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ORIGINAL RESEARCH

Effect of Helmet Use on Traumatic Brain Injuries and Other Head Injuries in Alpine Sport

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Introduction—Sport helmet effectiveness in preventing traumatic brain injury (TBI) has been repeatedly questioned. This study assesses the effect of helmet use on risk of TBI and other types of head injury (OTHI) in alpine sports.

Methods—From 2012 to 2014, data on the injured population were collected by physicians in on-mountain clinics in 30 French ski resorts, and interviews were conducted on the slope to sample a noninjured control population. Two sets of cases (1425 participants with TBI and 1386 with OTHI) were compared with 2 sets of controls (2145 participants without injury and 40,288 with an injury to a body part other than the head). The effect of helmet use on the risk of TBI and OTHI was evaluated with a multivariate logistic regression adjusted for age, sex, sport, skill level, crash type, and crash location.

Results—Using participants without injury as control, we found that helmet wearers were less likely to sustain any head injury (odds ratio $[OR]_{TBI} = 0.65$; $OR_{OTHI} = 0.42$). When considering participants with an injury to another body part as control, the risk of OTHI was lower among helmet wearers (OR_{OTHI}: 0.61). However, no significant effect was found for the risk of TBI. Participants with low skill levels, those aged <26 and >50 years, snowboarders, and those involved in collision and in snowpark accidents were at higher risk of head injury.

Conclusions—This study confirms the effectiveness of helmets in protecting users from head injuries but questions their effects on TBI, especially concussion.

Keywords: ski, snowboard, concussion

Introduction

Head injury is the leading cause of death and catastrophic injury among skiers and snowboarders and accounts for 3 to 15% of winter sports-related injuries.[1] Since 1993, several helmet-wearing campaigns have been launched in France, focusing mainly on children. A growing awareness of head injuries, a reduction in the weight of helmets, and an improvement in the comfort of helmets have resulted in a spectacular increase in child helmet use (from 15% in 1995 to 97% in 2014) and, more recently, in adult helmet use (from 9% in 2005 to 59% in 2014).[2]

Ski helmets are designed to protect the head from penetration and to deform upon impact to absorb the impact energy and reduce head acceleration. The effect of using a helmet on the risk of sustaining a head injury has been studied previously in case control studies.[3–7] In 2010, Russel et al[6] conducted a systematic review of these studies and found that participants wearing helmets were significantly less likely to sustain a head injury (odds ratio [OR] 0.65, 95% confidence interval [CI] 0.52–0.80). In these studies, traumatic brain injuries (TBI) (defined here as concussion, severe TBI, and skull fracture) and the other types of head injuries (OTHI) such as lacerations, bruises, and face trauma were not differentiated, but their respective injury mechanisms differ. In skiing, TBI is usually induced by sudden deceleration of the head, whereas most OTHI

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are caused by the direct contact between the head and the surface of impact. A difference in the effect of the helmet regarding these different types of injury thus may be expected. This was recently highlighted by Dickson et al,[8] who suggest that helmets might protect against lacerations but have limited effectiveness against concussions.

In this work, we intend to use a case control study to evaluate the effect of helmet use and various confounding factors on the risk of both TBI and OTHI. Two hypotheses were tested: 1) the helmet reduces the risks of TBI and OTHI in the skiing population (control group = uninjured population), and 2) the helmet reduces the risks of TBI and OTHI when involved in a traumatic accident (control group = population with an injury to a body part other than the head).

Methods

STUDY POPULATIONS

The injured population

In most French ski resorts, injuries are treated on site at a local medical center. The data relating to this study were gathered in the medical facilities of 30 French ski resorts by the 50 physicians who contribute to the Médecins de Montagne epidemiological network. Among the injured individuals, 62% came to the centers on their own, and the others were delivered by the ski patrol (38%).[2] The only patients not seen in those centers were the most severely injured, who were directly transported to the nearest hospital (less than 0.2% of patients in 2009, according to an unpublished study based on the number of severe ski injuries treated in the hospitals of the Rhône-Alpes region). An injury was recorded when an Alpine sport participant consulted one of the resort's physicians who was part of the Médecins de Montagne group after a skiing or snowboarding-related accident. The type of injury was recorded, as was participant information (age, sex, sport, estimated skill level). Helmet use, type of crash (collision or not), and location (in a snow park or not) were also included in the survey. Data were collected over 3 seasons from 2011–2012 to 2013–2014. During that period, 49,398 injuries were recorded. All patients with missing information were excluded (n=6299 [15%]). The patients were divided into 3 groups: (case 1) those with a clinically diagnosed TBI including concussion, severe TBI, and skull fracture; (case 2) those with OTHI such as lacerations, bruises, and face trauma; and (control 2) those with an injury to a body part other than the head.

