), depending on the configuration of the gate layout. The radius of the circular arc and its angle can be determined by measurements taken from the image, and using relationship (4), the extra path that can be allocated to the skier can be calculated.

Relationship (2) provides a one-to-one[2] connection between the actual distance from the gate the skier passes through and the distance indicated by the application. Therefore, based on the path drawn by the application for the skier's run and by measuring the distance from the gate along the course, the distance from the gate the skier passed through can be established.

For some skiers, the differences between the two paths are greater, meaning the difference in distance covered is large, i.e., the skier traveled a longer path than the ideal one but also compared to other skiers. However, they still recorded one of the best times for the course.

Among the athletes who participated in testing the OptiPath application, those who achieved the top 7 times were selected. Wearable sensors (XSensDOT) were installed on these athletes, which allow monitoring of the body segment movements on which they are mounted. The test subjects had two sensors mounted on each leg, one on the thigh and one on the calf. The sensors were used to determine the angle of inclination of each athlete at each gate. The angle developed by the athlete is also influenced by the slope of the ski slope and the flex of the ski boots they are using. The aim was to use the XSensDOT sensors, along with the other developed technologies, to determine the factors that are important in alpine skiing performance and how they can be improved. Each of the four sensors used generates a data set that must be interpreted to determine the angle developed by the athlete at each gate. Figure 62 shows the arrangement of the sensor on the lower limb, but especially the orientation of the sensor's coordinate system relative to the skier's direction of travel.

[2] A one-to-one correspondence is the correspondence between the elements of two sets, given by a bijective function. A function f: A → B is called bijective if it is both injective and surjective. In other words, the function f: A → B is bijective if and only if for every y ∈ B, there exists a unique x ∈ A such that f(x) = y. The symbol ∃! means "exists uniquely."

Fig. 62 The arrangement of the sensor on the lower limb segment

The analysis of the following graphs allows for an understanding of how the athlete skis. It should be noted that the sensors were configured to collect data at intervals of 0.01667 seconds (i.e., to collect 60 values per second). The amount of data collected is considerable and shows that even the slightest movement of the segment on which the sensor is mounted will be recorded. A first analysis was made by measuring the knee angle. The study shows that for the athletes analyzed, the knee angle is small compared to the recommended optimal value. The highest recorded values are just over 60 degrees, regardless of whether we refer to the left or right leg.

Professional skiers have much higher values for this angle (over 110 degrees), and this value depends on the position of the leg during the turn, i.e., whether it is on the inside or outside of the turn. A small knee angle shows that the skier maintains a high position while executing turns at the gates. The high position means that their center of gravity is relatively high, indicating that instability during turns is significant and the balance generated during each turn is low. To verify this hypothesis, accelerations of the respective body segments (upper and lower leg) were also collected. The evolution of the minimum, maximum, and average accelerations along the three axes (X, Y, and Z) is shown in Figures 65, 66, and 67.

