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Recreational Alpine Skiing – An Introduction

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Abstract. Alpine skiing is the most common type of skiing performed on groomed and marked ski slopes. This review aims to help recreational skier improve their skiing ability by identifying conducive conditions for alpine skiing. Physically, strengthening balance, agility, and static leg strength via conditional training (ie. inline skating, roller blading, biking, running, sports stimulator) better prepares skiers for alpine skiing and reduces the chances of injury. Injury in knee and lower leg is the most common alpine skiing injury and the most severe are head injuries, highlighting the importance of wearing helmet, well-adjusted skis and suitable lane choice. Mentally, for beginners, increasing self-efficacy and decreasing fear and worry improves skiing performance. Whereas, for intermediate skiers, increasing worry or caution of the environment, increases performance. Technically, recreational skiers should attempt to perform symmetrical turns with greater range and speed of body movement. Lastly, the review presents recent technical and equipment advances in professional alpine skiing, reinforcing that the learning journey of alpine skiing is never ending. Hence, recreational skiers have a long and bright way to go, and researchers should try to expand their sample beyond adolescents and individuals in their early twenties, especially when investigating topics besides skiing injuries, to better generalize their impactful findings.

Keywords: alphine skiing, conditional training, turn symmetry

1. Introduction

Skiing, as physicists say, is the motion of a human sliding down an inclined plane on a porous medium (snow layer) [1]. Alpine skiing is the most common and well-known type of skiing and is performed on groomed and marked ski slopes. The colors of slopes are usually marked with green, blue, red, and black on the ski map representing increasing difficulty. Alpine skiing is a prevalent winter sport in Europe with 210 million alpine skiers a day, but its popularity is significantly lower in China, it's rapidly rising though [2]. In fact, Xinhua news in January of 2022 reported that China surpassed its national goal of having 300 million winter sports participants.

This review aims to help novice ski enthusiasts gain a better theoretical understanding of skiing, enabling them to learn more efficiently when on snow. This is especially helpful for ski enthusiasts living in urban cities that rarely snows and have to fly out to ski as this review allows them to better utilize the limited on-snow skiing time.

Specifically, by reviewing past studies, this paper listed valued motor ability in alpine skiing, proposed activities that selectively strength these abilities, and provided statistics on likelihood of injury. This help novice skier to better prepare for effective and safe learning. The author also presented mental attributes favorable to ski learning and identified physiological traits of expert skier during turns. This helps novice skiers better establish goals when learning. The paper ended with the technical and equipment advances in Olympic alpine skiing. This help ski enthusiasts who are already intermediate or expert amateurs understand their distance with professional skiers and know how to improve further.

2. Generic conducive factors to better skiing performance

2.1. Motor abilities

Professor Cigrovski studied 86 novice skiers in their twenties during a seven-day ski course and identified agility, static leg muscles strength, and balance as the three motor abilities impactful in alpine skiing learning process [3].

Agility, both side and frontal, is particularly important when performing short turns as it enables the skier to change direction swiftly. To improve agility, skiers could practice roller blading which shares similar motor movements with short turns. Additionally, roller blading can be practice anywhere under any temperature since it only needs a pair of roller blades and level ground. Static leg muscle strength is vital for long-term stable turn performances and ski manipulation. Doing squats, running, and rowing are but a few ways to improve static leg strength. It is also true the other way around: skiing is found to increase leg muscle power and one's aerobic capacity [4,5].

Balance refers to the ability to maintain the projection of center of body mass beyond the surface of support [6]. When one turns, one shifts the body's pressure mainly left or right, minorly forward or backward, while maintaining the central optimal position, requiring balance [7,8]. Skier also has to maintain this position regardless of ski terrain and speed. During the turn, skier's body mass is predominantly applied to the outer leg, requiring the skier to balance on one leg. Hence, balance is likely not only correlated, but causatively related to alpine skiing [9]. Both high and low achievers after a ten-day skiing course improved significantly compared to their initial balance assessment score. The change is more drastic in low achievers. In contrast, control group shows no significant change in balance performance after ten days of physical activity. In other words, good balance improves skiing performance and skiing improves balance. Also, as a beginner, do not ski when there is fog or snow or other weather conditions that obstructs line of sight which leads to worsened balance [10]. Not only does skiing improve balance, balance also improves skiing as it prevents injury, particularly for competitive skiers [11].

