Submitted: 17 August, 2022 Accepted: 06 March, 2023 Published: 30 April, 2023 DOI:10.22514/jomh.2023.032

JOMH
Journal of Men's Health

ORIGINAL RESEARCH

Study comparing the vibrations recorded by professional and non-professional male athletes in winter sports, skiing *vs.* snowboarding

Andrei Gheorghita[1], Catalin Ionite[1,*], Mariana Rotariu[1], Marius Turnea[1], Dragos Arotaritei[1], Mihai Ilea[1], Iustina Condurache[1]

[1]Department of Biomedical Sciences, Faculty of Medical Bioengineering, "Grigore T. Popa" University of Medicine and Pharmacy, 700454 Iași, Romania

***Correspondence**
andrei-catalin.ionite@umfiasi.ro
(Catalin Ionite)

Abstract

Winter sports such as skiing and snowboarding are becoming increasingly popular among all age groups, as practicing these sports has seen an upward trend, which has led to an increase in the number of injuries and pathologies related to them. Practicing skiing/snowboarding entails a series of vibrations occurring in the equipment, their propagation along the kinetic chain impacting both in a positive and negative way the health of the person in question. The study was a comparison, skiing *vs.* snowboarding, between the vibrations experienced by professional and non-professional athletes, with the main objective of determining which of them produces greater vibrations and identifying the negative and positive effects they have. The study was performed under field conditions using sensors designed to record vibrations on the ski/snowboard (tip/nose and tail), as well as vibration sensors located in the ankle, knee, hip and lumbosacral areas, designed to record the propagation of vibrations along the kinetic chain. The results show a higher level of vibrations recorded on the ski than on the snowboard, while their transmission along the kinetic chain is inversely proportional. The conclusion relates to the choice of skiing/snowboarding. Therefore, due to the Whole-Body Vibration phenomenon, young people are more likely to choose snowboarding due to the possibility of increasing bone quality and quantity, while older people are rather fond of skiing, given its effect along the kinetic chain, which protects the skeletal system. Studies have provided evidence to suggest alpine skiing is an appropriate activity for elderly as a health-enhancing sport. Thus, perhaps alpine skiing could provide the physical activity needed to counteract age-related degradation processes and loss of function.

Keywords

Winter sports; Vibration; Transmission; Kinetic chain

1. Introduction

Winter sports (skiing and snowboarding) are becoming increasingly popular among all age groups, as practicing these sports has seen an upward trend [1, 2]. A study conducted in 2000 indicates that, since 1970, when the idea of snowboarding appeared, the popularity of this sport has constantly grown. According to the 1994–1995 National Ski Areas Association (NSAA) Kottke National Business Survey, 14% of the 54 million visits to the United States were made by passionate snowboarders [3].

Practicing winter sports generates vibrations and shocks that are transmitted from the ski/snowboard to the spine, passing through the joints (ankle, knee, hip joint, sacroiliac, sacrolumbar, lumbar spine), bone system (leg bones, tibia, femur, pelvis, vertebral bodies) and the muscular system.

Carlsoo S. argues that the musculoskeletal system (skeleton, joints and muscles) is elastic and plastic, properties that allow it to attenuate mechanical vibrations without causing injuries, but the system can only do this as long as the vibrations are within tolerable limits. The musculoskeletal system (skeleton, joints and muscles) is a system capable of absorbing various mechanical energies generated by trauma, impacts, and vibrations without sustaining injury [4].

This is also possible due to the S-shape of the spine and its shock-absorbing structures (intervertebral discs), to the sacroiliac joints, the hip joint, the knee and the ankle, where the ascending and descending forces meet to diminish.

The thickness and structure of the articular cartilage also contribute to the body's ability to absorb vibrations. Ligaments and tendons are anatomical structures that contain collagen fibers, which help reduce tension, and the muscular system is not only capable of contraction, but, due to its elasticity, it is able to both passively and actively dampen the tension stress generated by vibrations and shocks [4].

The evidence presented by Carlsoo S. suggests that all the above elements are sufficient to dampen, absorb and reduce the vibrations generated by physiological movements, but in our free time we want to practice all kinds of activities, which expose us to non-physiological vibrations, to which our body is not adapted [4]. Studies identified by Carlsoo S. suggest that both vibration and shock may cause joint damage or may accelerate and exacerbate present or evolving degenerative pathologies [4].

Skiing, regardless of the form in which it is practiced (competitive or recreational), is often associated with a very high rate of injuries and, according to the statistics, about 40.6 people have died skiing/snowboarding each year on an average during the past 10 years [5].

Marietti S. compared ski injuries snowboard injuries and noted first of all that the average age of snowboarders is lower than that of skiers, with snowboarders averaging 25 years (16–32 years old), and skiers 42 years (23–52 years old) with a $p < 0.0001$. He analyzed 1099 skiers and 296 snowboarders. Multiple injuries were recorded in 64 skiers (5.8%) and only 13 snowboarders (4.4%) with $p = 0.416$. In the case of 172 injuries (15.7%) the skier was not responsible for the accident, and in the case of snowboarders 21 (7.1%) of them were not responsible for the injuries, the value of the accuracy coefficient being $p = 0.0002$ [6].

Pierpoint L.A. noted, in a 2000 study, the tendency of young people to choose snowboarding, and the tendency of older people to ski. The author conducted a study over a period of 4 years (2012/13–2016/17), which revealed that skiers are 34.3 +/− 19.3 years old while snowboarders are 23.2 +/− 10.5 years old with $p < 0.001$. It was also noted that the incidence of falls was higher for snowboarders (84.8%) than for skiers (72.3%). In the case of a collision with a natural obstacle, the skiers took the lead with 9.7% compared to 7.4% for snowboarders. The lower percentage of falls in the case of skiers is explained by the fact that this sport is practiced by the elderly [7].

Moore T.P. conducted a study in a Colorado clinic over a period of 10 years (1988–1999) and observed that, out of a total of 7430 snowboarding injuries, 74.1% were in males and 25.9% in females. The sportsmen's experience of is a decisive factor in the classification of accidents, as 45.2% of the accidents involved beginners, 31.4% intermediates and 23.4% experts. Compared to skiing, injuries of the upper body predominated in snowboarding (49.1% of injuries were on the upper limbs), while 12% of the lower body injuries were sustained on the ankle and only 3% were talus fractures [3]. In 2021, Rugg C.D. published a study in which he tried to determine the incidence of snowboarding accidents by sex. The Austrian records for the period 2005–2018 were studied and the findings show that men sustained 3536 injuries and women only 2155 injuries [8]. Dickson T.J. conducted a study to count injuries over a 10-year period (2008–2018) in Western Canadian Resorts. 29 out of 52 sources were analyzed and it was concluded 1/3 of the 107,540 reported injuries, in males, the percentage reported in the case of females being 42% [9].

Most injuries in both skiers and snowboarders were caused by carelessness, not adapting their walking style to their level of experience, but mostly due to loss of control of the equipment. Gosselin P. mentions in 2021 that vibrations can affect the comfort, control and performance of skis, and excessive vibrations can lead to ski edge release, which will lead to loss of control, and better damping can lead to decreased and altered feedback received by the rider from the skis [10]. Glenne B. reached the same conclusion when he claimed, in 1999, that vibrations could cause snowboarders and skiers to lose control of the edge on snow, leading to injuries [11].

Pino E. stated that 50% of snowboarding accidents are in the lower limbs (where ankle injuries are the most common). There were also notable differences between the production mechanisms and the range of injuries between snowboard and ski riders, with a higher percentage of upper body injuries [12].

Sachtleben argues that the incidence of both brain injury and spinal cord injury is much higher in snowboarders than in skiers, which may be explained by the fact that in some cases the rider may be thrown off the board [1].