The study was approved by the regional ethical research committee (Comité de Protection des Personnes Sud Méditerranée I, Committee reference: RO – 2016/01).

The noninjured population (control 1)

From the 30 resorts included in the study, we selected a representative sample of 10 ski resorts from which to closely study the winter sports participants.[9,10] These ski resorts were selected according to 4 criteria defined by the French Ministry of Tourism: 1) geographic distribution; 2) annual revenue; 3) the type and altitude of the ski resort; 4) specific features (eg, having a snow park).

Interviews were conducted at the bottom of the ski slopes on 7 specific days of the season in each year in each resort (approximately 1000 interviews were conducted each year). As far as was possible, the interviewer stopped 1 in every 10 skiers who went past and invited them to participate in the study. Sport, sex, age, self-assessed skill level, and helmet use were recorded. Interviewers reported that it was often difficult to interview children (often in ski classes). To avoid bias resulting from an underreported child population, we decided to exclude children under the age of 16 years from the study.

Additionally, to account for sampling bias, a systematic count of the general participants at the ski area was performed at the bottom of the slopes in each resort over 1 hour on each of the days the survey was conducted (approximately 40,000 skiers and snowboarders were counted each year). Sport, sex, and helmet use were recorded. The survey data were weighted according to the proportion of snowboarders and helmet wearers in the counted population.

THE CASE CONTROL STUDIES

To evaluate risk factors for head injury, case control studies were performed.

Case selection

Two sets of cases were included in the study. The first set (case 1) consists of patients with a clinically diagnosed TBI (n=1425) (skull fracture, minor and severe TBI). The second set (case 2) are patients with OTHI (n=1386) (lacerations, bruises, and face trauma).

Control selection

We also considered 2 control sets. The first group (control 1) is made up of 2145 noninjured skiers and snowboarders interviewed between 2012 and 2014.

The second control group (control 2) was composed of all patients with an injury to a body part other than the head (n=40,288).

STATISTICAL ANALYSIS

Logistic regressions were conducted using Statistica 12 (StatSoft, Tulsa, Oklahoma, USA) and OR, and 95% confidence intervals were estimated. The regression using the noninjured population as control takes into account the weights assigned to that population (weight function in Statistica). Two-tailed P values <0.05 were accepted for statistical significance.

VARIABLE OF INTEREST

The exposure of interest is helmet use, and we used 2 sets of adjustment factors. Regressions using noninjured (control 1) as control were adjusted for age, sex, sport, and skiing ability. Similarly, regressions with an injury to a body part other than the head (control 2) as control were adjusted for these same 4 variables (first adjustment). We then added 2 other variables into the regressions: the type of crash (no collision/collision with obstacle/collision with participant) and its location (in a snow park or not) (second adjustment). We also explored the adjustment for the year of the accident, but its effect was not significant in any regression; therefore, it was not included.

Results

Of the 43,099 skiers and snowboarders injured during the 2012–2014 period, 1425 experienced a TBI and 1386 experienced OTHI. Among the TBIs, 36 (2.5%) were identified as skull fractures; the characteristics and severity of the other TBIs were not provided. The helmet-wearing rate was lower among participants who had sustained any type of injury (37%) than among the noninjured population (51%) (Table 1).

Table 1. Characteristics of the populations studied: (case 1) patient with clinically diagnosed TBI, (case 2) patient with OTHI (lacerations and bruises to the head and face trauma), (control 1) noninjured skiers and snowboarders interviewed at the bottom of the resorts, and (control 2) patients with injury to another body part than the head

