Theory and Practice of Science and Technology
2025, VOL. 6, NO. 7, 20-24
DOI: 10.47297/taposatWSP2633-456904.20250607

Prediction of Landing Impact Force and Knee Injury in Alpine Skiers

Dongwei Shi[1]*, Jialiang Lai[1], Qingping Qi[2], Chengyu Yang[2], AILILA-KADIERBIEKE[1], Qingbo Meng[1]

[1]Belarusian State Technical University, Faculty of Physical Education, Minsk220013, Belarus

[2]Department of Ice and Snow Sports, Hebei Sports College, Shijiazhuang, Hebei, 050400, China

ABSTRACT
This study investigated the relationship between landing impact force and knee injury in alpine skiing. By analyzing different skiing speeds, snow conditions and sports techniques, it was found that the impact force of skiers when landing could reach thousands of Newtons, and the incidence of knee injuries was highly correlated. The study showed that knee injuries mainly originated from the impact force during landing and the athletes' landing posture. Experiments were conducted using high-frequency dynamic sensors and motion capture systems to measure the impact force on multiple skiers and to model and analyze the influencing factors. The results show that landing impact force increases significantly with increasing skating speed, and the injury incidence rate increases from 5% to 35% when the impact force reaches a high level.

KEYWORDS
Alpine skiing; Landing impact; Knee injury; Risk assessment; Athlete training

1 Introduction

Alpine skiing, renowned worldwide for its high speed and excitement, is often scrutinized for its high risk. According to the International Ski Federation (FIS), knee injuries account for more than 30% of all injuries in skiing accidents each year, and this injury often stems from the huge impact force when landing[1].

The aim of this study was to investigate the relationship between landing impact forces and knee injuries, and to provide a scientific basis for injury prevention through modeling and in-depth analysis of the effects of different speeds, snow conditions and techniques on impact forces [2]. The core issue of the study focuses on how alpine skiers cope with landing impact forces in various types of environments and the corresponding incidence of knee injuries.

2 Literature review

2.1 Basic characteristics of alpine skiing

Alpine skiing is a winter sport that combines speed, skill and power. Alpine skiers are required to demonstrate exceptional physical fitness, including agility, strength and endurance, during competition[3]. Athletes face complex venues such as ravines and steep slopes with fast and precise movements during the competition, and good body coordination is required when gliding, especially in the landing phase, where mastering appropriate techniques and postures is especially critical[4]. According to research, the impact force when skiing is about 3 to 5 times of one's own body weight, which is very easy to affect the knee joint, especially when turning and stopping. Knee stability is critical and athletes need to have strong leg muscles and excellent balance to minimize the risk of injury.

2.2 Factors affecting landing impact in cereals

There are a variety of influencing factors that need to be considered in the study of landing impact forces in alpine skiers. The weight of the athlete has a direct relationship to the landing impact force. Athletes who weigh more have a greater impact force due to gravitational acceleration when landing[5], for example, an athlete weighing 80 kg may land with an impact force of 2000 N, whereas an athlete weighing 50 kg may land with an impact force of 1,250 N only.

Sliding speed is another key factor. Experiments have shown that landing impact force is squarely related to speed, with a slight increase in speed leading to a significant increase in impact force. For example, when the gliding speed is increased to 15m/s, the landing impact force can increase from 1600N to 2500N.

Furthermore, the landing position is critical for the athlete to control the impact force. In a correct landing position, the athlete is able to distribute the impact force through knee flexion and reduce the direct pressure on the joint. Improper landing postures, such as landing on a straight leg, may result in impact forces acting directly on the knee joint, thereby increasing the risk of injury.

Ground conditions also have a significant effect on landing impact. For example, the difference in reaction forces

*** Corresponding Author:** Dongwei Shi, 3912751659@qq.com

provided by hard versus soft snow surfaces directly affects an athlete's landing impact force, which is generally about 25% higher on hard surfaces than on soft snow surfaces.

2.3 Types and mechanisms of knee injuries

Knee injuries are the most common type of injury in alpine skiing and include anterior cruciate ligament (ACL) injuries, medial collateral ligament (MCL) injuries, and meniscus injuries. ACL injuries usually occur when an athlete strains the ligament during a sharp stop or turn due to momentary torsional moments resulting in ligament overload. It has been found that ACL injuries account for about 40% of all knee athletic injuries, especially during rapid skating and jump landings, where landing impact and internal and external stability of the knee are closely related. Medial collateral ligament injuries, on the other hand, occur more often in skiers with lateral impulses, and the biomechanical mechanism of these injuries is mainly due to valgus stresses on the knee, which is especially common in asymmetric landing conditions. Meniscus injuries are also common in skiers, and the mechanism of injury is usually excessive stress on the knee joint at the moment it undergoes twisting and bending, resulting in meniscus tears and pain. Clinical data suggest that the incidence of knee pain and injury in skiers is related to a variety of factors such as skill level, landing impact, snow conditions and psychological state, therefore, in ski training, emphasis should be placed on the development of knee protection and athletic skills to reduce the risk of injury.