Machold W. conducted a study on the winter sports program organized by the Austrian school. The study included 7221 participants, of whom 2745 used a snowboard. Of these, a total of 2579 (94%) spent a total of 10,119 days of snowboarding and were assessed using a questionnaire. A total of 152 snowboarders suffered an average of 10.5 injuries per 1000 days of snowboarding requiring medical attention, and 5.4/1000 injuries were moderate to severe [13]. Weinstein S. concluded in his study that upper body injuries are the most common in snowboarders, especially in the wrist, as they use their hands to protect themselves and skiers mostly sustain injuries to the lower limbs, knee ligament injuries being the most common [14]. A study published in 2021 and conducted over 9 years (2010–2019) on The National Electronic Injury Surveillance System (NEISS) identified a number of 361 skiers and snowboarders who suffered facial injuries. The number of pediatric patients was higher, *i.e.*, 52% (187 out of 361 patients were children), the highest injury rate being on acceleration, namely 51.9% compared to 39.1% in adults, with $p < 0.05$ and a hospitalization percentage of 4.8% compared to 1.15% in adults, with a $p < 0.05$. Adults had a 30% higher rate of facial fractures than children (13.9%), with a $p < 0.001$ [15].

The paper was conducted in two stages and was conceived to identify the vibrations perceived by the snowboard or ski, but also their transmission along the kinetic chain, and once these vibrations are identified, their correlation with other literature findings and with the effects, both positive and negative, produced by them.

2. Materials and methods

The study was a comparison, skiing *vs.* snowboarding, between the vibrations experienced by professional and non-professional athletes, with the main objective of determining which of them produces greater vibration and identifying the negative and positive effects they have.

Therefore, the study was conducted over a period of 4 months, from December 2021 to March 2022, it included two stages and was conceived to identify the vibrations perceived by the snowboard or ski, but also their transmission along the kinetic chain, and once these vibrations are identified, their correlation with other literature findings and with the effects, both positive and negative, produced by them.

The first stage took place in Campulung Moldovenesc (Suceava County) at the Rarau Ski Slope (Table 1 and Fig. 1) and was performed on men with a height between 175–185 cm, weight between 75–80 kg, shoe size 41 EU. They were beginners, practicing winter sports, *i.e.*, skiing and snowboarding, for 3 years (3 winters).

TABLE 1. Rarau ski slope features [16].

Length	2840 m
Steepness	medium
Height difference	455 m
Average inclination	0.166
Slope width	30–80 m
Departure altitude	1220 m
Arrival altitude	756 m
Transport capacity	1.008 pers/h
Artificial snow machines	9

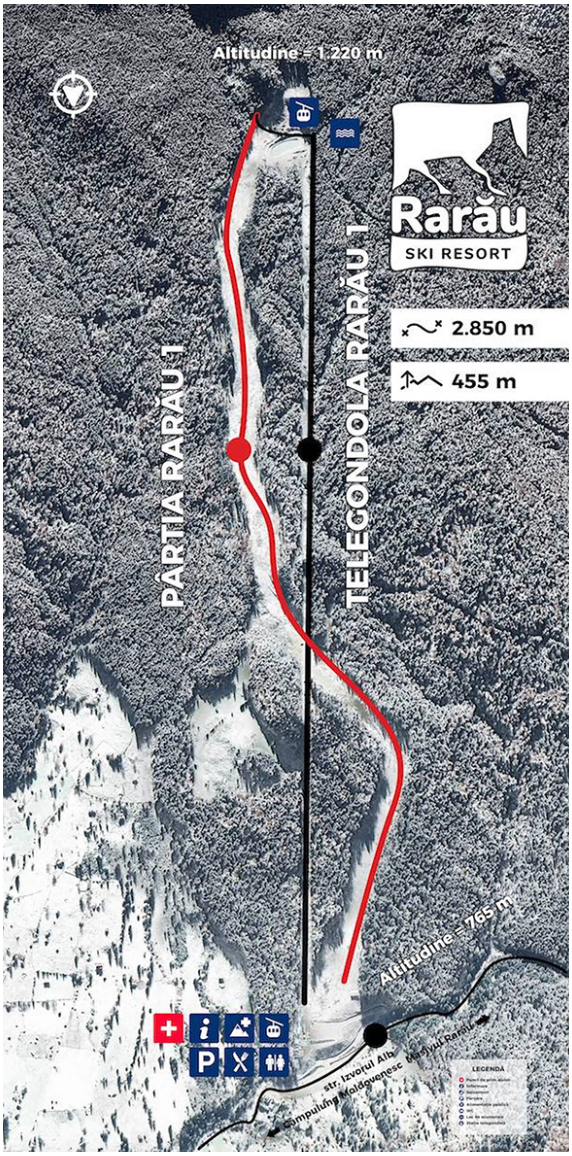

FIGURE 1. Rarau ski slope [16].

At this stage, the sensors (explained 2.3) were attached to the snowboard and ski riders. The sensors were attached 15 cm from the tips/noses and tails of the snowboards and skis, on the tibial ankle, knee, hip and lumbosacral joint (l5-s1).

The sensors were placed to allow measuring the vibrations occurring on the snowboard/ski, as well as the transmission of vibrations to the foot, wrist, knee, hip and sacro-lumbar region. The sensors were attached to the snowboard/ski with double adhesive tape. On the snowboard and skis, the sensors were placed 10 centimeters from the tips and 10 cm from the tail, in the middle of the respective ski or snowboard. On the athlete, the sensors were placed on: the skin projection of the external malleolus (distal end of the fibula), the skin projection of the external part of the intra-articular space of the knee, the skin projection of the greater trochanter of the femur and the skin projection of the intervertebral space of the fifth lumbar vertebra and the first sacral vertebra. In order to be able to measure the transmission of vibrations to the body as accurately as possible, the sensors were attached directly to the skin projection of the mentioned joints using adhesive tape.

These sensors will track the vibrations transmitted from the snowboard/ski to the mentioned joints. Thus, we try to identify the intensity of the vibrations reaching these joints so that people who want to start practicing these sports can make a correct decision based on pre-existing conditions in their ankle, knee, and hip joints or spine (lumbar section).

The evaluation protocol was as follows:

—the path was marked so that athletes use exactly the same route from start to finish;

—the athletes were equipped in the changing rooms with the necessary sensors to retrieve the data;

—the athletes received a recording device to keep in their pocket;

—the athletes had to turn on the data recording device when they started their descent;

—athletes;

—the athletes went down on the marked path, without deviating from it;

—the athletes had to maintain a constant speed of 40–50 km per hour, which was monitored with the help of the device; if they increased/decreased the speed, the device emitted an acoustic signal;

—after reaching the finish line, the athletes turned off the device;

—the Secure Digital (SD) card with the recorded data was replaced by a new SD card and the activity was resumed;

—the card with the recorded data was inserted into the laptop where the data was stored.

In the second stage of the research, the data was inventoried, compared, processed and analyzed using the software devices mentioned and explained in Chapter 2.3.

2.1 Snowboard type and technology used in the research

The snowboard used in this research was a Burton Ripcord Flat Top Snowboard (beginner level) with a Soft and Playful personality. According to the characteristics of this snowboard (Table 2), its Park score is 4/10, its Mountain score is 8/10 and

TABLE 2. Snowboard size details [17].

Board size	Weight range	Waist width	Stance location	Running length	Side radius	Sidecut depth	Stance width	Nose width	Tail width	Effective edge
154	54–82 kg	250 mm	−25	1150 mm	7.7 m	21.6 mm	530 mm	295.7 mm	290.7 mm	1200 mm

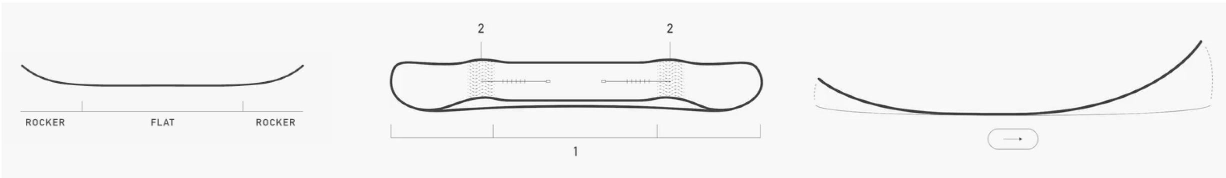

FIGURE 2. Technical details of the snowboard used [17]. 1—softer/thinner zones. 2—thicker/stiffer zones.

its Powder score is 4/10 [17].