	Cases		*Controls*	
Variable	*Case 1 TBI (n=1425) n (%)*	*Case 2 OTHI (n=1386) n (%)*	*Control 1 No injury (n=2145) n (%)*	*Control 2 Injury to other body part (n=40,288) n (%)*
Helmet use				
Yes	586 (41)	405 (29)	1086 (51)	15,152 (38)
No	839 (59)	981 (71)	1059 (49)	25,136 (62)
Ski ability				
Beginner	137 (10)	105 (8)	98 (5)	5794 (14)
Intermediate	693 (49)	607 (44)	715 (33)	18,536 (46)
Expert	595 (42)	674 (49)	1332 (62)	15,958 (40)
Age (y)				
16–25	541 (38)	450 (32)	609 (28)	10,565 (26)
26–50	580 (41)	644 (46)	1264 (59)	20,687 (51)
>50	304 (21)	292 (21)	272 (13)	9036 (22)
Sex				
Female	607 (43)	429 (31)	836 (39)	18,621 (46)
Male	818 (57)	957 (69)	1309 (61)	21,667 (54)
Sport				
Skiers	1090 (76)	1208 (87)	1786 (83)	32,593 (81)
Snowboarders	335 (24)	178 (13)	359 (17)	7695 (19)
Collision				
No	1056 (74)	974 (70)		36,357 (90)
Obstacle	108 (8)	198 (14)		758 (2)
User	261 (18)	214 (15)		3173 (8)
Snow park				
No	1349 (95)	1322 (95)		38,900 (97)
Yes	76 (5)	64 (5)		1388 (3)

TBI, traumatic brain injury; OTHI, other types of head injury.

HEAD INJURY VS NO INJURY

Compared with participants with no injury (control 1), participants with head injuries (both TBI and OTHI) were more likely to be aged under 26 or over 50 years and to have a low skill level (beginner and intermediate). Snowboarders were at higher risk of sustaining TBI, whereas skiers were at higher risk of sustaining other types of head injury (Tables 2 and 3).

We found that individuals wearing helmets were at lower risk of sustaining TBIs (adjusted OR=0.65) and OTHI (adjusted OR=0.42), as well as nonhead injuries (adjusted OR=0.63), when compared with participants without helmet.

HEAD INJURY VS INJURIES TO ANOTHER BODY PART

Compared with participants with injury to a body part other than the head (control 2), patients with head injuries (TBI and OTHI) were more often aged under 26 years and had a good skill level. Those injured during a collision or in a snow park were more likely to sustain a head injury. Snowboarders had a higher risk of TBI, whereas skiers had a higher risk of OTHI (Tables 2 and 3). Men more often sustained OTHI than women, whereas there was no significant relationship between sex and risk of TBI.

When involved in a traumatic accident, helmet-wearing participants were at a lower risk of OTHI (second adjusted OR=0.61). The effect of helmet use on the risk of TBI, however, was not significant.

Discussion

HELMET USE AND RISK OF HEAD INJURY

Results of the case control study suggest that helmet-wearing participants were less likely to be involved in

Table 2. Multivariate logistic regression models for the risk of TBI

	Case 1: TBI (n=1425) Control 1: No injury (n=2145)		*Case 1: TBI (n=1425) Control 2: Injury to other body part (n=40,288)*		
Variable	*No adjustment OR (95% CI)*	*First adjustment OR (95% CI)*	*No adjustment OR (95% CI)*	*First adjustment OR (95% CI)*	*Second adjustment OR (95% CI)*
Helmet use					
Yes	**0.68 (0.59–0.78)**	**0.65 (0.56–0.75)**	**1.15 (1.04–1.29)**	1.03 (0.92–1.15)	1 (0.9–1.12)
No	**1**	**1**	**1**	1	1
Ski ability					
Beginner	**3.14 (2.38–4.14)**	**2.92 (2.19–3.9)**	**0.63 (0.53–0.77)**	**0.56 (0.46–0.69)**	**0.62 (0.51–0.75)**
Intermediate	**2.17 (1.88–2.5)**	**2.14 (1.84–2.48)**	**1 (0.9–1.12)**	**0.99 (0.88–1.1)**	**1.03 (0.92–1.15)**
Expert	**1**	**1**	**1**	**1**	**1**
Age (y)					
16–25	**1**	**1**	**1**	**1**	**1**
26–50	**0.52 (0.44–0.6)**	**0.52 (0.44–0.61)**	**0.55 (0.49–0.62)**	**0.54 (0.48–0.62)**	**0.56 (0.49–0.63)**
>50	**1.26 (1.03–1.54)**	**1.46 (1.18–1.81)**	**0.66 (0.57–0.76)**	0.65 (0.56–0.76)	0.66 (0.56-0.77)
Sex					
Female	1.16 (1.01–1.33)	1.06 (0.91–1.22)	0.86 (0.78–0.96)	0.92 (0.83–1.03)	0.91 (0.82–1.02)
Male	1	1	1	1	1
Sport					
Skiers	**1**	**1**	**1**	**1**	**1**
Snowboarders	**1.53 (1.29–1.81)**	**1.62 (1.35–1.94)**	**1.3 (1.15–1.48)**	**1.22 (1.06–1.39)**	**1.25 (1.09–1.44)**
Collision					
No					**1**
Obstacle					**4.54 (3.67–5.62)**
User					**2.94 (2.55–3.39)**
Snow park					
No					**1**
Yes					**1.29 (1.01–1.65)**

TBI, traumatic brain injury; OR, odds ratio; CI, confidence interval.