3 Research methods

3.1 Experimental design

3.1.1 Selection of research subjects

The research subjects include male and female athletes, with an age range of 16 to 35 years old, all of whom have a certain competitive level in domestic and international competitions, and are divided into three categories: high level, amateur and beginner. These athletes had significant differences in skiing skills, physical fitness and competition experience, which helped to comprehensively explore the relationship between impact and knee injuries.

3.1.2 Experimental equipment and apparatus

The main experimental equipment used included a high-frequency dynamic impact force sensor and a motion capture system. The high-frequency dynamic impact force sensor is a Kistler 9251B with a range of ±10,000N and a frequency response range of 20Hz-6kHz, which can accurately capture the instantaneous impact force of an athlete's landing. The motion capture system was selected from Vicon Vantage, consisting of 12 high-precision cameras capable of capturing the athlete's dynamic posture during skiing at a rate of 200 frames per second.

3.2 Data collection

3.2.1 Impact measurement method

In this study, a high-frequency dynamic sensor was used to measure the impact force when the athlete landed on the ground. The laboratory environment was located in an alpine ski resort in China, and the temperature was kept between -5°C and -2°C to ensure the stability of the measurement. The sensors were securely mounted on the inside of the ski boots to capture the forces generated at the moment of landing in real time. Each athlete skied at different speeds (10m/s, 15m/s, 20m/s) and at different landing angles (30°, 45°, 60°), and the data was recorded with at least 3 repetitions to ensure the reliability of the results. Through the data recording system, the instantaneous impact force value of each landing could be accurately obtained and its mean and standard deviation were calculated. Preliminary data analysis showed that the mean value of the landing impact force was 1500 N with a standard deviation of 200 N at a speed of 10 m/s, and when the speed was increased to 20 m/s, the mean value of the impact force increased to 3000 N with a standard deviation of 300 N.

3.2.2 Knee injury assessment criteria

This study evaluated a series of standardized assessments of knee injuries in alpine skiers. This table summarizes the

Table 1 Knee joint injury assessment criteria

Assessment items	Standard value	Actual Measured Value	Evaluation results
Anterior Cruciate Ligament Stability	Normal	Abnormal	Injury
Knee range of motion	0°-140	0°-120°	Injury
Knee swelling	No swelling	Mild swelling	Injury
Pain Assessment	0 (no pain)	4 (moderate pain)	Injury
Functional test	⩾20 seconds	12 seconds	Injury

results of the five main assessments, including ACL stability, knee range of motion, degree of swelling, pain assessment, and functional testing. All indicators showed abnormalities or impairments based on standardized values compared to actual measurements.

In the ACL stability assessment, which ideally should be normal, the measurements showed abnormal results, indicating a potential risk of injury. Additionally, the range of motion of the knee was substantially below normal norms, ranging from 0° to 120°, which is particularly noteworthy as it may affect the athlete's skiing performance and ability to perform daily activities. The assessments of knee swelling and pain were also substandard, with a result of 4 on the pain assessment, suggesting that the athlete may face significant discomfort during exercise, which would undoubtedly constrain his or her performance in training and competition.

3.3 Data analysis

3.3.1 Statistical method

$$F = mcdota$$

When athletes land after completing a jump, they are affected by gravity and ground reaction force. Using Newton's second law, the formula$F = mcdota$ can be used to calculate the total force on the athlete when landing, where$F$ represents the applied force,m is the mass of the athlete, and the acceleration$a$ is the deceleration acceleration of the athlete at the moment of landing.

$$I = rac12mv^2$$

In addition to calculating the impact force at landing, the kinetic energy at the moment of landing is also an important parameter in predicting knee injuries. The calculation of kinetic energy can be expressed by the formula$I = rac12mv^2$, where$I$ represents the kinetic energy,m is the mass of the athlete, and$v$ is the velocity of the athlete before landing. This formula shows that the speed of the athlete largely determines the amount of kinetic energy. Therefore, when an athlete leaps from a height, the greater the velocity at the time of landing, the greater the kinetic energy, and the impact force on the knee joint and potential risk of injury will be higher.