The technologies applied on the snowboard are a combination of rocker at the nose and tail, and a flat surface in the middle (Fig. 2). These technologies allow a flat top bend that provides stability, balance and a permanent edge control that allow the subject to control the tip and the tail kick up, being forgiven with the controller of the board [17]. The 5 mm tamper allows the subject to turn easily providing feel and focus and the flex of the board increases the pop in the tail and provides bigger resilience in the nose part, allowing the riders to maintain a better control on all terrains [17].

The snowboard has a classic snowboard shape, with a slightly longer nose than tail. This design allows the subject to focus on the pop in the tail, providing plenty of float, flow and control. The core of the board is a Fly 900G core, that is a classic snowboard from tip to tail wood core. The wood core allows the ridder to make the best of it because it lightens the load but it does not sacrifice the flex, pop or strength. It also uses a Biax Fiberglass (Fig. 3) and features a jib-friendly, torsional soft flex and a forgiving feel that is great for beginners in the park (1—Topsheet, 2—Top glass 90° & 0° stitched, 3—Core, 4—Bottom glass 0° & 90° stitched, 5—base) [17].

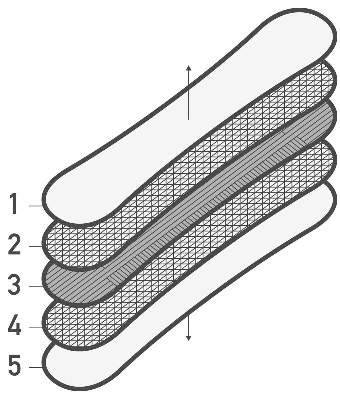

FIGURE 3. Layers of the snowboard used [17]. 1—Topsheet; 2—Top glass 90° & 0° stitched; 3—Core; 4—Bottom glass 0° & 90° stitched; 5—base.

2.2 Ski type and technology used in the research

The skis used in the research are Atomic M 10 GW (beginner's ski) that are simple to use and offers the rider a consistent feel, allowing the subject to ski with confidence (Table 3). They are strong and robust, offering and all-round performance having a radius halfway between giant slaloms (gs) and slalom, being super versatile for all types of slopes.

TABLE 3. Ski size details [18].

Ski size	Tip Width (mm)	Waist Width (mm)	Tail Width (mm)	Radius (mm)
161	118.5	70	102.5	13

The Technology (Fig. 4) in this system is a 100% camber with an 87° side edge angle (this angle is necessary because a blunt edge cannot easily penetrate the snow surface and at the same time bypass/change direction; if the edges are too sharp and it gets very snowy, the ride is unstable. This 87° percentage makes the skis more intuitive, easier to handle and with better grip on both snow and ice) and a 1.0° based edge angle (slightly raises the edge of the ski from the snow to make them more maneuverable, with better grip and aggression in curves) [18].

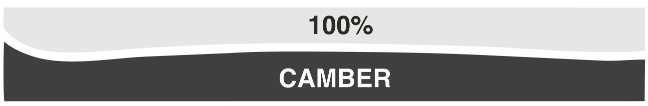

FIGURE 4. Technical details of the ski used [18].

Fig. 5 shows the various technologies employed to manufacture the skis used in our research (Fig. 5) [18]:

• Dura Cap Sidewall—it is a type of construction that has no sidewall, where the top sheet folds down over the edge, making the ski easier to handle. It has fantastic durability and the rounded shape picks fewer dents and digs;

• Power Woodcore;

• TI Stabilizer—it is a titanal layer placed under the core for better shock absorption and higher torsional flex;

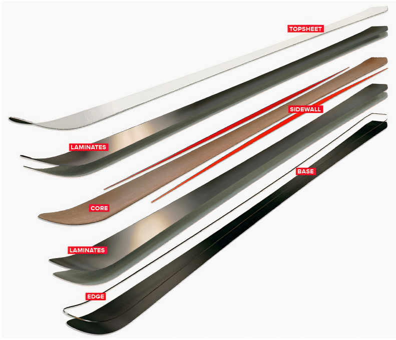

FIGURE 5. Layers of the ski used [18].

• Densolite Core—made of foam core that is agile and has good vibration dampening properties. It is used for effortless skiing;
• Multi Radius Sidecut;
• Structured Topsheet;
• Tip Protector.
• Leisure Trak L;
• Active Camber 0/100/0.

2.3 Sensors, data acquisition and programs used

2.3.1 Data acquisition system

Data acquisition (Fig. 6) was done using Arduino DUE, the most powerful arduino board. The Arduino platform has been used successfully for several other similar data acquisition purposes, including monitoring human activity, and integrated *via* ZigBee and Wi-Fi Networks [19]. Using Arduino library and SDcard library, the microcontroller can be programmed to save all data in a *.csv file format (or other supported formats). Once the data is written in *.csv format, it can be opened, modeled and plotted in MATLAB software (Version R2021a, MathWorks, Natick, MA, USA).

The system consists of six Motion Processing Unit (MPU) 6050, which is a triple axis accelerometer and gyro for calculating angular velocities and accelerations. The block diagram of the whole system is shown in Fig. 6.

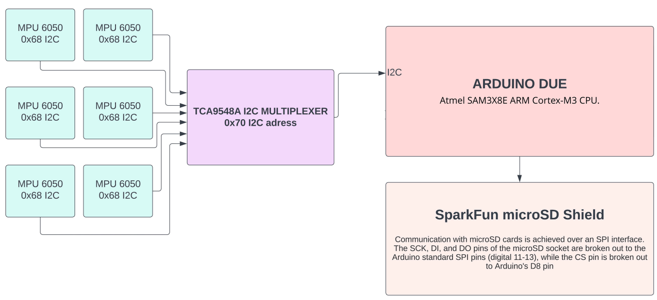

FIGURE 6. Block diagram of the data acquisition system. I^2C, Inter-Integrated Circuit; ATMEL, Advanced Technology for Memory and Logic; ARM, Advanced Reduced Instruction Set Computer Machine; CPU, Central Processing Unit; SPI, Serial Peripheral Interface; SCK, Serial Clock; DI, Data In; DO, Data Out; CS, Chip Select.

2.3.2 System components

The Arduino (Fig. 7) Due is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 Central Processing Unit (CPU). It is the first Arduino board based on a 32-bit Advanced Reduced Instruction Set Computer Machine (ARM) core microcontroller. It has 54 digital input/output pins (of which 12 can be used as Pulse Width Modulation (PWM) outputs), 12 analog inputs, 4 Universal Asynchronous Receiver-Transmitter (UARTs) (hardware serial ports), an 84 MHz clock, a Universal Serial Bus (USB) On The Go (OTG) capable connection, 2 Digital to Analog (DAC), 2 Two-Wire Interface (TWI), a power jack, a Serial Peripheral Interface (SPI) header, a Joint Test Action Group (JTAG) header, a reset button and an erase button (Table 4).

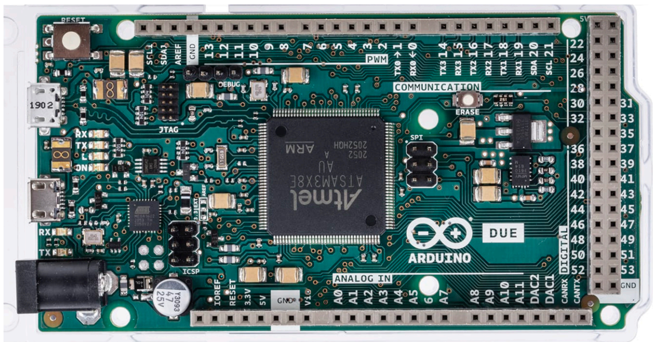

FIGURE 7. Arduino DUE board.

The sensors used are MPU-6050 module which is a three-axis gyroscope and triaxial accelerometer. The MPU-6050 sensor contains a Micro Electro Mechanical System (MEMS) accelerometer and a MEMS gyro in a single chip (Fig. 8). It is very accurate, since it contains 16-bits analog to digital conversion hardware for each channel. Therefore, it captures the x, y, and z channels at the same time (Table 5).

