Recorded Speed on Alpine Slopes: How to Interpret Skier's Perception of Their Speed?

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Abstract The speed before the accident is a necessary data to understand the injury mechanisms and to evaluate means of protection. In order to interpret the reported speed of a skier in an accident survey, this study aims to identify the governing factors of skiing speed and to propose ranges of speed combining the identified factors and the skiers' perception of their speed. Travelling speed of 1399 skiers and snowboarders was measured with a radar speed gun. Gender, sport, helmet use, skill level, difficulty, and preparation of the slope were recorded. 170 recorded skiers were interviewed about their age, their skill level, their perceived speed ("slow to medium," "high," or "too high"), and their estimated speed (km/h). Linear regression models were used to evaluate the effect of each factor on skiing speed. The mean recorded speed was 43.4 (±15.2) km/h. It was 37.5 (±9.8) km/h when the perceived speed was "low to medium" and 49.0 (±14.6) km/h when the perceived speed was "high." The factors best explaining skiing speed were the skill level ($\eta^2 = 0.26$) and the slope difficulty ($\eta^2 = 0.19$). Gender, age, sport, and slope preparation were found to have a small but significant effect ($\eta^2 < 0.1$; $p < 0.05$). Those factors also influenced the speed perception: for the same perceived speed, "less skilled" skiers and skiers on easy slope tended to go on average 6 km/h and 8 km/h slower than the "more skilled" and those on medium slope, respectively. Finally, skiers estimated their measured speed fairly (*r*: 0.53). They tended to overestimate the speed when they went slower than 35 km/h but underestimated it at higher speed. Ranges of speed were obtained regarding perceived speed, skill level, and difficulty of the slope. This should be considered when interpreting skiers' evaluation of their speed in accidents reports.

Keywords Ski • Snowboard • Speed • Speed perception

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1 Introduction

Each year approximately 150,000 ski and snowboard-related injuries are treated in a French medical centers [1]. One of the main factors affecting the kinematic of the accident and the injury severity is the speed of the participant prior to the accident [2, 3]. Indeed, the energy involved in the accident and the kinematic of the fall are related to the speed of the participant before the accident. In order to investigate these injury mechanisms, it is necessary to develop a robust understanding of skiing speed just before the crash. That understanding is also useful to evaluate means of protection such as ski helmets and protection mats whose effectiveness depends on the impact speed and the energy involved in the accident. In epidemiological study, the only available data on skiing speed before the accident, is the victims' perception of their own speed [1, 3]. To access skiing speed before the crash, a translation between the perceived speed and the measured speed is therefore necessary.

In order to propose such a translation, understanding the factors influencing skiing speed and its perception is crucial. Shealy et al. [4] and later Rueld et al. [5] showed that sport, gender, skill level, age, and risk-taking behavior might affect both skiing speed and the ability of the skiers to estimate their speed. Recently, Brunner et al. [6] also revealed that the skier's perception of their speed might also depend on those factors. However, those studies were conducted on the same kind of slopes (medium difficulty); therefore, the difficulty and preparation of ski slope were never considered as factors influencing skiing speed.

2 Objective

This study investigates the measured speed on alpines slope and its perception. The first objective is to identify the factors having the greatest effect on skiing speed. The second objective is to obtain the range of speed regarding those identified factors and skier's perception of their speed.

3 Materials/Methods

3.1 First Investigation: Evaluation of the Factors Not Related to the Perception of the User

The objective of this first investigation is to identify the factors best explaining the skiing speed. Using a discreet radar speed gun with an accuracy of ±2 km/h (Pocket radar, Pocket Radar, Inc., Santa Rosa, California), speed measurements were performed in three different French ski resorts [Grand Bornand (n = 158), La Clusaz (n = 747), and Courchevelle (n = 494)], during five full days of the 2013/2014

French winter holidays. A trained observer standing in the skier's way measured the skiing speed during their approach. The radar we used only measured subjects moving in line with the radar beam which was not always the case of the skier because of the turn performed. This might lead to an underestimation of the actual speed. In order to limit that underestimation, the speed of the skier was measured during an observation period of three or four turns, and only the maximum speed was recorded. The observer also recorded helmet use and estimated the gender, and the skill level of the skier. The evaluation of the skill level was performed by the same trained observer according to criteria defined by Sulheim et al. [7]. The speed of 1399 skiers and snowboarders was recorded on wide slopes of different difficulties rated according to the European classification of ski slopes: green (very easy), *blue* (easy), *red* (medium), and *black* (hard) and of different preparations (well-groomed or bumpy). The "bumpy" slopes were slopes left ungroomed during several days, where some small moguls had appeared. The bumpy slopes selected in this study were *blue* (84 recorded users) and *black* (62 recorded users). Those slopes were busy because it was the middle of the peak season and the weather was sunny. As much as possible, the speed measurement was performed on consecutive skiers and snowboarders.