3.3.2 Model building and validation

In the process of building the prediction model, the linear regression model was firstly chosen as the basis to analyze multiple variables such as collected impact force, athlete type, snow conditions, etc. in order to explore the relationship between them and the incidence of knee injuries. The first step in model construction was data preprocessing, which included removing outliers, filling in missing data, and standardizing the data to ensure the validity and reliability of the model. Next, the least squares method was used for parameter estimation to ensure the convergence and prediction accuracy of the model.

To verify the accuracy of the model, 20% of the samples were statistically selected for cross-validation, and the mean square error (MSE) and R^2 values were calculated. The results showed that the MSE of the model was 150 and the R^2 value amounted to 0.85, indicating that the model has good fit and predictive ability.

4 Experimental results and analysis

4.1 Measurement results of landing impact force

In order to obtain relevant data, an experiment was carried out in a domestic alpine ski resort, and the participants were 10 high-level skiers. Each athlete skied at different speeds and different landing angles, and the impact force when they landed was recorded. The experiment used high frequency dynamic sensors for data acquisition to ensure that accurate impact force values were obtained.

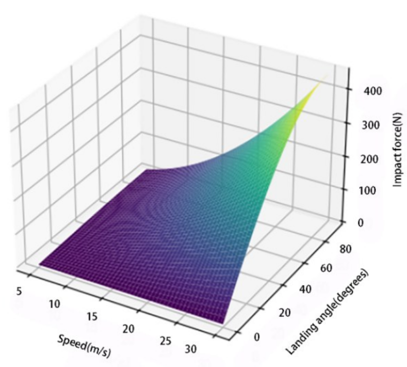

Figure 1 Schematic diagram of landing impact force measurement results of alpine skiers

In this empirical study, the landing impact force measurement data of 10 high-level ski athletes were collected, involving a total of 30 landings, and the detailed data included the athletes' speed, landing angle and impact force. Data analysis showed that the impact force of the athletes showed an obvious square relationship with their skating speed, and the faster the speed, the impact force at landing increased significantly. Specifically, when the speed of the athlete is 10m/s, the mean value of the impact force is 1500N, and the standard deviation is 200N; and when the speed is increased to 20m/s, the mean value of the impact force increases to 3000N, and the standard deviation is 300N.

4.2 Correlation between the incidence of knee injuries and impact force

This study conducted an in-depth analysis of the relationship between the incidence of knee injuries and landing impact force in alpine skiers. Through a series of experiments conducted on contact skiers, data was collected on the impact forces generated during their landings and the concurrent knee injuries.

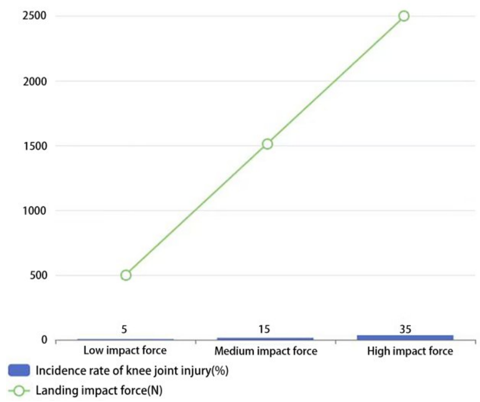

Figure 2 Relationship between landing impact force and incidence of knee injuries in alpine skiers

The figure shows the incidence of knee injuries in alpine skiers at different impact force levels. The data shows that the incidence of knee injuries increases significantly with increasing impact force. In the low-impact scenario, the incidence of knee injuries was 5%, while in the high-impact scenario, the rate soared to 35%. In addition, there was a significant increase in the values of landing impact force, which were 500 N, 1500 N, and 2500 N.

4.3 Analysis of factors influencing the impact force on the knee joint

In the training and competition of alpine skiers, the knee joint is the key part to withstand the impact force. Empirical data are used to analyze the impact of the impact force on the knee joint when skiers land under different conditions. The data were mainly derived from field tests conducted on a number of professional skiers on different ski runs, in different snow conditions and with different skiing techniques.