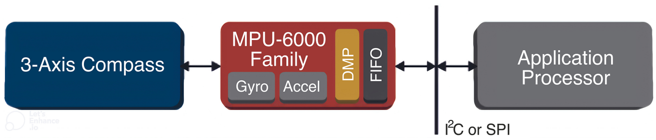

FIGURE 8. Block diagram of MPU-6050 sensor. Digital Motion Processing (DMP), First In First Out (FIFO), Inter-Integrated Circuit (I^2C).

The MPU-6050 (Fig. 9) devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor™ (DMP™), which processes complex 6-axis Motion Fusion algorithms. The device can access external magnetometers or other sensors through an auxiliary master I^2C bus, allowing the devices to gather a full set of sensor data without intervention from the system processor. The devices are sold in a 4 mm $\times$ 4 mm $\times$ 0.9 mm Quad Flat No-Lead (QFN) package.

The sensor nodes, the 3D accelerometer data is processed by filters in order to decrease the noise. The 3D accelerometer data is stored to an SD card. After the recording ends, the data is transferred to a PC and processed and analyzed. The

TABLE 4. Arduino Due specifications.

Microcontroller	AT91SAM3X8E
Operating voltage	3.3 V
Input voltage (recommended)	7–12 V
Input voltage (limits)	6–16 V
Digital Input/Output (I/O) pins	54 (of which 12 provide PWM output)
Analog input pins	12
Analog output pins	2 (DAC)
Total Direct Current (DC) output current on all (I/O) lines	130 mA
DC current for 3.3 V pin	800 mA
DC current for 5 V pin	800 mA
Flash memory	512 KB all available for the user applications
Static Random Access Memory (SRAM)	96 KB (two banks: 64 KB and 32 KB)
Clock speed	84 MHz
Length	101.52 mm
Width	53.3 mm
Weight	36 g

TABLE 5. MPU 6050 Specifications.

AD Converter	16-bit AD converter-chip, 16-bit data output
Chip	MPU-6050
Power supply	3-5 V (internal low dropout regulator)
Communication	I2C communication protocol standard
Gyro Range	±250 500 1000 2000°/s
Acceleration range	±2 ±4 ±8 ±16 g
Size	2 × 1.6 × 0.1 cm

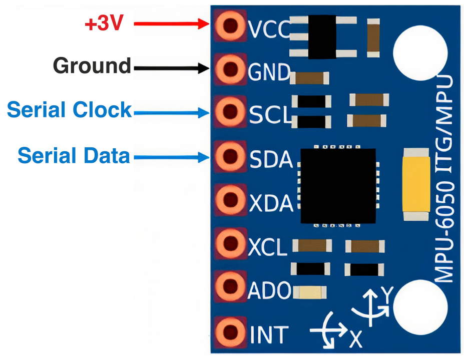

FIGURE 9. MPU6050 pinout.

software used for data analysis and processing is MATLAB 2021a. Therefore, we need a filter based on an algorithm described in equations x-x. The inertial signal data passes through lowpass filter, Derivation, squaring function, Moving-Win integration, Normalized, and data fusion before thresholds are set.

The inertial sensor data passes through a lowpass filter in the first step in order to reduce the frequency interference and other noise.

The lowpass filter is described by the formula:

$$H_{LP}(z) = \frac{1 - z^{-6}}{1 - z^{-1}} = 1 + z^{-1} + z^{-2} + z^{-3} + z^{-4} + z^{-5} \quad (1)$$

And the cascade transfer function is:

$$H_{LP}(z) = \frac{1}{32}\left(\frac{1 - z^{-6}}{1 - z^{-1}}\right)^2 \quad (2)$$

The corresponding difference equation is:

$$y[n] = 2y[n-1] - y[n-2] + \frac{1}{32}(x[n] - 2x[n-6] + x[n-12]) \quad (3)$$

After the lowpass filtering, the signal is differentiated. We use a five-points differentiator described by the formula:

$$H_{dif}(z) = 0.125 * \left(2 + z^{-1} - z^{-3} - 2z^{-4}\right) \quad (4)$$

Thus, the difference equation then becomes:

$$y[n] = \frac{1}{8}(2x[n] + x[n-1] - x[n-3] - 2x[n-4]) \quad (5)$$

After differentiation, all points are squared. The difference equation is described by the formula:

$$y[n] = (x[n])^2 \quad (6)$$

After squaring, a moving window integration algorithm is used to get feature information. And the formula is:

$$y[n] = \frac{1}{N}(x[n] + x[n-1] + \ldots + x[n-(N-1)]) \quad (7)$$

Here N is related to the sampling rate. In our task, the sample rate is 20 samples/sec, hence N is 10. After the operation above, the x-axis of the accelerometer cannot be fused with the y-axis of the gyroscope directly. They must be normalized before data fusion. The normalized factor is their range. The data fusion is calculated from:

$$Y_{(n)} = \sum_{n=1}^{M} \frac{A_n}{A_1 + A_2 + \ldots + A_M} X(n) \quad (8)$$

This TCA9548A I2C (Fig. 10) multiplexer module can bind up to eight I^2C of the same address. It serves, selects and sends commands to the selected set of I^2C pins. The multiplexer is on I^2C address 0x70 (but can be adjusted from 0x70 to 0x77), writes a single byte with the desired multiplexed output number to that port so that future I^2C packets will get sent to that port. The multiplexer made it possible to connect the 6 MPU6050 sensor to Arduino. The sensor used the same I^2C address (0x68) so using TCA9548 is mandatory.

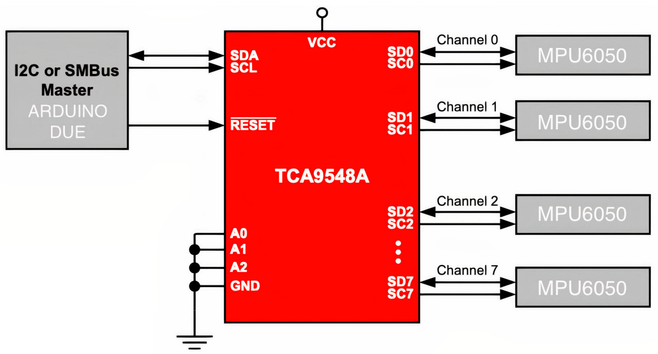

FIGURE 10. TCA9548A I^2C multiplexer block diagram. SDA, Serial Data; SCL, Serial Clock; A0, Analog 0 pin, A1, Analog 1 pin; A2, Analog 2 pin; GND, Ground.

Card data loggers are electronic devices which automatically monitor and record environmental parameters over time, allowing conditions to be measured, documented, analyzed and validated. The data logger contains multiple sensors to receive the information and a SD Card chip to store it. The information stored in the data logger is then transferred to a computer for analysis. Using microSD data cards for storage provides a virtually unlimited number of measurement because sensor data and time data are stored as plain text in a comma-separated values format (.csv) and each data value consists of only a few bytes of storage. When our paper was written, a 32 GB microSD card cost less than \$10, which can theoretically store billions of measurements. MicroSD cards also allow ease of use of data retrieval through interfacing with most modern computers because of the SD card reader builtin.

3. Results

Vibration analysis is one of the most important techniques for obtaining mechanical data, making it possible to dynamically evaluate the behavior of the equipment, but also its transmission and impact along the human kinetic chain. The results were analyzed analytically from the tip of the ski/snowboard successively to the lumbosacral joint.

As shown in Fig. 11, the data recorded by the sensor at the tip of the ski shows a much higher vibration compared to the data recorded by the sensor at the tip of the snowboard (Table 6). These findings prove that the vibration level will be directly proportional to the elasticity of the material, the shape and the position of the ski/snowboard.

