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THE INFLUENCE OF SKI HELMETS ON SOUND PERCEPTION AND SOUND LOCALISATION ON THE SKI SLOPE

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Abstract
Objectives: The aim of the study was to investigate whether a ski helmet interferes with the sound localization and the time of sound perception in the frontal plane. **Material and Methods:** Twenty-three participants (age 30.7±10.2) were tested on the slope in 2 conditions, with and without wearing the ski helmet, by 6 different spatially distributed sound stimuli per each condition. Each of the subjects had to react when hearing the sound as soon as possible and to signalize the correct side of the sound arrival. **Results:** The results showed a significant difference in the ability to localize the specific ski sounds; 72.5±15.6% of correct answers without a helmet vs. 61.3±16.2% with a helmet ($p < 0.01$). However, the performance on this test did not depend on whether they were used to wearing a helmet ($p = 0.89$). In identifying the timing, at which the sound was firstly perceived, the results were also in favor of the subjects not wearing a helmet. The subjects reported hearing the ski sound clues at 73.4±5.56 m without a helmet vs. 60.29±6.34 m with a helmet ($p < 0.001$). In that case the results did depend on previously used helmets ($p < 0.05$), meaning that that regular usage of helmets might help to diminish the attenuation of the sound identification that occurs because of the helmets. **Conclusions:** Ski helmets might limit the ability of a skier to localize the direction of the sounds of danger and might interfere with the moment, in which the sound is firstly heard.

Key words:
Skiing, Ski helmet, Sound localization, Hearing

INTRODUCTION

Due to the high number of injuries on ski slopes, ski helmets have become a widely used protective gear. The main reason for their usage is the fact that among all injuries which alpine skiers and snowboarders usually sustain, head injuries are the most life-threatening ones [1–4]. Many studies claim that a ski helmet usage has a proven benefit when it comes to a head protection [5–9]. However, the extent of this protection is still unclear.

The limitations of ski helmets have been discussed in the recent study [10]. The authors have concluded that while a ski helmet usage increases, the frequency of ski trauma does not

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decrease significantly. The reason for that paradox may be higher skiing speeds as well as increased risky behavior (risk-compensation theory) or the fact that ski helmets might interfere with the auditory or visual stimuli [11,12]. Professional skiers, like ski patrollers and some ski teachers are often reluctant to wearing a helmet precisely for that reasons [13].
If a ski helmet covers skier's ears, then it may interfere with a skier's hearing ability. Surprisingly, a very limited number of studies deals with this problem. In our recently published study we have concluded that the ski helmet wearers might misinterpret the sounds of potentially dangerous situations on the slopes, like a snowboarder breaking or a skier passing by, due to the distortion of the sound caused by a helmet [11]. Studies dealing with combat helmets point out that there is an adverse impact of combat helmets on sounds localization. So, conventional military helmets may cause hearing problems resulting in the inability to distinguish front from rearward sound sources [14].
The human central nervous system (CNS) interprets and localizes the sounds that are played from a lateral side in a manner that sound intensities will be slightly different in the 2 ears. It is mostly because the paths are of different lengths and the sound has to travel longer to reach the opposite ear, so the sound pressure decreases with distance. Also, the head that is in between slightly blocks the sound-wave travelling to the opposite side. As a ski helmet increases the volume of that shadow or blockage it may be assumed that it would further diminish the sound pressure of the original sound. All of that may lead to time delay in hearing identification.
For such reasons the aim of this study has been to examine the effects of wearing a ski helmet on the auditory localization and timing of sound perception in the field conditions, simulating on-the-slope situations.

MATERIAL AND METHODS

Twenty-three subjects (age: 30.7±10.2 years old; 6 female, 17 male; skiing experience: 8.3±5.7 years) were tested on the slope, with and without wearing a protective ski helmet, in a random order with 6 randomly alternating upcoming acoustic stimuli for each of the conditions. They were asked about any prior serious medical conditions regarding the auditory system (all declined) and if they wore a ski helmet previously. Since they served as their own controls, it was not extremely important to evaluate their exact hearing status on the field (as we did previously in the study conducted in a laboratory) [11].
The acoustic stimuli were used to test the correct localization and hearing identification. Two sets (with or without a helmet) containing 6 acoustic stimuli per set were used. Altogether there were 12 stimuli per each subject, 4 from each side and 4 in the direct line (in a random order for all subjects) or 276 probes in the study altogether. The specific sound stimuli were produced due to the continuous short turn's performance by upcoming skiers approaching the subjects from behind.
The 6 acoustic stimuli were the same for all the participants as they were generated by the same 6 skilled ski teachers, all male, using slalom skis (the ski length: 165 cm / 12.5 m radius). The estimated sound pressure level of the stimuli was around 50–55 dB and in the frequency domain of 2–4 kHz (these values are estimated through the data obtained in our previous study [11], determining the sound pressure levels and the frequency domains of the on-the-slope sounds, where A-weighted sound pressure levels in decibels were measured in the abovementioned situations and the frequency domains were analysed using the model 2260 Investigator by Brüel & Kjær Sound & Vibration Measurement A/S, Denmark).
Upcoming skiers randomly choose the approach from one of the lateral sides or the central approach. Consequently, the chance performance for correct localization for each subject in both protocols, wearing a helmet and non-wearing a helmet protocol, was 1/3 (33.3%).
In both conditions (trails) each subject had to respond to a sound clue as soon as possible (meaning at