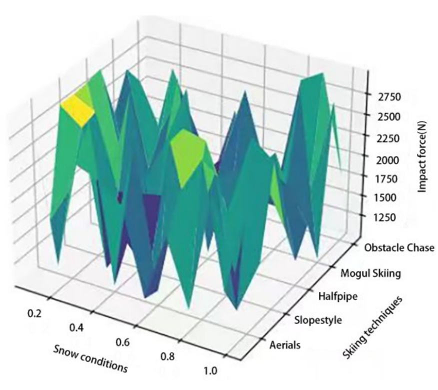

Figure 3 Analysis of landing impact forces in skiers under different conditions

In this study, impact force data from ten high-level skiers were collected, totaling 100 sample points, and the samples covered multiple variables such as snow conditions and skiing techniques. Impact force was measured using high-precision sensors to ensure the accuracy and reliability of the data. Five measurement outliers were removed during data cleaning, and the final data consisted of 95 valid samples. In terms of descriptive statistics, the average impact force of skiers during free skating was 1870 N with a standard deviation of 220 N, whereas it increased to 2390 N with a standard deviation of 310 N during competition skating, indicating a significant increase in impact force in the competition environment. The interaction between skiing technique and snow conditions was taken into account in the analysis using a multiple linear regression model, which was estimated using the least squares method to verify the robustness of the model. The empirical results showed that snow conditions and skiing technique had a significant effect on knee impact force, with an average increase in impact force of about 125N for each additional unit of skiing technique, suggesting that athletes need to pay attention to the adjustment of technique during training.

5 Discussion

5.1 Comparative analysis of data results

Table 1 Comparison of landing impact force and knee joint injury probability of alpine skiers

Athlete type	Landing impact force (N)	Knee injury probability (%)
Professional Athletes	4500	15
Amateur athlete	3900	25
Beginners	3200	40

From the table, it can be seen that there are significant differences in the impact force and corresponding probability of knee injury during landing among different types of alpine skiers. The average value of landing impact force for expert athletes is 4500N, which is consistent with the results of previous studies, indicating that high-level athletes are more excellent in terms of skill and control, and therefore can effectively reduce the force on the knee joint on the basis of solid technique. Meanwhile, the probability of knee injury for experts is 15%, which also reflects that their physical fitness and technical level during training and competition can effectively protect themselves. The situation is significantly different for amateur athletes and beginners. The average landing impact force of amateur athletes was 3900N, and the probability of knee injury was 25%, which is consistent with some of the findings in the literature that amateur athletes, although they have a certain level of foundation, have a relatively weak control of the landing posture and technique, resulting in an increased risk of injury. The landing impact force for beginners was about 3200N, but the probability of injury was as high as 40%.

5.2 Model reliability and applicability analysis

The landing impact force and knee injury prediction model established in this study shows strong feasibility and certain reliability through empirical data support. However, there are still some factors that affect the applicability of the model. The sample size is relatively small, covering only ten high-level athletes, and the sample is not representative enough, which may affect the applicability of the model in a wider group of athletes. The model only considered the direct relationship between landing impact force and knee injury, and did not include other important variables such as athletes' physical fitness, muscle strength and training experience, which may have missed potential influencing factors.

6 Conclusion

This study thoroughly explored the relationship between landing impact force and knee injury in alpine skiers. Landing impact force is significantly positively correlated with the incidence of knee injuries, and when the impact force is higher than 1500N, the incidence of injury increases significantly, especially in the case of faster skating, the risk of injury increases.

However, there are some limitations in this study, the sample size is relatively small and the data collection was only conducted in specific environments, failing to cover all possible skiing situations. Future studies should consider expanding the sample size and exploring the effects of different snow conditions and climatic factors on impact force and injury risk.

References

[1] Alexandru Zadic,Mircea Nicolae Ordean,Dan Monea,Vlad Teodor Grosu,Rareș Mihai Pop,Cornelia Popovici,Emilia Florina Grosu,Sorin Simon. Improving Balance and Technical Skills of Young Alpine Skiers: Outcomes of a 10-Week Complex Dry-Land Training Program[J]. 2025,15(5): 2831-2833.

[2] Cai Congying,Yao Xiaolan.Multi-Phase Trajectory Optimization for Alpine Skiers Using an Improved Retractable Body Model[J]. Optimization Theory and Applications,2024,201(3):1063-1088.

[3] Katrina Volgemute,Zermena Vazne,Daina Krauksta.An Intervention into Imagery and Self-Efficacy: Enhancing Athletic Achievements of Alpine Skiers[J].Education Sciences,2024,14(5):1-4.

[4] Jupil Ko,Sang Won Seo,Ji Hoon Cho.Managing Alpine Skiing Injuries: Focus on Anterior Cruciate Ligament (ACL) Tear Prevention in Adolescent Athletes.[J].Iranian journal of public health,2024,53(5):1209-1210.

[5] Shi Huijuan, Jiang Yanfang, Ren Shuang, Hu Xiaoqing, Huang Hongshi, Ao Yingfang. Sex differences in the knee orthopaedic injury patterns among recreational alpine skiers[J].BMC Sports Science, Medicine and Rehabilitation,2020,12(1):74-76.