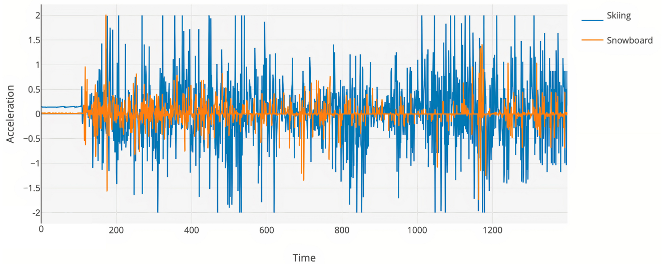

FIGURE 11. Vibrations recorded at the tip of the ski/snowboard (raw data).

The same phenomenon is visible at the tail of the ski/snowboard, where the recorded data also shows a higher amplitude of vibrations in skis.

By analyzing Figs. 11,12, one may note that the vibration level is higher at the tip of the ski compared to the snowboard and lower at the tail of the former compared to the latter (Table 7). We can conclude that the tip of the skis is responsible for taking over and attenuating the vibrations from the ground, while in snowboarding it is the tail that does that.

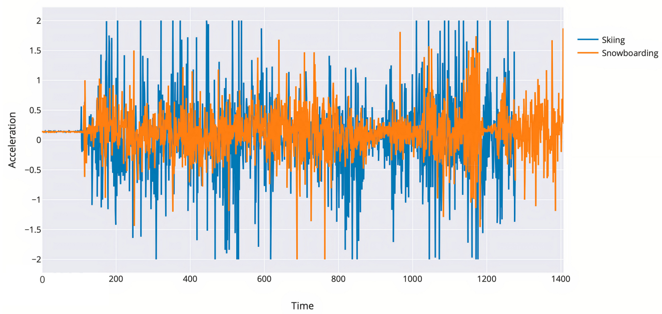

FIGURE 12. Vibrations recorded at the tail of the ski/snowboard (raw data).

The vibration amplitude was greater at the tip of the skis and attenuated at ankle level. By comparing the two Figs. 11,13, we can see that the material from which the ski is made, as well as the shape, but also the position of the body had a very important role in attenuating the vibrations (contact between the ski and the ground).

The data was recorded on all 3 axes using an accelerometer placed on the athlete's peroneal ankle, which recorded higher amplitudes of movement on all 3 snowboard axes (Table 8).

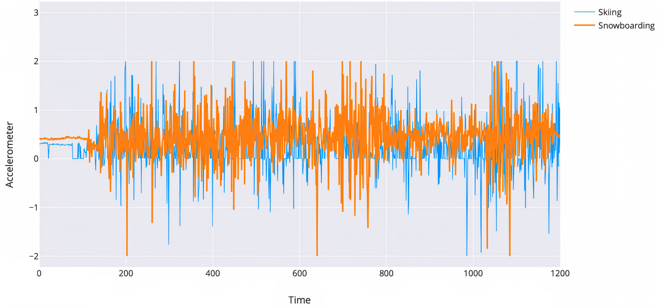

FIGURE 13. Vibrations recorded by ankle accelerometer (raw data).

A significant difference is noticeable in the case of the X axis, Fig. 14, more precisely in the case of lateral movements, due to the position of the snowboard. This is due to the fact that the snowboarder must adjust the center of gravity within the X axis, but also dampen the vibrations transmitted by the board.

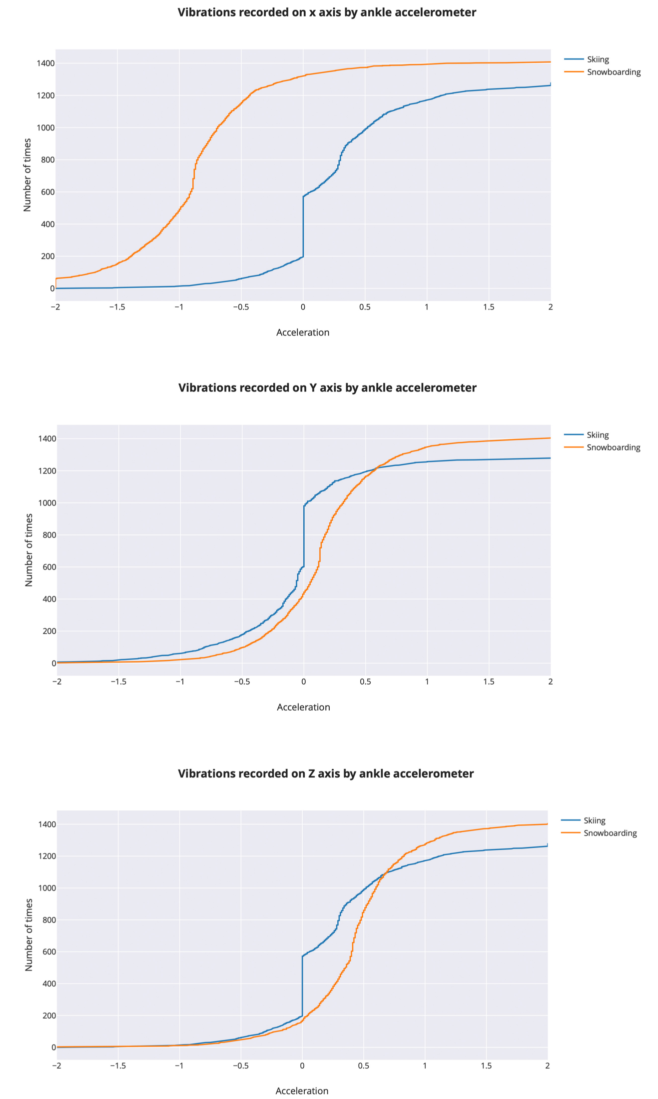

FIGURE 14. Vibrations recorded on x, y, z axis by the accelerometer on the ankle.

TABLE 6. Vibration recorded at the tip of the ski/snowboard.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	2	3	64	4	15	36
−1.5/1	5	12	93	9	25	55
−1/0.5	1240	1176	923	1139	1142	956
−0.5/0	249	347	79	194	263	49
0/0.5	404	225	43	207	135	41
0.5/1	28	66	42	77	52	33
1/1.5	3	9	19	32	19	20
1.5/2	0	1	12	7	7	16

TABLE 7. Vibration recorded at the tail of the ski/snowboard.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	0	9	32	18	16	33
−1.5/1	9	20	27	40	57	38
−1/0.5	1095	1054	282	987	976	258
−0.5/0	331	396	94	357	537	76
0/0.5	718	552	134	497	283	119
0.5/1	132	123	329	134	107	282
1/1.5	20	47	186	51	49	135
1.5/2	7	8	115	14	24	117

TABLE 8. Vibration recorded by ankle accelerometer.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	75	4	1	77	13	4
−1.5/1	293	11	5	177	39	11
−1/0.5	818	1051	763	910	1131	965
−0.5/0	145	299	94	106	422	185
0/0.5	43	675	634	61	212	658
0.5/1	18	151	378	16	61	181
1/1.5	7	32	85	13	12	65
1.5/2	4	13	14	5	8	20

The ankle vibrations recorded on the Z axis (up/down) are higher in the case of snowboarding, which denotes the use of ties with a higher resistance to mechanical stress.

These vibrations recorded at the ankle (external ankle) correlated with the vibrations recorded by the snowboard (tip/tail) suggest that the contact between the foot, the board, and the ground is poorer, which can lead to loss of control due to joint instability. In other words, the period of contact between the ground, the board and the foot will be shorter for snowboarders than for skiers.

Analyzing the 3 axes in Fig. 14, we conclude that, regardless of the axis, the vibrations will be more marked snowboarding.

Fig. 15 confirms the previous results namely that the level of vibrations is higher than in skiers. According to this data, ankle and knee vibrations are higher in snowboarding, due to poor vibration dampening by the snowboard. This data is inversely proportional in skiers, as skis are affected by higher vibrations, but they have the ability to mitigate them and hence their propagation to the upper joints is also reduced.