To improve balance, inline skating is an ideal choice. Inline skating and skiing share almost identical movements in ankles, knees, and hips as well as in leg muscles and back extensors [12]. Consequently, inline skating and skiing achieve speed and change direction or turn while maintaining an ideal balance position in exceedingly similar ways [13]. Indeed, there is no significant difference between alpine skier's movements during slalom turn and inline skater's movements when performing a similar radius turn on ice [14]. Inline skating has the advantage of being more accessible than skiing since a small ice rink is much more common than a snow resort. Rationale aside, inline skating helps boost skiing performance in skiing beginners is also supported by experimental data in children and adults [15,16].

Inline skating and roller blading are examples of conditional training for alpine skiing. These activities contribute to better performance in skiing without skiing on snow. Hence, conditional trainings help overcome the structural (only available on leveled mild slope with crushed snow) and temporal limitation (only available below 0 Celsius) of skiing [17]. Other examples include mountain biking, uphill and downhill running, football, sports gymnastics, and ski stimulator which is a cardio and resistance machine on land that allows individual to perform skiing behavior [17,18]. These exercises prepare one's body for skiing and lowers the chance of injury.

Speaking of injury, the perceived high risk of skiing has been a predominant concern for parents and many others. It is a valid but slightly overexaggerated concern with a promising trend. Since the 1970s, injury rates have dropped from around 5 to 8 per 1000 skier-days to about 2 to 3 per 1000 skier-days. Among which, children and adolescents are more at risk than adults[19].

Table 1. Alpine skiing Injury probability in youth population.

	Age	Number of injuries/1000 ski days	Experiment Duration (Source)
Children	<14	3.9	1 year[20]
	<13	3.32	3 years [21]
	0-6	2.81	1 year [22,23]
	7-12	4.75	
Adolescent	13-17	4.35	

Regarding type of injury, head and neck injuries are the most severe and fatal injuries for alpine skiers [24-27]. Hence, all skiers of any age should wear helmet to decrease incidence and severity of head injury [28-30]. Macnab et al. found absence of helmet use increased risk of head-injury by 1.8 times. Binding adjustment to equipment and educational awareness are also important, especially for adolescents. Beginners should set a low binding release value, allowing the ski to detach easily when one falls and choose boots with a low flex rating, supporting and stabilizing the skier's shin (Women's: 50-70 / Men's: 60-80). This reduces the likelihood of beginners drastically twisting their legs or ankles when skiing or after falling. The binding interface on the ski-boot-binding system has reduced probability of lower extremity injuries, particularly successful in reducing tibial shaft fractures, boot-top contusions, and ankle injuries, but not the knee [30-32].

Table 2. Prevalence of different types of injury in alpine youth skiers.

	Head & Spinal Injury (%)	Upper Extremities (%)	Lower Extremities (%)	Sample (Source)
Children (<13)	9.7	14.63	63.42	41 injured [21]
	Head: 14.1 Spinal: 3.6	15.4	64.1	204 injured [21]
	7.1	14.8	69.8	431 injured [33]
Adolescent (13-19)	6.5	14.6	72.1	
Youth (<18)	Female: 23.7	19.5	53.6	832 injured [34]
	Male: 35.8	21.3	39.1	
Youth's average	16.7	16.7	60.4	/

Table 3. Prevalence of different types of injury in alpine adult skiers.

Mean Age	Head (%)	Spine (%)	Upper Extremities (%)	Lower Extremities (%)	Sample (Source)
24	15	5	14.63	63.42	2911 [35]
30	12.4	2.9	27.4	57.9	2326 [36]
27.9	16	3	20	52	24340 [37]
32	8.1	Not reported	Not reported	54.7	2433 [38]
Adult's average	12.8	3.6	20.7	57	/

Consequently, the most common alpine skiing injuries across all age groups and varying skiing ability are injuries in the lower extremities [33,39,40]. Among which, knee ligament injury, namely the anterior cruciate ligament and medial collateral ligament, is the most prevalent, accounting for 10 to 33 % of all skier injuries [41-45]. Hence, do not blindly chase after adrenaline and select overly challenging ski lanes which would likely bring burden to your legs that are beyond their current bearing ability.