3.2 Second Investigation: Combining the Identified Factors with Perception of the User

Based on the identification of the most important factors influencing skiing speed, a second investigation was conducted. The aim was to combine those identified factors with the users' perception of their speed. 200 randomly selected measured skiers and snowboarders were stopped and interviewed by a research assistant at the bottom of the ski slope. The assistant recorded the gender, age, helmet use, sport, as well as the skiers' self-estimation of their skill level (beginner, intermediate, or advanced). Users were then showed the observation area where they had been measured and were asked to estimate their perceived speed (low to medium, high, or too high) and their measured speed (km/h). The measured speed was transmitted to the research assistant by walkie-talkie and was also recorded. This method is very similar to the one described on medium slopes by Shealy et al. [4] and Rueld et al. [5]. In our second investigation, the slopes selected were large red (medium) and *blue* (easy) because the first investigation had showed that red and *blue* slopes differ in typologies of skill level and speed of the participants and because those are the slopes where most accident occur [8].

Due to the small number of interviewed snowboarders ($n = 24$), only skiers were included in the statistical analysis. In the same way, the speed categories "high" and "too high" were grouped as well as the skill level "beginner" and "intermediate" because only 10 skiers estimated their speed as "too high" and only three declared being a beginner.

3.3 Data Analysis

In order to evaluate the effect of each factor (i.e., whether the mean speed is significantly different between groups and by how much), we used the factorial ANOVA of a Generalized Linear Model (GLM). This choice was made because the GLM enables us to test the effect of each factor regardless of the other factors tested. Two-tailed p-values <0.05 were considered for statistical significance. All variables with a significant effect (significant difference of mean speed between the categories) were used in the final model. The variances explained by the models were assessed with the coefficient of determination (R^2). Effect size was evaluated using partial η^2 measuring the variance explained by each factor with 0.01, 0.1, and 0.25 for small, medium, and large effects. We analyzed the measured speed according to the perceived speed and the other factors best explaining skiing speed. Additionally, we investigated the measured speed regarding the self-estimated speed (in km/h).

4 Results

4.1 First Investigation: Evaluation of the Factors Not Related to User's Perception

1246 skiers and 153 snowboarders were measured in 3 different ski resorts, and on 10 ski slopes of different difficulties (from very easy to very hard) and different preparation (groomed or bumby). The mean skiing speed recorded was 43.4 (±15.2) km/h. The mean recorded speeds regarding slope difficulty, slope preparation, skill level, sport, gender, and helmet use are presented in Table 1. The results of the linear regression model are presented in Table 1. Table 2 summarizes the effects of each factor on the measured speed. Skill level ($\eta^2 = 0.26$; $P < 0.001$) and slope difficulty ($\eta^2 = 0.19$; $P < 0.001$) were the factors best explaining the variance of the skiing speed. Gender ($\eta^2 = 0.06$; $P < 0.001$), sport ($\eta^2 = 0.03$; $P < 0.001$), and slope preparation ($\eta^2 = 0.01$; $P < 0.001$) had a small but significant effect on skiing speed (Table 2). However, the effect of the use of helmet was not significant and was not included in the final model.

The linear regression model, presented on Table 1, explained 47% of speed variance. According to this model, intermediate skiers tended to go 11.7 km/h faster than beginner and 11.5 km/h slower than advanced skier. Speed of males was higher than the speed of females, by a mean of 3.1 km/h. Skiers were 2.8 km/h faster than snowboarders. Finally, the slope difficulty and preparation had a great influence on skiing speed. Skiers went faster on red and green slopes than on blue slopes by a mean of 7.2 km/h and 5 km/h, respectively. However, they travelled 9.0 km/h slower on black slope than on blue slope. Users went on average 1.7 km/h faster on a well-groomed ski slope than on a bumpy slope.