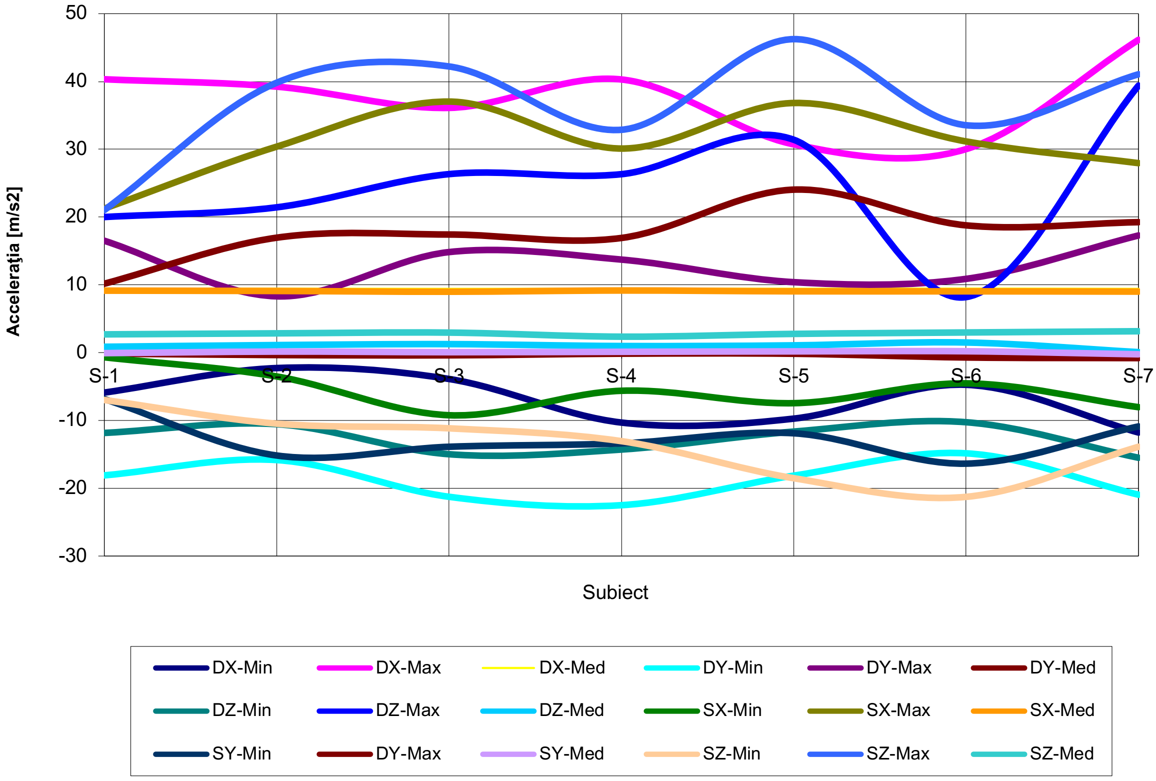

Fig. 65 The evolution of the skiers' accelerations for both lower limbs (directions X, Y, and Z; minimum, maximum, and average acceleration)

The analysis of the figures shows that among the athletes studied, there are some who, during the run, can generate an increase in acceleration through the movement of their lower limbs as they pass between the gates, which in turn will increase their speed. The important direction for the time set in the run, in this case, is the Z direction, i.e., the direction of forward movement, and it depends on the placement of the sensor on the respective body segment (see Fig. 62). The accelerations in the X direction show how quickly the skier moves their body and, implicitly, their lower limbs in the vertical direction. This acceleration is closely correlated with the movement in the Z direction. On the other hand, the acceleration in the Y direction (lateral acceleration) shows what happens during the turns the skier makes. Usually, but this is not a rule, high accelerations in the Y direction indicate that the skier is making trajectory corrections during the movement. The consequence is that in such situations, the skier will lose time.

The study of Figures 66 and 67 shows that the lowest time achieved in completing the course was for the skier who generated the highest accelerations in the X and Z directions (X-Max and Z-Med). By closely studying the mentioned figures, it is observed that other athletes also recorded high values for accelerations in the X and Z directions, but their time was not low. For these athletes, we also need to look at the value of the acceleration in the Y direction. For these skiers, it is observed that the values of acceleration in the Y direction are high, indicating that the skier is making aggressive corrections to their trajectory.

Chapter 14 Final conclusions and elements of originality derived from the final research

14.1. Conclusions

Optimizing the training process in alpine skiing involves an objective analysis of both theoretical and practical-methodical aspects involved in enhancing performance, particularly the influence of certain aspects on the general framework of preparation.

The development, enhancement, and validation of procedures regarding the use of XSensDOT sensors in alpine skiing provide the foundation for improving and modernizing training by leveraging the potential of new technologies, demonstrating that these possibilities are real when starting from the initial stage of training.