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2.2. Mental attitude

Besides being physically prepared for alpine skiing, being psychologically prepared is also important. Cigrovski surveyed 340 participants before and after a ten-day identical skiing program [46]. The questionnaire had 31 questions evaluating courage (bravery), 16 questions evaluating worry (being troubled about actual or potential problems), 10 questions evaluating self-efficacy (perceived capability of succeeding in a task), and 9 questions evaluating fear (being aware of danger). The study found that, regarding gender, increasing self-efficacy, increases performance for males, while decreasing fear, increases performance for females. Regarding ability, the study found that reducing fear and increasing worry and self-efficacy, increase performance for beginners, and decreasing worry, increases performance for skiers.

Overall, in novice skiers, fear is negatively correlated with skiing and self-efficacy is positively correlated with skiing. Indeed, self-efficacy is positively correlated with parallel turn performance in 126 students [47]. The correlation is also true vice versa as experienced skiers score significantly higher on average in self-efficacy, as well as determination (continue to try despite difficulties) and mastery (control) than novice skiers.

Other than emotions during skiing, attitude toward skiing is also an interesting factor. Males are found to have a more positive initial skiing attitude [48,49]. However, a study of 136 ski beginners in their twenties found that upon completion of the seven-day alpine ski course, both the women and men changed their attitude toward skiing in a positive direction and the statistical significance between genders was lost, indicating alpine skiing's attraction even to the ones that were initially indifferent. A more positive attitude toward physical activity in general is beneficial as it encourages a healthier lifestyle, which improves quality of life and decreases diseases occurrence [50].

3. Technical conducive factors to better skiing performance

Recreational skiers can improve their skiing ability by understanding the difference in ski motion between elite skiers and intermediate skiers as captured by biosensors. Usual alpine ski course begins with teaching snow plough, where skier's ski form two sides of a triangle. The greater the degree of the angle created by the two skis, the more significant the speed reduction. However, skiing with one's legs constantly in this position is unsustainable if the course gets longer and/or the slope gets steeper. The subsequent elements taught are parallel turns (PT). As the name suggests, the skier's skis are now in parallel and skier turns across the slope instead of traveling straight down the fall line in the case of snow plough. Fall line, a common terminology used in alpine skiing, refers to the most direct line of descent down a slope. This sequence of teaching snow plough then parallel turns is known as the combine approach. Other instructors choose to skip teaching snow plough and teach the parallel turns directly, also known as the direct approach. Males are found to learn better with a combined approach, while females' learning performances show no significant difference across the two approaches [49].

Either way, PT is the basic component of alpine skiing for all skiers. When making PTs, biosensors like the inertial measurement units (IMUs) on the ski measures how fast the ski's angle with the snow surface changes, or angular velocity, measured in degrees per second. IMUs on skier's waist, on the other hand, measures the degree or range of waist rotation. Plantar pressure distribution sensors or insoles inside the ski boats record pressure in each of the artificially divided sections of the feet, and the X-sense movement suit captures skier's skiing position. With the help of these biosensors, researchers compared performances between elite and intermediate skiers. The main difference is that elite skiers perform turns with more aggressive motion and with greater symmetry [51]. Specifically, recreational skiers should aim to achieve the following five goals.

3.1. Increase skis' angular velocity at the beginning and end of the turn

For each PT, expert skiers' angular velocity is large at the beginning of the turn, constant in the middle, and large in the reversed direction at the end of the turn as they initiate into the next turn. Whereas, intermediate skiers' angular velocity is relatively small at the beginning and end and varies more in the middle [51]. Hence, recreational skiers should try to increase the tilt angle of the ski faster at the beginning and end of each parallel turn.

This would minimalize skidding, in turn decreasing friction with the ground and increasing the ground reaction force (GRF). GRF refers to the amount of force bared by the skier and his/her skis [52]. A larger GRF is crucial to better turning performance in alpine skiing as it allows one to shorten the duration of one's turn and increase one's general skiing velocity. Indeed, the GRF reaches 3000 N, 3.5 times the skier's average body weight for professional skiers participating in Olympic events. Larger GRF from minimal skidding and maximal carving would allow skiers to transition from PT to the short turns (ST) [53]. STs are chopped unfinished parallel turns performed in a narrower corridor with greater difficulty than PT. Mastering the short turn would allow one to ski in more diverse terrains.

3.2. Increase body's range of movement

One central movement present in various turning elements in alpine skiing is waist rotation which range is found to be significantly larger in expert skiers than that found in intermediate skiers [51]. Range of movement could also refer to knee flexion. When performing STs, skiers are found to be in a lower position with more flexed knees than when performing parallel turns [53]. Hence, recreational skiers should aim to move one's waist and flex ones' knee in a wider range while maintaining balance.