the 1st moment that he/she heard the sound) and to signalize it by raising the left hand, the right hand or both hands indicating the correct side of the acoustic stimuli arrival. At the moment of the subject's hand raise, the main researcher noted the distance of the upcoming skier from the subject in meters, and the correct or incorrect answer about the direction, from which the sound stimuli was arriving.

The experimental procedure was conducted on a ski slope which was adequately prepared with an artificial snow. The dimensions of the slope were 35×110 m (Figure 1). The shortest distance between the distance markers and the test area was 30 m, while the distance between the markers was 10 m. As presented in the Figure 1, the ski slope polygon that was used was the best we could choose in the Dolomiti region in Italy, as we tried to find the one which had minimal lateral tilts of the slope. Even though the distance markers were placed on the side of the slope (as we did not want them to be the obstacle for the skiers) the skiers providing sound clues skied to a direction of the subject. In that manner we tried to keep the minimal differences in spatial angular separation between the bottom of the hill and at the top of the hill.

The methodological limitations of this study are actually at the same time its advantages. The main advantage of the study is that it was performed in the field conditions.

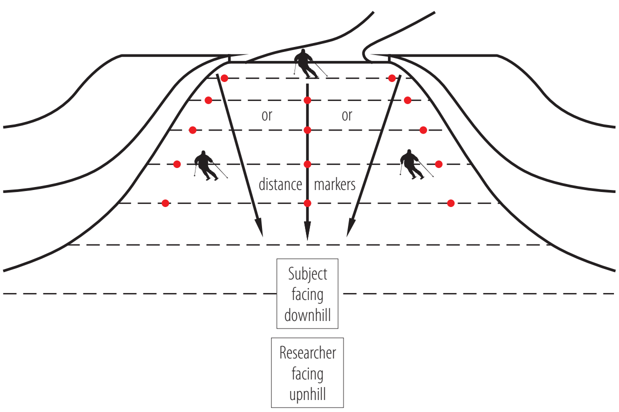

Fig. 1. The experimental settings showing 3 different approaches towards the subject

As the 1st study that we published was done in a more controlled environment (in an audiology laboratory and on the field with exact sound pressure measurements) [11] we now opted for a real situational study which could give us an insight what really happens on the ski slope.

Data analysis

The ability to localize the specific ski sounds without and with wearing a protective ski helmet was analyzed by means of parametric and non-parametric statistics. As the subjects underwent the testing procedure in 2 conditions (with and without a helmet) they served as their own controls. For that reason, the Wilcoxon matched pairs test was used for the data analyzed by non-parametric statistics (yes/no answers) and the Student's t-test for dependent samples was used for quantitative data as distance in meters. The Chi^2 test was used for the evaluation of the differences in proportions of the wright or wrong answers of the correct side localization among the subjects who used a helmet before and who have never used a helmet.

RESULTS

The results of the Wilcoxon matched pairs test showed a statistically significant difference in the human ability to identify the direction of the upcoming specific ski sounds with and without wearing a protective ski helmet ($T = 24\ 000$, $Z = 2678$, $p < 0.01$). In percentage terms, that meant 72.5±15.6% of correct answers without a helmet vs. 61.3±16.2% with a helmet.

There were no statistically significant differences found in the subject's responses depending on which skier was providing the sound clue, and whether the skier was left, right, or centered ($p > 0.05$).