The development of the OptiPath application, through which the skier's trajectory during giant slalom runs was evaluated, highlighted two paths: an ideal path and another, the skier's actual path. Comparing the two paths led to differences in times recorded by athletes. This research shows that when the two paths are close, the time gained by the athlete through shortening the path decreases significantly. The development of the OptiPath application was based on the following pillars:

- **efficiency,** referring directly to the possibility of drawing conclusions that can optimize the performance of alpine skiers aged 14-16 years;
- **simplicity,** meaning that even individuals without specific and extensive technical training can use the application in the simplest way possible;
- **accessibility,** directly referring to the fact that the tools needed to use OptiPath are simple: a video camera (a mobile phone camera can be used to film the training sessions), a smartphone to determine coordinates, and a PC (laptop or desktop) to analyze the training;
- **utility,** represented by the professional level at which the application can be useful for performance athletes.

One of the most interesting aspects of our research is the fact that the athlete with the best time did not cover the shortest distance, which means that the athlete who covered the shortest distance did not generate the highest speed on the course. The reason for this is insufficient balance during the course.

The characteristics of each athlete, understood as individual particularities, are crucial for covering the shortest distance and for identifying the main differences that lead to achieving a better time.

For these reasons, we believe it is necessary to conduct research that analyzes athletes' perceptions regarding the use of modern technologies. Another investigation could focus on their expectations regarding the effects of the tool used.

It is important to note that the software created—OptiPath application, as well as the sensors used—XSensDOT/Movella—contribute to identifying the ideal path, helping athletes become aware of both the main technical mistakes they make and the methodology for correcting them.

The research contributes to understanding the importance of using modern information technology in the training of alpine skiers, both at the athlete level and among specialists/coaches.

The evaluation system used in the research, represented by the control trials, proved its efficiency through the values recorded in each of the trials. The experimental program used in the research, represented by the means and methods employed in the experimental phase, led to achieving the main research objective, which was to improve performance in alpine skiing through simulation and video analysis of the training sessions. The significant differences recorded by the subjects in the final tests provide another argument for the experimental organizational approach and for the validation of the research results.

By using the ideomotor training sequence in the final experimental research, significant differences were obtained in the control trials during the final testing, validating the experimental methodological approach used.

The experimental training program used in the final research resulted in improved performance in alpine skiers aged 14-16 years, confirming the research hypotheses.

Final conclusion: The experimental research conducted, quantified in the results obtained from the control trials, the use of information technologies in the training of alpine skiers aged 14-16 years, and the application of the new technologies/tools created, allow us to assert that the hypotheses of the final research were fully confirmed, which gives both validity and innovativeness, as well as authenticity, to the proposed research approach.

14.2. Elements of originality and innovation drawn from the final research

In the current context of the digital age, the field of sports training is undergoing a profound transformation, with significant implications for athletes. This imminent change inspired me to develop an innovative application designed to improve athletes' performance through video monitoring of training sessions. The application of advanced technologies in monitoring and analyzing training sessions provides the opportunity to obtain precise and immediate feedback, thus facilitating the adjustment and optimization of training techniques to maximize athletes' performance.

The interdisciplinary nature of the research is also represented by the development, for the first time in our country, of mathematical equations (multiple linear regression equations) designed to calculate the best times that alpine skiing subjects could achieve, based on the 4 parameters and 11 subparameters identified by the CARV application as being of maximum importance in alpine skiing.

In this context, I believe that using the OptiPath application in training is an opportunity for both coaches and athletes, as it can improve performance through its use. Furthermore, I believe that these modern training methods will achieve the expected success, and finding the right balance between traditional training and those using this method remains an ongoing challenge.

The OptiPath application represents a groundbreaking innovation in alpine skiing. The innovation lies in the fact that, until now, no application has been designed to compare the ideal course with the skier's real course. OptiPath contains both established elements from the field and new aspects, or those assimilated from related fields, to fully achieve the initially proposed objectives.

Another innovative element is the mathematical model designed, which allows for the anticipation of an athlete's performance when certain proposed values are reached.