Table 1 Speed characteristics (on the left) and results of the multiple linear regression analysis of skiing speed considering skill level, gender, sport, helmet use, slope difficulty, and slope preparation (on the right)

		Measured speed (km/h)	Multiple linear regression analysis		
		Mean (SD), range	*B* (SD)	*T*	*p*
All groups (n = 1399)		43.4 (±15.2), 13–98			
Regression constant			31.9 (±0.8)	42.4	<0.001
Skill level	Advanced (n = 729)	50.0 (±14.8), 21–98	11.54 (±0.6)	20.5	<0.001
	Intermediate (n = 603)	37.7 (±11.5), 15–80	Ref*	–	–
	Beginner (n = 67)	23.3 (±8.5), 13–61	−11.7 (±0.9)	−12.4	<0.001
Slope level	Green (n = 204)	48.4 (±15.4), 19–90	5.0 (±0.7)	7.5	<0.001
	Blue (n = 499)	37.8 (±12.3), 13–89	Ref*	–	–
	Red (n = 537)	49.9 (±15.2), 15–98	7.2 (±0.5)	14.4	<0.001
	Black (n = 159)	32.7 (±9.2), 15–61	−9.0 (±0.8)	−11.8	<0.001
Gender	Female (n = 435)	37.0 (±12.2), 13–74	−3.1 (±0.3)	−9.4	<0.001
	Male (n = 964)	46.3 (±15.5), 13–98	Ref*	–	–
Sport	Snowboard (n = 153)	38.3 (±13.3), 15–80	−2.8 (±0.8)	−5.9	<0.001
	Ski (n = 1246)	44.0 (±15.3), 13–98	Ref*	–	–
Grooming	Bumpy (n = 146)	33.7 (±10.4), 16–89	−1.71 (±0.5)	−3.2	0.001
	Groomed (n = 1253)	44.5 (±15.3), 13–98	Ref*	–	–
Helmet	Yes (n = 756)	44.5 (±15.7), 13–93	**	–	0.19
	No (n = 643)	42.1 (±14.5), 14–98	Ref*	–	–

B unstandardized coefficient, *SD* Standard deviation
*The model's reference was: an unhelmeted male skier with intermediate skiing ability travelling on a well-groomed blue slope
**The effect of helmet use was not significant and it was not considered in the final model

Table 2 Results of the two linear regression models: the first model refers to the first investigation; it evaluates the effect of helmet use, slope difficulty, slope preparation, type of sport, gender, and skill level on the measured speed. The second model refers to the second investigation; it evaluates the effect of slope difficulty, gender, age, helmet use, reported skill level, and perceived speed on the measured speed

Factors	df	*F*	*p*	η^2	R^2
Model 1: Observer perception (N = 1399)					0.47
Evaluated skill level	2	241.90	<0.001	0.258	
Slope difficulty	3	110.21	<0.001	0.192	
Gender	1	88.22	<0.001	0.060	
Sport	1	34.97	<0.001	0.025	
Slope preparation (grooming)	1	10.34	0.001	0.007	
Helmet	1	1.71	0.191	0.001	
Model 2: User's perception (N = 176)					0.39
Reported skill level	2	24.43	<0.001	0.127	
Perceived speed	1	14.68	<0.001	0.080	
Slope difficulty	1	13.24	<0.001	0.073	
Age	3	3.32	0.021	0.056	
Gender	1	5.34	0.022	0.031	
Helmet	1	12.98	0.023	0.030	

Df degree of freedom, *F F*-statistics, η^2 effect size (amount of speed variance explained by the factor), R^2 coefficient of determination (amount of speed variance explained by the model)

4.2 *Second Investigation: Interpretation of the Skiers' Estimation of Their Own Speed*

176 skiers were stopped and interviewed. Their mean speed was 43.2 km/h, which was slightly lower than the mean speed of the skiers in the previous experiment (44.0 km/h). Most of the "less skilled" skiers perceived their speed as "low to medium"(64%), while among the "more skilled" group (n = 110), 48% declared travelling at "high" speed and 9% at a "too high" speed. The mean recorded speeds, regarding the reported skill level, skier's perceived speed, age, gender, helmet use, and slope difficulty, are presented in Table 3.