The patients with clinically diagnosed TBI (case 1) are compared with skiers without injury interviewed on the slope (control 1) and with patients with an injury to another body part than the head (control 2). The ORs are presented without adjustment, adjusted for helmet use, ski ability, age, sex, and practice (first adjustment), and with the preceding variables plus the type of crash and its location (second adjustment). All significant effects ($P \leq 0.05$) are in bold.

Table 3. Multivariate logistic regression models for the risk of OTHI (lacerations and bruises to the head and face trauma)

	Case 2: OTHI (n=1386) Control 1: No injury (n=2145)		*Case 2: OTHI (n=1386) Control 2: Injury to other body part (n=40,288)*		
	No adjustment OR (95% CI)	*First adjustment OR (95% CI)*	*No adjustment OR (95% CI)*	*First adjustment OR (95% CI)*	*Second adjustment OR (95% CI)*
Helmet use					
Yes	**0.4 (0.35–0.46)**	**0.42 (0.36–0.48)**	**0.68 (0.61–0.77)**	**0.64 (0.56–0.72)**	**0.61 (0.54–0.69)**
No	**1**	**1**	**1**	**1**	**1**
Ski ability					
Beginner	**2.12 (1.59–2.84)**	**2.3 (1.69–3.13)**	**0.43 (0.35–0.53)**	**0.47 (0.38–0.58)**	**0.51 (0.41–0.63)**
Intermediate	**1.68 (1.45–1.93)**	1.76 (1.51–2.04)	**0.78 (0.69–0.87)**	**0.83 (0.74–0.93)**	**0.88 (0.78–0.98)**
Expert	**1**	**1**	**1**	**1**	**1**
Age (years)					
16–25	**1**	**1**	**1**	**1**	**1**
26–50	**0.69 (0.59–0.81)**	**0.63 (0.54–0.74)**	**0.73 (0.65–0.83)**	**0.62 (0.55–0.7)**	**0.65 (0.57–0.73)**
>50	**1.45 (1.18–1.78)**	**1.25 (1–1.55)**	**0.76 (0.65–0.88)**	**0.56 (0.48–0.65)**	**0.58 (0.49–0.68)**
Sex					
Female	**0.7 (0.61–0.81)**	**0.62 (0.53–0.72)**	**0.52 (0.46–0.59)**	**0.52 (0.46–0.58)**	**0.53 (0.47–0.59)**
Male	**1**	**1**	**1**	**1**	**1**
Sport					
Skiers	**1**	1	**1**	**1**	**1**
Snowboarders	**0.73 (0.6–0.89)**	0.82 (0.66–1.01)	**0.62 (0.53–0.73)**	**0.58 (0.49–0.68)**	**0.59 (0.49–0.69)**
Collision					
No					**1**
Obstacle					**8.88 (7.48–10.55)**
User					2.62 (2.25–3.06)
Snow park					
No					**1**
Yes					**1.33 (1.02–1.74)**

OTHI, other types of head injury; OR, odds ratio; CI, confidence interval.

The patients with OTHI (case 2) are compared with skiers without injury interviewed on the slope (control 1) and with patients with an injury to another body part than the head (control 2). The ORs are presented without adjustment, adjusted for helmet use, ski ability, age, sex. and practice (first adjustment), and with the preceding variables plus the type of crash and its location (second adjustment). All significant effects ($P \le 0.05$) are in bold.

any type of traumatic accident (crude OR_{TBI}=0.68; crude OR_{OTHI}=0.4; crude $OR_{nonhead\text{-}injury}$=0.59). This result was expected for head injuries because it had already been reported by various studies.[3–7] However, the reduced risk of nonhead injury was surprising because the helmet does not protect other parts of the body. This result suggests that helmet users take less risk than those who do not use helmets. This contradicts the "risk compensation theory," which implies that the perception of being protected by the helmet might lead participants to take more risks.[11,12]