3.3. Separate movement in upper and lower body

Throughout each turn, skier's upper body should predominantly face the fall line or down the snow slope, while skier's lower body turns with the direction of the skis [54]. This would enable skiers to perform shorter turns and initiate the next turn faster without having to turn one's body from the direction of the turn to the opposite direction of the turn. In other words, the lower body directly influences turn performance, while the upper body contributes to turn execution by adding stability and balance during the turn [55]. This separation is the premise to learning short turns and carving later. In fact, when elite skiers carve by turning the edge of their skis with their legs and maintaining stability of their trunks, the novel technique is known as the "cross-under," particularly notable during the giant slalom Olympic event [56].

3.4. Shift outside foot pressure, or plantar pressure, from toe to heel

Pressure distribution in the two feet of expert skiers is around 75% in the outside foot and 25% in the inside foot [53,57]. This shows that the outside foot is primarily responsible for the turning of the ski due to shifted skier's center of mass, while the inside foot helps with skier's stability. The pressure in the inside foot increases as turn duration shortens. The pressure in both feet increases when the slope is steeper, when the skier performs harder technique, and when the skier is steering instead of initiating or completing the turn [57,58]. In both feet, highest force is found over the medial part of the feet [59,60].

Specifically with the outside foot, pressure is majorly in the toes or forefoot region at the beginning of the turn and shifts to the heel during the steering phase of the turn [51]. This tendency to shift pressure from toe to heel is found in expert skiers, while intermediate skiers show either very limited shifting or random shifting of pressure [57]. Hence, recreational skiers should try to shift their center of mass from the toe to the heel when performing each turn.

3.5. Symmetrical and stable movement when turning left and right

The most notable difference between elite and intermediate skiers is elite skiers perform more stable and symmetrical turns, consistent in the ski, waist, knee, and feet [51]. Indeed, symmetry is a major metric differentiating skilled and recreational skiers (Canadian & American Ski instructor website). There is no significant laterality or dysbalanced strength found in male and female Austria World Cup skiers, and professional skier's muscle strength symmetry reflects their movement symmetry.

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Not only is limb symmetry largely beneficial to skiing performance, it also decreases the risk of injury. Indeed, limb dominance with stronger muscle strength in one leg increases injury risk for young skiers. Skiers of any level should aim to increase symmetry and stability in their skiing performance since complete symmetry is impossible, even for professional athletes [52]. More specifically, focus on keeping the shank angle and hip flexion of the outside leg same for each turn [52]. This attempted replication would increase chance of symmetry and maintenance of postural stability, leading to better balance. Improved balance is necessary in carving, a more advanced turning technique that steers the skis out of the fall line faster than skidding, enabling the transition from PT to ST.

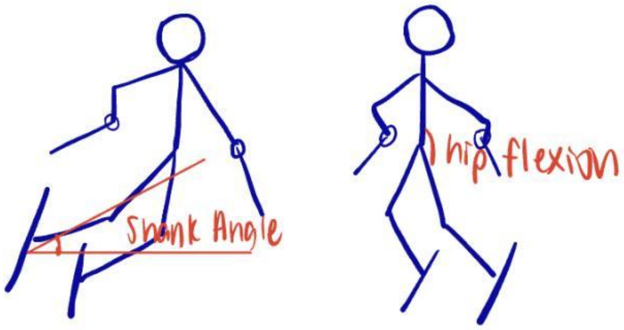

Figure 1. Labeled diagram of mentioned angle when skiing.

4. Professional alpine skiing

When recreational skiers felt they have mastered the above goals, they often wonder what their distance with a professional athlete is. The Olympics provides five basic alpine skiing events to all athletes. The goal for each event is to finish with minimal time. The first event is downhill, where skier skis in a straight line with maximal speed around 130 km/h down the slope with a vertical drop of 800-1100m (for men) and 450-800m (for women). The second event is Slalom when skiers ski past gates or plastic poles with width from 4 - 6 meters. The gates set a relatively clear turn path, and the competitor skis twice, the one with the minimum combined time wins. The vertical descent in slalom is 180m to 220m for men and 140m to 180m for women. The third event is the giant Slalom with a larger vertical descent (250-450m for men and 250-400m for women) and wider gates (4-8 m). The fourth event is Super G with a downhill slope and ski boundaries marked by sparse gates. The vertical drop for Super G is 400-650m (for men) and 400-600m (for women). The last event is combined where the skiers make one downhill run and one slalom run. Again, the competitor with the shortest total time of the two runs wins.