The results of the linear regression model are presented in Table 3. Table 2 summarizes the effects of each factor on the measured speed. The qualitative factor best explaining the measured speed was the self-reported skill level ($\eta^2 = 0.13$; $P < 0.001$) followed by the perceived speed ($\eta^2 = 0.08$; $P < 0.001$) and the slope difficulty ($\eta^2 = 0.07$; $P < 0.001$). Age, gender, and helmet use had also a small but significant effect on user's speed ($\eta^2 < 0.06$; $P = 0.02$). The effect of age was also significant ($\eta^2 = 0.06$; $P = 0.02$). Participants older than 40 years old were 4.2 (±1.4) km/h slower than the younger skier. Figure 1 presents the repartition of measured skiing speed regarding the qualitative perception of the speed and the two factors best

Table 3 Second investigation: Speed characteristics (on the left) and result of the multiple linear regression analysis (GLM) of skiing speed considering perceived speed, perceived skill level, slope difficulty, gender, age, and helmet use (on the right)

		Measured speed (km/h)	Multiple linear regression analysis		
		Mean (SD), range	*B* (SD)	*t*	*p*
All groups (n = 176)		43.2 (±13.7), 18–79			
Regression constant			42.3 (±1.0)	44.1	31.9 (±0.8)
Perceived speed	Low to medium (n = 89)	37.5 (±9.8), 18–63	Ref*	–	–
	High (n = 87)	49.0 (±14.6), 20–79	3.3 (±0.9)	3.83	<0.001
Reported skill level	Less skilled (n = 66)	37.1 (±12.2), 18–66	Ref*	–	–
	More skilled (n = 110)	46.8 (±13.2), 22–79	4.3 (±0.9)	4.94	<0.001
Slope difficulty	Blue–easy (n = 113)	40.1 (±13.2), 18–79	−3.1 (±0.9)	−3.64	<0.001
	Red–medium (n = 63)	48.7 (±12.8), 23–76	Ref*	–	–
Gender	Female (n = 50)	37.6 (±9.9), 18–69	−2.1 (±0.9)	−2.31	0.02
	Male (n = 126)	45.4 (±14.3), 20–79	Ref*	–	–
Helmet	No (n = 84)	39.4 (±11.7), 20–74	−2.1 (±0.9)	-2.29	0.02
	Yes (n = 92)	46.6 (±14.4), 18–79	Ref*	–	–
Age	<20 (n = 42)	48.4 (±14.5), 20–79	**	–	0.052
	20–30 (n = 32)	45.1 (±15.1), 18–76	**	–	0.25
	30–40 (n = 52)	43.5 (±12.3), 20–72	Ref*	–	–
	>40 (n = 50)	37.2 (±11.2), 20–72	−4.2 (±1.4)	−2.94	0.004

B unstandardized coefficient, *SD* standard deviation
*The model's reference was: an helmeted male skier age between 30 and 40 years declaring a low-to-medium speed and a beginner or intermediate skill level and travelling on well-groomed red slope
**The difference with the reference was not significative

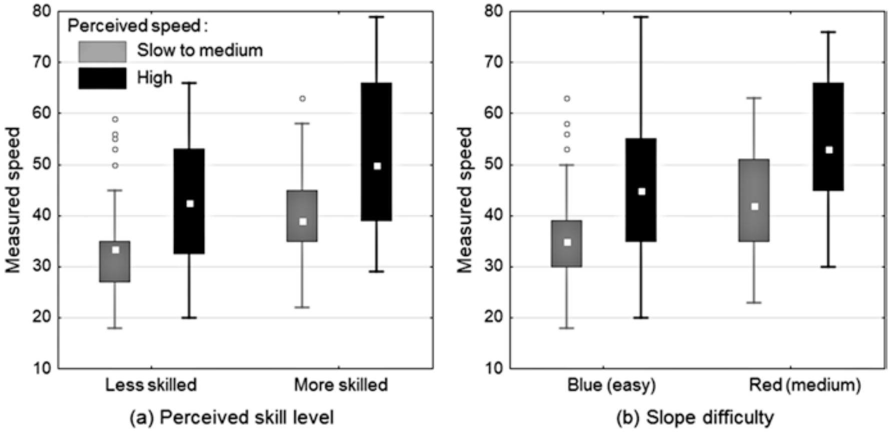

Fig. 1 Measured speed (**a**) regarding the perceived speed and the perceived skill level and (**b**) regarding the perceived speed and the slope difficulty. The boxplots presents the minimum, the first quartile, the median (small white square), the third quartile and the maximum speed for each category. The outliers are presented with small grey circle