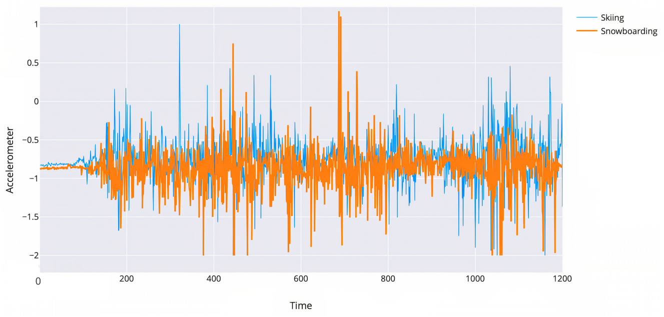

FIGURE 15. Vibrations recorded by knee accelerometer (raw data).

In terms of vibration analysis, Fig. 16 also shows a noticeable difference on all 3 axes, as snowboarding vibrations are undeniably higher.

The biggest difference is recorded on the Y axis, and is due to the movements produced by the snowboarder. Snowboarders make movements on the front/rear edges of the board to control the snowboard. These edges are made of a hard material, which fails to mould to the unevenness of the ground and transmits vibrations directly to the human kinetic chain (Table 9).

The body's ability to absorb shocks through the anatomical structures of the ankle and knee, respectively, diminishes the ascending forces reaching the hip. However, the recorded data (Fig. 17) shows much higher vibrations in snowboarders (Table 10).

As in the previous cases, the results obtained on the 3 axes (Fig. 18) show higher values in snowboarders. Compared to the recordings obtained on the other anatomical structures, the difference in vibrations between skiing and snowboarding is the smallest.

The lowest vibrations were recorded in the lumbosacral joint (Fig. 19). The differences at this level were significantly smaller than those recorded in other joints (Table 11). This is due to the ability of the kinetic chain to dampen shocks through anatomical structures inside the ankle and knee joints.

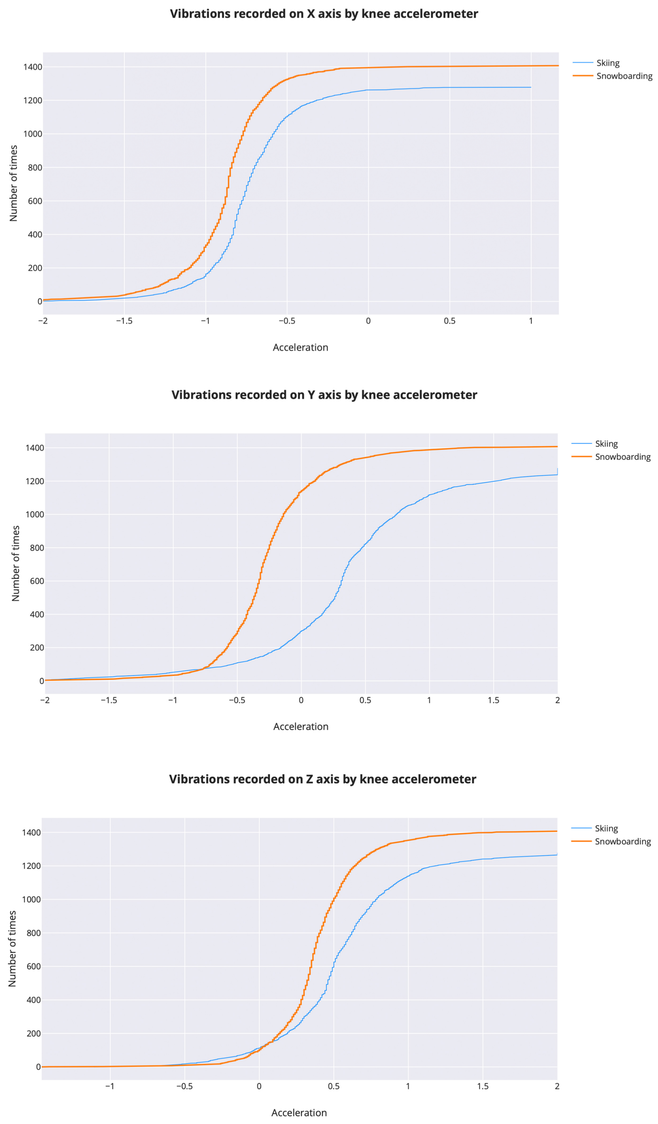

FIGURE 16. Vibrations recorded on x, y, z axis by the accelerometer on the knee.

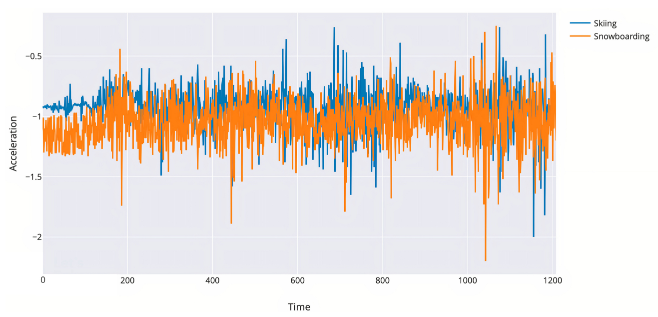

FIGURE 17. Vibrations recorded by hip accelerometer (raw data).

In addition to the data recorded at the hip, there is also data collected in the sacroiliac joint, which acts as a shock absorber, separating the descending forces of the body along the unnamed lines of the coxal bone, where the descending forces meet the ascending forces (ground response), diminishing and canceling each other.

TABLE 9. Vibration recorded by knee accelerometer.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	22	4	0	18	17	0
−1.5/1	249	16	2	128	27	1
−1/0.5	986	1202	905	1114	769	595
−0.5/0	50	791	70	155	187	92
0/0.5	5	169	825	15	519	483
0.5/1	1	39	308	0	290	511
1/1.5	2	12	39	0	80	100
1.5/2	0	2	5	0	38	22

TABLE 10. Vibration recorded by hip accelerometer.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	7	0	0	18	0	2
−1.5/1	308	0	0	738	8	192
−1/0.5	939	1221	570	496	1268	1075
−0.5/0	13	20	7	5	835	73
0/0.5	0	1194	561	0	56	1
0.5/1	0	52	654	0	0	0
1/1.5	0	0	1	0	1	0
1.5/2	0	0	0	0	0	0

TABLE 11. Vibration recorded in the lumbosacral area.

Ranges	Snowboard Axis x	Snowboard Axis y	Snowboard Axis z	Ski Axis x	Ski Axis y	Ski Axis z
−2/1.5	5	0	0	1	0	1
−1.5/1	686	0	0	78	0	15
−1/0.5	515	1267	1280	1192	1274	1263
−0.5/0	2	335	953	44	932	527
0/0.5	3	885	269	0	270	5
0.5/1	0	11	0	0	5	0
1/1.5	0	1	0	0	1	0
1.5/2	0	0	0	0	0	0

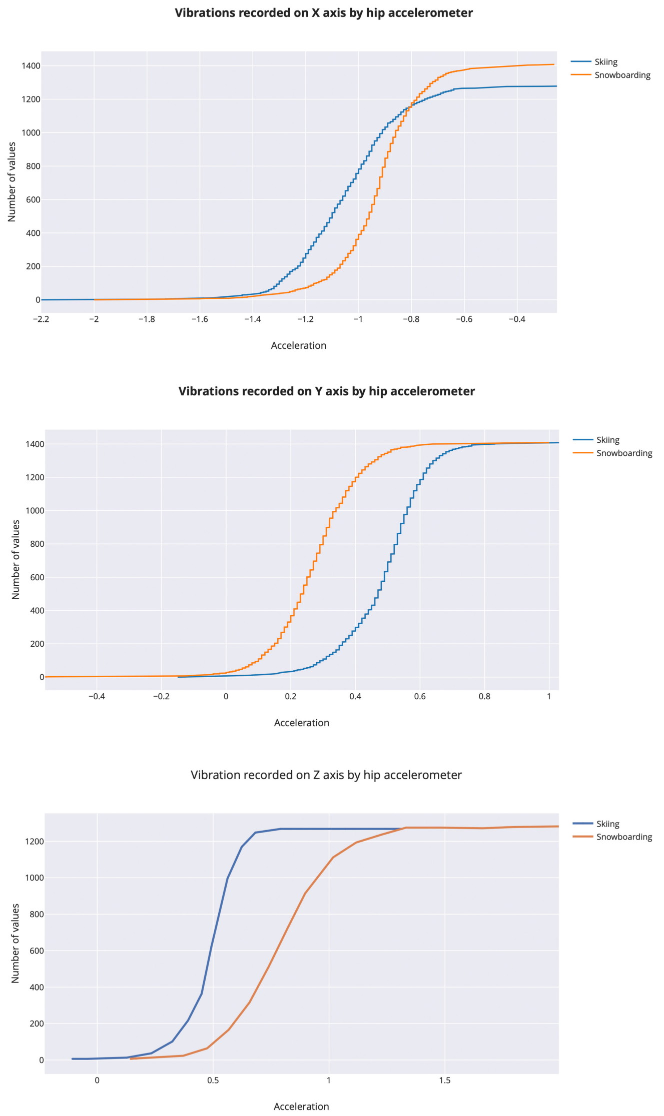

FIGURE 18. Vibrations recorded on x, y, z axis by the accelerometer on the hip.