In the 2nd part of the data analysis, the spatial timing, at which the acoustic stimuli were firstly heard was compared in the conditions of wearing and not wearing a helmet. Also, the results were in favor of not wearing a helmet. The subjects reported hearing the sound without

Table 1. The influence of previously used helmets on the obtained results*

Respondent	Correct side localization [n (%)]		Distance of the stimuli at which the subject perceived the sound (M±SD) (m)	
	without a helmet	with a helmet	without a helmet	with a helmet
Used a helmet before (N = 12)	52 (72.2)	46 (63.9)	72.8±6.41	62.2±4.87
Never used a helmet (N = 11)	48 (72.7)	39 (59.1)	73.9±6.87	56.1±5.42
	$Chi^2 = 0.01$ $p = 0.920$ Cramer's V = 0.0	$Chi^2 = 0.02$ $p = 0.887$ Cramer's V = 0.08	Student's t = –0.488 $p = 0.623$	Student's t = –1.501 $p < 0.05$*

* It seems that the subjects who were used to wearing a helmet before did react to the sound clues earlier than their counterparts who never wore a ski helmet ($p < 0.05$). Still it was not as early as without a ski helmet.
M – mean; SD – standard deviation; Chi^2 – Chi square test.

a helmet averagely at the distance of 73.4±5.56 m, while with a helmet it was identified at the distance of 60.29±6.34 m ($p < 0.001$).

To simplify, we could say that 11% of the subjects localized sounds better without a helmet and the performance on this test did not relate to whether they were used to wearing a helmet before i.e., wearing a helmet did not lead to a positive adaptation on the sound localization in space (Table 1). Likewise, the sound was firstly identified on 13 m sooner on average without ski helmets but in this case the results did depend on previously used helmets (Table 1) meaning that the subjects who were used to a helmet previously, managed to perceive the sound earlier with a helmet than the subjects who were not used to wearing it.

DISCUSSION

The main results of the study have shown that helmeted skiers might have a hearing problem because ski helmets might limit the ability to localize the sound and interfere with the distance, at which the sound is firstly heard.

The sound localization might be of crucial importance when trying to escape from auditory warning dangerous situation. Skiing may be very hazardous if a skier is not skillful enough to avoid numerous dangerous situations on the overcrowded slopes. Obviously, the skier's ability to localize the direction of the sound may be a very useful tool for that purpose. Nevertheless, to the best of our knowledge, there is no single study in skiing science literature dealing with that problem, even though it has previously been identified in military medicine [14–16]. When the sophisticated kevlar protective army helmet is worn, it might diminish the auditory localization ability [16]. The soldiers' ability to localize auditory warnings may be diminished if they wear a conventional army helmet which covers the ears, particularly in combination with a hearing protection device [17].

Expectedly, helmets without ear coverage were significantly less disruptive than the ones with half or full coverage conditions [18]. Similarly, a skier wearing a helmet might also be confused about the origin and the direction of the sound, so a collision might easily happen. For that reason skiing helmets without the full coverage should be recommended.

As the sound identification in this study occurred sooner without ski helmets and did depend on previously used helmets it would lead to the conclusion that skiers who had used a helmet before were better adapted to hearing the sounds sooner, that is, recognizing it at lower decibel level.

In a laboratory study the influence of the new, all-in-the-ear protectors on sound localization was investigated as the ear protectors used so far have gained limited use in real hunting situations because they interfered with a rifle handling, eye glasses, listening to the conversation and environmental sounds, and impaired sound localization ability. In conclusion they stated that all-in-the-ear protectors preserved the sound localization ability, by minimizing the dissipation of the sound, in contrast to the other tested protectors [19]. The skiing helmet, on the contrary, is covering the whole head, probably causing the dissipation of the sound.

It is also very interesting that even though in motorcycling and in bike-cycling, protective helmets are widely used, we could not find any study about their impact on sound localization or a rider's ability to identify the distance of sound source origin. Maybe it is because in traffic it might not be as important as in skiing since in traffic the taken direction is depending on the road, while in skiing a skier chooses his/her own path.

Our study solves only a minor part of the problems connected with the sound localization and ski helmets. In our previous study, which was performed in a laboratory [11], we announced that it would be the next step in our future research. Some authors investigating military helmets noted that sound localization cues may be severely disrupted by hearing protection and that a listener could recover little or no information regarding the direction of sound source origin [20]. That study has also proven that ear protection causes errors in the lateral orientation accounted for by front-back confusions, indicating that protective devices disrupt high-frequency spectral cues that are the basis for discriminating front from back sound sources [16]. In our opinion that can be very important in skiing. The similar conclusion has been stated in a more recent study showing that both the degree of ear coverage and ear occlusion significantly determine the outcome and there are decreasing abilities of the weavers in the sound source localization [13].

CONCLUSIONS

To conclude, we think that it is important that the problem of sound localization is also now addressed in skiing. It seems that the conventional and widely used ski helmets might limit the ability to localize the sound and might interfere with the distance, at which the sound is firstly heard. All of that could increase the risk of collision. Although the overall protective value of ski helmets is not at all questionable, due to the significant auditory limitations caused by wearing helmets its protection role might be compromised. Skiers should be aware of that and adjust their behavior on the slope accordingly.

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