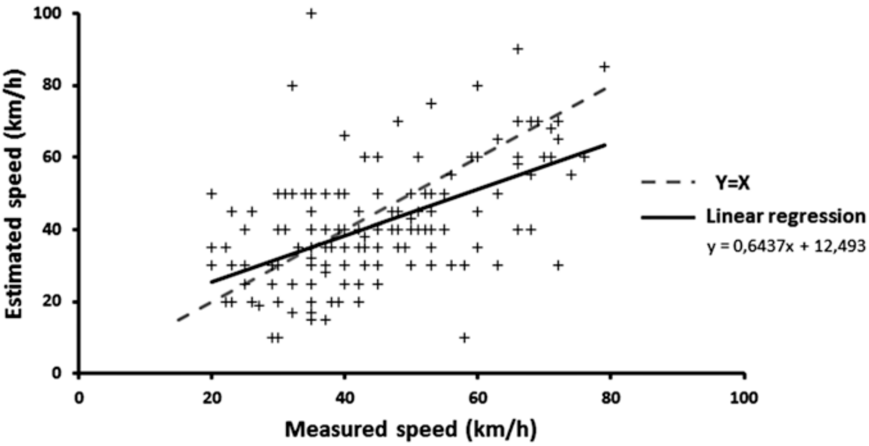

Fig. 2 Users' quantitative estimation of their own speed with regard to the measured speed

explaining the skiing speed, namely, the skill level (a) and the slope difficulty (b). The linear regression model including the perceived speed and the reported skill level explained 24% of the speed variance. 25% of speed variance was explained by the model including the perceived speed and slope difficulty.

Among the 176 skiers interviewed, 166 accepted to give a quantitative estimation of their measured speed. Figure 2 presents the measured speed as a function of that estimation. The mean estimated speed was 40.6 (±16.5) km/h, while the mean measured speed was 43.7 (±13.7) km/h. Pearson correlation coefficient between evaluated and measured speed was 0.56 ($P < 0.001$) and the absolute difference between the two speeds was 11 km/h. Finally, the linear regression ($R^2 = 0.31$) revealed that users travelling at a speed higher than 35 km/h tended to overestimate their speed, whereas faster users tended to underestimate their speed.

5 Discussion

The main finding of this work was the identification of the skill level and the difficulty of the slopes as two governing factors of skiing speed. These two factors also influence the perception of skiing speed. In order to propose an interpretation of the perceived speed registered in an accident report, the ranges of speed were obtained considering skill level, sloped difficulty, and perceived speed.

5.1 Factor Best Explaining Skiing Speed

In the first investigation, the mean speed of the 1399 users measured on ski slopes of different difficulty was 43.4 (±15.2) km/h. It was 49.9 (±15.2) km/h on medium slopes. This result is consistent with the speed measured on ski slopes of medium difficulty by Shealy et al. [4] (43.0 (±11.2) km/h) and Rueld et al. [5] (48.2 (±14.3) km/h). As in both these studies, we found that skill level, gender, and sport had a significant effect on skiing speed. In the second experiment based on 170 skiers interviewed, we also found that age had a significant effect on skiing speed according to Rueld et al. [5] as well as perceived speed in agreement with Brunner et al. [6]. Moreover, we found that the difficulty of slopes and their preparation had a significant influence on skiing speed which had not been previously investigated.

The contribution of each factor on the variation of skiing speed was evaluated. In the first investigation, evaluating factors not related to user's perception, we found that the two factors best explaining the speed variation was first the skill level ($\eta^2 = 0.26$; $P < 0.001$) and secondly the difficulty of the slopes ($\eta^2 = 0.19$; $P < 0.001$). In the second experiment, taking into account perception of skiing speed and of skill level, we obtained similar results. The factors accounting for the highest variation of speed were the self-reported skill level ($\eta^2 = 0.13$; $P < 0.001$), the self-estimated speed ($\eta^2 = 0.08$; $P < 0.001$) and the slope difficulty ($\eta^2 = 0.07$; $P < 0.001$). Gender, sport, and age had a small but significant effect ($\eta^2 < 0.1$; $p < 0.05$).