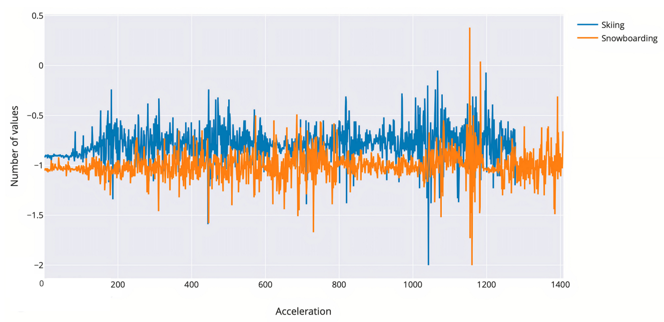

FIGURE 19. Vibrations recorded by accelerometer in the lumbosacral area (raw data).

Compared to the previous recordings in this situation (Fig. 20), lower vibration values are observed on all 3 axes, which proves the efficiency of the kinetic chain to absorb external shocks.

The recorded and processed data shows an obvious and clear difference of the vibrations experienced by the two categories of athletes. According to this data, in skiers, most vibrations are at the level of the ski, but their propagation along the human kinetic chain is much diminished, while in snowboarders, the vibrations recorded by the board are smaller, but their propagation along the specified kinetic chain is much more brutal.

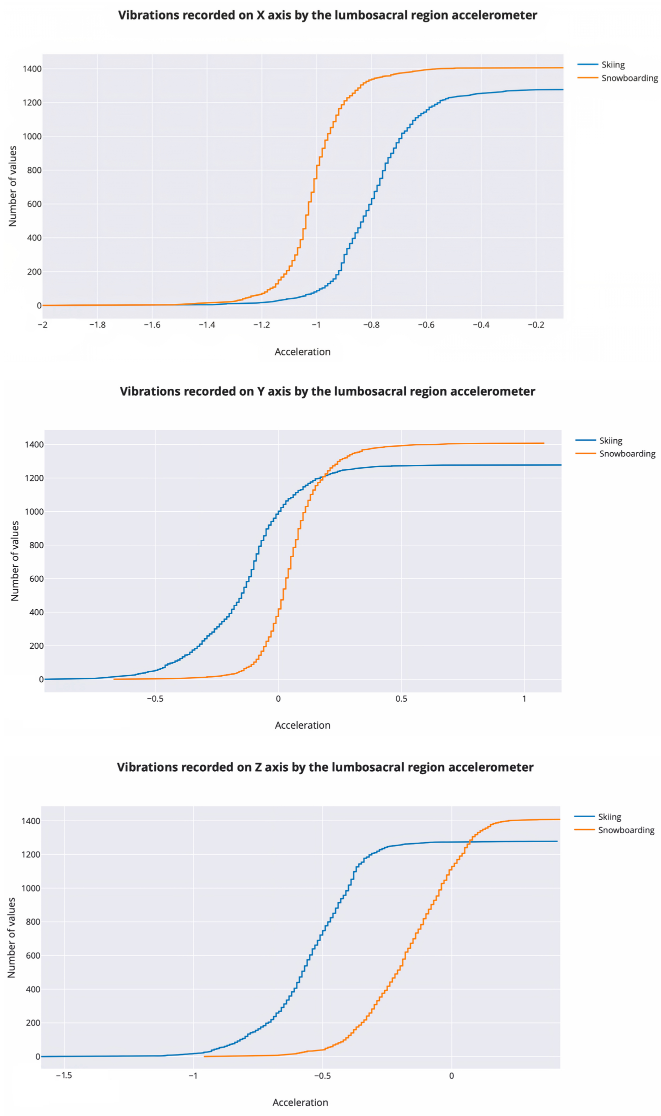

FIGURE 20. Vibrations recorded on x, y, z axis by the accelerometer in the lumbosacral area.

4. Discussion

The results of this study showed that the vibrations occurring in the ski (both tip and tail) are much higher than those occurring in the snowboard (nose and tail). As Gosselin P. mentioned in 2021, vibrations can affect the comfort, control and performance of skis, and excessive vibrations can lead to ski edge release, which will result in loss of control. Therefore, better damping can lead to lower and altered feedback received by the rider from the skis [10]. The increased vibrations on the ski suggest the repeated loss of contact between the ski and the ground, which leads to a higher risk of injury due to loss of control of the ski. Glenne B. claimed in 1999 that vibrations could cause snowboarders and skiers to lose control of the edge on snow, leading to injuries [11]. Supej M. also demonstrated in 2018 that skiing (competitive or recreational) is often associated with a very high rate of injuries [5]. Supej M. also tackled the connection between vibrations and the risk of injury in 2019, when he suggested that vibrations lead to loss of contact and lack of control, and that skiing has the potential to overload the skier and especially cause serious injuries [20]. Gosseling P. did another fantastic thing, namely a comparative study on the vibrations affecting skis on snow and on ice. According to his findings, the frequencies recorded on ice are higher than those occurring on snow, but the similarities between measurements made on snow and measurements made on ice suggest different results for different surface conditions (hardness, unevenness and irregular size). He also identified the same response patterns [10]. Despite the rather high level of vibrations detected on both skis and snowboards, the injury rate decreased in 2011 due to technological advances [1].

The resulting data show that the vibrations recorded on the equipment are inversely proportional to those recorded by the sensors placed on the body (ankle, knee, hip and sacrum). Thus, whereas the vibrations on the equipment were higher on skis than on snowboards, there were less vibrations transmitted to the kinetic chain in skiers than in snowboarders. Several authors have attempted to record these vibrations, as well as their transmission along the kinetic chain to the cervical level.

The study carried out by Supej M. (Table 12) focused on the transmissibility of vibration from skis to the lumbar spine and head. According to the table, short swings carry the highest risk of injury and low back pain due to increased vibration [20].

TABLE 12. Summary of peak power spectrum values measured at the ski boot for the steering phase, shocks and transient vibrations and the entire turn for various skiing styles: snow-plough swinging, basic swinging, short swinging and carved turns [20].

	Steering phase (g^2/Hz)	Shock and transient vibrations (g^2/Hz)	Entire run (g^2/Hz)
Snow-plough swinging	0.0046	0.0145	0.0037
Basic swinging	0.0800	0.1840	0.0400
Short swinging	0.2220	1.1800	0.1180
Carved turns	0.0850	0.1870	0.0780

The results obtained in the study compared to the results obtained by Supej M. in 2019 show that snowboarders have a higher risk of developing pain in the lumbar spine or of triggering it if the athletes already suffer from this condition. This was also confirmed by Gosselin M. in 2021, who concluded that the whole body's exposure to vibrations is directly related to low back pain, but some studies have shown that lower frequency vibrations can lead to overload of the lumbar segment and thus to injury [10].