Bearing the goal of minimalized time and maximized speed in mind, athletes reduce aerodynamic drag and increase velocity by minimizing their frontal area exposure. They also minimalize short radius turns which uses more mechanical energy compared to longer turns. Additionally, to maintain speed, skiers tend to initiate their turns earlier, before reaching the gate, which enables faster entry to the next turn, also known as the singe motion" technique [61,62]. Skiers also minimalize skidding and maximize carving. During carving, steering takes place along the ski edges without the lateral skid component. Consequently, all forces are directed to the forward instead of forward and sideward motion of the ski, achieving higher velocity under the same force. In fact, velocity is in a positive feedback loop with GRF, so GRF is highest in downhill, the event with the highest velocity [53]. Lastly, though path choice is a major contributing factor, skiers usually choose higher velocity over a shorter trajectory [63].

Other than the skier's skill, equipment worn by skiers also contributes toward this central goal. For example, wearing extremely tight clothes or compression garments (CG) is shown to significantly reduce air drag [64]. This is significant because about 20% of the skier's total mechanical energy loss was due to air drag. Additionally, CG can reduce muscle vibrations at high impact and help athletes control the center of mass [64]. This is vital as it leads to better maintained balance when performing skilled turns under high velocity and on challenging terrain. Another example is lifter plates placed under the binding and connected to the boots which allows more angling in the skis [65]. Boot-fitting uses the elasticity of boots to better fit the boot's shape with skier's feet, allowing better transfer of skier's action to the skis [64,67]. Boots have also developed thinner, more anatomical shells. Skis usually have a sandwich construction with wooden core and metal edges, which enables carving turns even on low friction surface like ice or hard snow. The international skiing federation (FIS) have also recently developed side-cut radii and waist width regulation of skis to prevent injury (FIS-ski.com). Additionally wearable technologies including the biosensors listed before and the global navigation satellite systems (GNSS), inertial motion capture systems, accelerometers and sensors that measure GRF. These technologies are often used in training to help coaches and skier better evaluate and improve their skiing performance.

Despite the advanced equipment and mastered skill of professional athletes, there still are significant limitation, physiologically. One example is skeletal muscle fatigue and accumulation of oxidative stress. Indeed, alpine skiing usually includes 90 to 120 seconds of high-intensity exercise where the skier's muscle is in constant contractions with all fiber types activated. During this period, there is restricted blood flow, meaning limited oxygen supply to the working muscles and build-up of oxidative toxins. Continued exercise beyond this duration lead to temporary loss of motor control, forcing elite skiers to rest. Indeed, the intensity of alpine skiing cause skier to increase their aerobic energy metabolism and oxygen uptake to 75% – 100% of maximal aerobic power during the giant slalom . Additionally, aerobic respiration only provides for less than half of the total energy, the rest comes from anerobic respiration, resulting in muscle glycogen depletion and lactate accumulation [68].

5. Conclusion

In conclusion, this review summarized conditions conducive to alpine skiing. Physically, strengthening balance, agility, and static leg strength via conditional trainings (ie. inline skating, roller blading, biking, running, sport stimulator) better prepares you for alpine skiing and reduces chances of injury. Injury in knee and lower leg is the most common and head injuries the most severe, highlighting the importance of wearing helmet, well-adjusted skis and appropriate lane choice. Mentally, increasing self-efficacy or confidence and decreasing fear and worry improves skiing performance for beginners, and increasing worry or caution of the environment, increases performance for intermediate skiers. Technically, recreational skiers should attempt to perform symmetrical turns with greater range and speed of body movement. Ending on the recent technical and equipment advances in the alpine skiing winter Olympics, reinforces that the learning journey of alpine skiing is never ending.

Despite, these promising results, there are still significant limitations. Notably, most investigative studies of alpine skiing are focused on individuals either in their twenties or adolescents, while adults over twenty-five or the elderlies are rarely included. This limitation is found across various fields (kinetics, kinematics, physiological, and psychological) and is especially apparent for investigative studies conducted on experimental and control groups, causing the generalization of insightful findings to be very limited. In addition, majority of the studies are focused on professional alpine skiing, more should be conducted on recreational, novice or intermediate skiers.

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I wrote this paper entirely on my own by reading all the studies I could find on alpine skiing, driven by my own interest as a recreational alpine skier.

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