The evaluated contribution of each factor was not quite consistent with the work of Brunner et al. [6]. In their study, they interviewed and measured the speed of 416 adult skiers on medium slopes. They found that it was the gender which had the highest effect on skiing speed ($\eta^2 = 0.07$; $P < 0.001$). The effect of gender was more than twice higher than both the effect of perceived speed ($\eta^2 = 0.025$; $P = 0.007$) and the effect of reported skill level ($\eta^2 = 0.01$; $P = 0.05$). These differences are surprising but might be partly explained by differences in the methodology of the two studies. First, the two studies did not evaluate the same factors: contrary to Brunner et al., we included in our study the difficulty of the slope but we did not include the perception of risk taking behavior. Secondly, there was a difference in the categories used during the interview to define each factor. For example three categories were used in our study to describe the skill level (beginner, intermediate, and advanced) while four categories were used by Brunner et al. (beginner, intermediate, advanced, and expert). These categories might have influenced differently the answer of the skier. Another explanation might be that skiers did not estimate their skill level correctly. In an investigation in which skiers were observed while skiing to their best ability, Sulheim et al. [7] found that "the correlation between observed and self-reported skiing ability was low to fair." That explanation is supported by the fact that when the skill level was evaluated by an observer (first investigation) its effect on skiing speed was larger than when evaluated by the skier themselves (second investigation) ($\eta^2 = 0.26$ and $\eta^2 = 0.10$, respectively). Finally, these differences in the effect of each factor on skiing speed might be explained by differences in the locations, the types of ski resort and the periods in which the studies were performed. The data set of Brunner et al. was obtained in 2008–2009 in Austria, while our study was conducted in the French Alps, 5 years later.

Users' skill level, first evaluated by a trained observer and then estimated by the users themselves, was among the best explaining factors of speed ($\eta^2 = 0.26$ and $\eta^2 = 0.10$, respectively). In the first investigation, the skiers evaluated by the observer as advanced were on average 11.5 km/h faster than intermediate and 23.2 km/h faster than beginner. The effect of the skier's level had already been identified in every studies related to skiing speed [4, 5, 9, 10]. This difference in speed might partly explain that advance skiers' injuries are more likely to be severe [11].

A second important factor was the difficulty of the slope accounting for, respectively, 19.2% and 7.3% of the speed variance in the first and the second investigations (Table 2). This effect had, to our knowledge, not been evaluated in skiers previously. However, it is consistent with the work of Scher et al. [12] showing that intermediate snowboarders went faster on medium slopes than on easy slopes. According to the first investigation, skiers tended to go 14.4 km/h faster on red (medium) slopes than on blue (easy) slopes, probably due to a steeper slopes. On the contrary, users tended to go on average 9 km/h slower on black slopes than on blue ones. It might be because the increased technicality restricts the maximum speed to remain in control as discussed by Dickson et al. [10]. However, the measured speed in green slopes was surprisingly high (on average 5 km/h higher than in blue slopes). It was observed that the low steepness of the slope might encourage users to go straight in order to maintain a high speed rather than to perform turns. Green slopes are supposed to be the best areas for beginner. The measured high speed might explain that it is on easy slopes that most collisions leading to head injuries occur [13]. The preparation of the slope also had a significant effect on the measured speed, even if that effect was smaller than that of the difficulty of the slope. Indeed, users tended to go significantly slower (1.7 km/h on average, p-value = 0.001) on bumpy slopes than on well-groomed slopes (Table 1). According to this finding, the preparation of the ski slopes could be used as preventing measures to reduce skier's speed in areas identified as dangerous, such as intersections, low visibility areas, and slow zones [10, 14, 15]. More generally those results confirm that the typology of the slopes has a great effect on the users' speed. To better target prevention strategies on the slopes, further work should focus on the understanding of skiing speed regarding the slope typologies. GPS data-logging devices seem to be a promising technology to improve knowledge in that direction [16, 17].