Lack of control of the ski or snowboard can lead to severe accidents caused by falls, but these accidents are different in both situations. Moree T.P.'s study revealed that, compared to skiing, snowboarding involved more upper body injuries (49.1%), *i.e.*, in the upper limbs, while in the lower body 12% were ankle injuries and only 3% were talus fractures [3]. Pino E. reached the same conclusion, namely that about 50% of accidents in snowboarding are in the lower limbs (where ankle injuries are the most common) and they consist of fractures, contusions, ligament sprains, *etc.* [12]. Pino E. also noticed that most accidents in the lower limbs involve the front part (the one giving the direction) because the weight of the rider is not evenly distributed [12]. Weinstein S. showed in his study that upper body injuries are the most common in snowboarders, especially in the wrist, as they use their hands to protect themselves, and skiers mostly sustain injuries to the lower limbs, knee ligament injuries being the most common [14]. The use of wrist protection reduced the risk of injury to the wrist from 2% to 0.5% with a $p = 0.048$ [13]. Adams C. claimed in 2021 that the use of a wrist guard decreases the occurrence of impact injuries, but raises the issue of the type of material on which the rider must rely [21].

A study published in 2021 and conducted over a period of 9 years (2010–2019) on The National Electronic Injury Surveillance System (NEISS) identified a number of 361 skiers and snowboarders who suffered facial injuries, among others. Adults had a higher rate of facial fractures, the percentage being 30% compared to 13.9% in children, $p < 0.001$ [15].

Notable differences were also observed between the production mechanisms and the range of injuries between snowboard and ski riders, such as: predominant impact on the torsion face (as a major injury mechanism), the significant lack of thumb injuries, the increase in the number of ankle injuries, a higher percentage of injuries affecting the upper body [12].

These vibrations are thought to have beneficial effects on the human body, but they must be understood as such and must be recommended depending on age, condition, pathology, sex, *etc.* The vibrations spreading from the ski/snowboard along the human body are called whole body vibration (WBV).

Author Thompson W.R. wrote in an article published in 2014 that most studies in both animals and humans suggest that high and low frequency vibration therapies improve bone strength by increasing bone density and decreasing bone resorption. He also mentions that there is scientific evidence that vibrations are useful in treating sarcopenia, which affects the fragility of the skeleton and the risk of falling of aged individuals [22]. Kasturi G. also wrote in 2011 that WBV can stimulate the growth of bone and muscle mass, and it can also suppress adipogenesis, as shown in animal studies, but human studies suggest that the use of these techniques is promising for reducing fracture risk by increasing bone density [23]. Von Stengel S. exemplified in 2015 how WBV works in two ways: "increases bone strength" and "reduces the risk of falling" [24]. Most WBV studies have been performed on animals and have shown positive effects on increasing bone strength, increasing muscle mass, suppressing adipogenesis, stimulating recovery systems in cases of osteoporosis, sarcopenia and metabolic syndromes [22–29]. Xie L.Q mentions in a

2006 article that applying a high-frequency, short-term, low-magnitude mechanical stimulus can promote anabolic activity in the adult skeleton. He also found in a study on mice that extremely low mechanical loads were enough to reduce the activity of osteoclasts in the epiphyseal and metaphyseal region of the tibia by 30% [30].

Several authors reviewed literature trying to determine the effects of WBV on the skeletal system. Swolin-Eide D. reviewed the literature of the past decade and noted that the use of WBV in pediatric cases is an extraordinary, safe method of metabolic and non-pharmacological approach that leads to increased bone mass in pediatric cases [31]. Rehn B. also identified in a systematic review in 2008 that eight of the nine articles in the study showed positive effects of whole body vibration exercise on bone density in the lower limbs and pelvis in postmenopausal women [32]. A systematic review of literature was also made by Baloy R.K. in 2021, where the identified studies presented substantial evidence supporting the use of WBV in increasing bone mineral density [33].

Both studies on mice and reviews on the effects of WBV show beneficial effects on the bone system. In addition to these studies, studies performed on cyclists have shown beneficial effects. For example, Prioreschi A. is an author who, in 2012, tested the effect of WBV training on cyclists, because he noticed that they have better pelvis Body Mass Density (BMD) than sedentary people. Thus, he performed WBV training on cyclists to increase BMD in the hip and spine, and the final results were promising, as it improved all the studied parameters [34]. Prioreschi A. and McVeigh J.A. claimed, in 2011, that road cyclists have lower bone mass than ordinary people, thus having a higher risk of fracture in case of injury. He managed to increase their bone mass and density after ten weeks of WBV training [35].

In 2011, Von Stengel S. demonstrated that WBV training is an effective way to reduce the risk of osteoporosis by increasing BMD in the lumbar spine and lower limbs [36].

5. Conclusions

Both skiing and snowboarding are becoming increasingly popular worldwide. According to research findings, snowboarding is ideal for younger riders (aged 23 to 25 years on the average), while skiing is recommended for individuals aged 34 to 42 years on the average, with a predominance of the male gender in both sports. Also, the rate of severe injuries is higher in males than in females.

Most injuries in both skiers and snowboarders were caused by carelessness, not adapting their walking style to their level of experience, but most often due to loss of control of the equipment.

The vibrations recorded on the skis are higher than the vibrations recorded on the snowboard. This suggests that people who use skis run a higher risk of being thrown off them. This is due to the more frequent loss of contact with the ground, which increases the difficulty of maintaining control of the skis.

Although the vibrations recorded on skis are higher than those recorded on snowboards, their propagation was found to be inversely proportional. The vibrations transmitted along the kinetic chain (ankle, knee, hip and lumbosacral area) by the skis are smaller than those transmitted by the snowboards. This may be due to the shape, composition and materials of which the ski is made, which attenuate the vibrations transmitted along the kinetic chain.

Whole Body Vibration is beneficial because the external forces acting on the bone have positive effects on it, by increasing bone density and mass. Thus, young athletes who use the snowboard record higher WBV, which increases bone density and mass, while older people are advised to choose skiing instead of snowboarding because the WBV borne by the skeletal system is lower and hence more beneficial to the bone system in the demineralization process. A higher level of vibrations borne by the bone system in the process of bone demineralization may, over time, turn the benefits into negative effects materializing in small cracks and even fractures.

ABBREVIATIONS

BMD, bone mass density; GS, giant slaloms; MPU, Motion Processing Unit; NSAA, National Ski Areas Association; SD, Secure Digital; WBV, Whole body vibration; I2C, Inter-Integrated Circuit; ATMEL, Advanced Technology For Memory And Logic, ARM, Advanced Reduced Instruction Set Computer Machine; CPU, Central Processing Unit; SPI, Serial Peripheral Interface; SCK, Serial Clock; DI, Data In; DO, Data Out; CS, Chip Select; PWM, Pulse Widh Modulation; UART, Universal Asynchronous Receiver-Transmitter; USB, Universal Serial Bus; OTG, On The Go; DAC, Digital to Analog; TWI, Two-Wire Interface; JTAG, Joint Test Action Group; I/O, Input/Output; DC, Direct Current; SRAM, Static Random Access Memory; MEMS, Micro Electro Mechanical System; DMP, Digital Motion Processing; FIFO, First In First Out; SDA, Serial Data; SCL, Serial Clock; A0, Analog 0 pin, A1, Analog 1 pin; A2, Analog 2 pin; GND, Ground.

AVAILABILITY OF DATA AND MATERIALS

Availability of Data and Materials is not applicable in this study, but if needed, they can be made available in a reasonable time. Please contact the main author or the correspondent and we will make them available in accordance with the regulations.

AUTHOR CONTRIBUTIONS

AG and CA—initiated the study and recorded the data; MR and IC—reviewed the literature; MT and DA—processed and interpreted the recorded data; MI—supervised the whole process. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Declarationion of Helsinki, and the protocol was approved by the Ethics Committee of the Department of Medical Biosciences, "Grigore T. Popa" University of Medicine and Pharmacy. All subjects gave their informed consent for inclusion before they participated in the study.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Andrei Gheorghita, Catalin Ionite, Mariana Rotariu, Marius Turnea, Dragos Arotaritei, Mihai Ilea, *et al*. Study comparing the vibrations recorded by professional and non-professional male athletes in winter sports, skiing *vs.* snowboarding. Journal of Men's Health. 2023; 19(4): 11-25. doi: 10.22514/jomh.2023.032.