The originality of the doctoral thesis lies in its innovative approach to sports training through the use of modern technology, a method that has been little explored until now. According to research and the analysis of the specialized literature, the use of wearable sensors during training sessions is still in its early stages and has been insufficiently studied and utilized. Furthermore, the developed application, OptiPath, represents a premiere in Romania, offering a significant novelty in the field of sports training. Through OptiPath, both coaches and athletes can identify errors made during a skiing run, allowing for a detailed analysis of performance. Moreover, the integration of these technologies provides athletes and coaches with precise information about mistakes that lead to time losses during competitions and proposes concrete solutions for improving performance. This advanced technological combination facilitates immediate and effective feedback, thus contributing to the optimization of the training process and reaching a higher level of athletic performance.

Additionally, the originality lies in the innovative approach of using CARV and XSensDOT sensors during training. By using these previously mentioned sensors and based on the data provided by them, the factors important for alpine skiing performance were determined, along with the improvement of these factors.

Chapter 15 Dissemination of results and research limitations

15.1. Dissemination of results

The dissemination of the scientific results was achieved through participation in various scientific events, materialized by the publication of articles in different journals:

1. **Cătană (Brus), D.I.,** Enoiu, R.S., Aspects of psychological training in alpine skiing at the age of 14-16, Scientific Bulletin of naval Academy, Vol. 23, 2020
2. Enoiu, R.S., **Brus, D.I.,** Mîndrescu, V., New Technology in Education on Performance Analysis. Wearable Sensors Utility on Alpine Skiing, Revista Românească pentru Educație Multidimensională, 2023, Vol. 15

Additionally, I had the opportunity to participate in scientific sessions dedicated to PhD students, such as:

1. **Cătană, D.I**, Enoiu, R.S., Research on improving performance in alpine skiing through simulation and video analysis of training, Scientific conference of doctoral schools, The Ninth Edition, Galați, 10th-11th of June 2021
2. **Cătană, D.I**, Enoiu, R.S., Performance improvment research in alpine skiing through simulation and video analysis of training, 2024 Doctoral Conference, Brașov, 26-27 June 2024

15.2. The limits of the research

Regarding the limitations of the research, it can be mentioned that the relatively small number of participants, as well as their age, does not allow for the generalization of the conclusions to all age groups specific to alpine skiing performance. Consequently, we can only recommend the use of wearable sensors as well as the OptiPath application, which we developed and is an absolute novelty, during training sessions, without extending these recommendations to a larger population (and without further studies).

Abstract

At the beginning of the 21st century, alpine skiing has made significant progress in training techniques and equipment development, leading to improved performance for skiers. The doctoral thesis aims to analyze the application of modern training techniques, such as the use of videos and wearable sensors, to optimize training and enhance skier performance. A central component is the development of a software application that compares the ideal tracks with those followed by the skier, while the use of sensors allows for real-time monitoring and correction of technique. The thesis addresses the importance of technical and physical preparation in achieving competitive results both nationally and internationally and contributes to the integration of modern technologies in the training process to improve skier performance.

Optimizing training in alpine skiing requires a detailed approach that combines theoretical analysis with practical methods. The study highlighted significant improvements in athletes' performance, particularly in agility, balance, and coordination tests. The adaptation of training programs to new technologies has been an important factor in performance optimization.

A key aspect of the research was the use of the OptiPath application to analyze skiers' trajectories during giant slalom runs. This tool allowed for a comparison between the ideal trajectory and the actual trajectory, highlighting differences that influence final times. The analysis showed that an athlete's performance is not solely determined by the distance covered but also by technique and balance maintained throughout the course. This method provides athletes with valuable insights for adjusting and improving their execution in competitions.

The implementation of modern training techniques included the use of sensors to monitor athletes' movements and conduct detailed analyses of their training sessions. These methods provided precise data on the execution of each test, contributing to the refinement of training strategies. The study emphasized the importance of adapting training methods to the current demands of high-performance sports, utilizing technologies that enable a more detailed and objective assessment of athletes' progress.

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