The effect of the helmet on skiing speed is a controversial issue. According to Rueld et al. (2013a), that effect was nonsignificant whereas for Shealy et al. [4], helmet users were significantly faster than non-helmet users. In our first experiment, we did not find a significant effect between helmet use and the measured speed (Table 1, multiple linear regressions). However, in our second experiment, we found that there was a significant effect of helmet use on skiing speed, but it was the factor which had the smallest effect on skiing speed ($\eta^2 = 0.03$; $P = 0.023$). Therefore, according to our results helmet use might have an effect on the skiing speed but that effect is very small.

5.2 Interpretation of the Skier's Estimation of Their Own Speed

The results of the second investigation demonstrate that the perception of skiing speed depends on various factors such as skill level, slope difficulty, age, gender, and helmet use. For example, when perceiving their speed as "high," "less skilled" skiers were on average 9 km/h slower than the "more skilled" (42.5 (±14.1) km/h and 51.5 (±14.1) km/h, respectively). In order to better interpret the skiers' estimation of their own speed, we combined their perception of skiing speed with the best explaining factors, namely, the skill level and the difficulty of the slope (Fig. 1). To combine those information, enable a better prediction of the measured speed. Indeed, the regression model including the perception of speed and the reported skill level explained 24% of the speed variance. This is 7% higher than the regression model including the speed perception only (17%). However, we recorded a high variability of the measured speed among the defined categories of skiers as mentioned by Brunner et al. [6]: there was almost 50 km/h between the slowest and the fastest "less skilled" skiers who estimated their speed as "high." It shows that skiers' perception of their own skill level and their speed is not very precise nor very reliable and has to be taken carefully. We argue that it might be relevant to choose range of speed over mean speed in order to describe the speed of a category of skiers.

The quantitative estimation of the measured speed was also studied (Fig. 2). The Pearson correlation coefficient between estimated and measured speed was 0.53 which is consistent with the study of Shealy et al. [4] and Rueld et al. [5] (0.56). And the mean absolute difference between measured and estimated speed was 11.3 km/h. Interestingly, we found that skiers tended to overestimate their speed when travelling at a speed of under 35 km/h and underestimate their speed when travelling faster. Previously, Rueld et al. (2013a) had found a similar result but for a speed of 40 km/h. Based on those results, speed quantitative estimation should be included in an accident survey. However, the interpretation of such data is difficult, indeed, as reported in Rueld et al. [5], because a few users were incompetent in the evaluation of their speed: one skier claimed a speed of 30 km/h when, actually, he travelled at 72 km/h, or at the contrary one claimed a 80 km/h speed when he travelled at 32 km/h. Moreover, users were very reluctant to estimate quantitatively their speed and we doubt that many would accept to give such an interpretation in an accident survey.

5.3 Limitations

The second experiment was performed in order to interpret the reported speed of a skier in an accident survey. Even if there was a large variability in speed among each category of users, the study provides approximate speed ranges of these categories. For example, the advance skiers who perceived their speed as "low to medium" were at a speed of between 18 and 59 km/h, and a majority of them was at a speed of between 27 and 35 km/h. However, it is possible that in the medical center, due to the traumatic event, the users do not perceive their speed and their skill level the same way they would at the bottom of a ski slope.

The radar used in this study was designed to measure the speed of objects of various size from tennis ball to car at a speed from 11 to 600 km/h and could operate at a temperature as low as −7 °C. It was hence appropriate to measure skiers. Also the speed measurements were done in 1/50 s and were hence not affected by the slow movement made by the observer to track the skier. However, the radar measured the speed only in the direction in which it was pointing. To measure the speed accurately, the observer had to be in the skier's way which was not the case during the skier's turn. To tackle that issue, we chose to measure the skier during several turns and to record the highest measured speed during that observation period. However, the speed might still be slightly underestimated by the radar.

The gender and the skill level were evaluated by the observer during the observation period. The skier was included in the study when the observer was positive about their gender. Yet it is worth noticing that in the literature, there is reported bias associated with higher skill skiers more easily perceived as male [18].

6 Conclusion

In conclusion, we found that among the evaluated factors, the skiers' perception, the skill level, and the slope difficulty were the most influencing factors of skiing speed. These results should be considered in order to improve the prevention strategies on the slopes. We also provided ranges of speed associated with the skier's perception of their speed and considering skill level and the slope difficulty. This result provides insights to interpret the skiers' assessment of their own speed in an accident report. This is, therefore, a first step toward a precise accident reconstruction, leading to a better understanding of the accident mechanisms and a better evaluation of the means of protection.

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