When involved in a traumatic event, helmet wearers were at lower risk of OTHI, but no significant links were found between helmet use and the risk of TBI. We do not know the characteristics or severity of the recorded TBIs (except for the 36 skull fractures). In a previous study[13] conducted between 2012 and 2014 at 15 of the medical facilities of the Médecins de Montagne group, 97% of the TBIs recorded were rated mild (Glasgow score of at least 14). Hence, when we measured the risk of TBI, we were mainly measuring the risk of mild TBI (or concussion). The link between risk of mild TBI and helmet use was explored by Dickson et al[8] in skiing and Benson et al[14] in various other sports. Neither found a significant link. Currently, ski helmets are not developed nor evaluated for their capacity to protect from concussion[15]: The pass/fail criteria of the safety standard test is 250G.[16] This is significantly higher than the acceleration threshold for concussion.[17] Moreover, the test does not evaluate the capacity of the helmet to reduce rotational acceleration, important in TBI occurrence.[18] New helmet technologies were proposed to reduce the overall acceleration (EPS 4D,[19] D3O[20]) or specifically the rotational acceleration (MIPS[21]), but it is too soon to give an epidemiologic evaluation of these technologies. Our results and the large proportion of concussions among TBIs call for a re-evaluation of the mechanical capacity of the helmet to better protect against concussion.

OTHER RISK FACTORS FOR HEAD INJURY

Age, sport, skill level, and the type and the location of the accident affected the risk of head injury.

It was not surprising that young adults (16–25 years old) and older participants (>50 years old) were at a higher risk of head injuries than those aged 26 to 50 years. Adolescent and young adults have already been identified several times as a population at risk for most ski-related injuries,[5,22,23] which may be due to risky behaviors most frequently seen in the young.[24] Regarding older participants, impaired balance, fatigue, reduced flexibility (eg, due to arthritis), and weakness of biologic tissues associated with aging could explain a higher risk of falls and injuries.[25]

The greater risk of TBI for snowboarders than for skiers has already been well established and was associated with a snowboarding injury mechanism identified by Nakaguchi et al in 2002: the "opposite-edge phenomenon," described as a backward fall leading to an occipital impact.[26–28] However, we found that skiers were at higher risk of OTHI than snowboarders (crude OR_{OTHI}=1.37), suggesting different head injury mechanisms between skiers and snowboarders. Fukuda et al[26] found that among patients who sustained severe injury to the head, skiers were more likely to be involved in collision (against users or obstacles) than snowboarders; we found similar trends among all our patients (11% of collision for skiers, 6% for snowboarders). This might partly explain why skiers more frequently experience OTHI; these injuries are consistent with a direct contact of the head with a rigid surface, typically seen in collisions.

In the literature, beginners have been commonly identified as a population at high risk of injury.[23,27] In our study, when the injured population was compared with the uninjured population, both beginners and intermediates were at higher risk of head injury than experts (crude OR_{TBI}=3.14 and 2.17, respectively). However, when considering only those having sustained an injury (head injury vs injury to another body part), beginners were less likely to sustain a head injury than experts (crude OR_{TBI}=0.56). Experts are hence less likely to injure themselves, but when they do, injuries are more often to the head compared with the less skilled skiers. The injury pattern might also differ, and Goulet et al[29] found that experts' injuries were more likely to be severe.

Results suggest that the type and location of the accident also affect the risk of head injury. Snow parks have already been identified as places of risk,[30,31] and this study confirms that this is especially the case for head injury (adjusted OR_{TBI}=1.29 and adjusted OR_{OTHI}=1.33). We also found that when involved in a collision with an obstacle or with another user, the risk of head injury was 2 to 8 times higher than when involved in another type of accident (fall, jumps). Nonetheless, 70% of TBIs occurred in accidents unrelated to such collisions. In a previous study,[13] we found that during collisions, most TBIs were induced by an impact of the head with a rigid surface (the obstacle or the other user), whereas during falls and jumps, the injury resulted from the impact of the head against the snow. Thus, a helmet must answer 2 mechanical challenges: 1) protecting the head from impact with rigid obstacles, which are most likely to induce a head injury, and 2) protecting the head against impact on snow, which is most frequently seen.

STRENGTHS AND LIMITATIONS

In this work, all TBI and OTHI were diagnosed by trained ski injury physicians in clinics maintained at the 30 resorts studied. The strength of this study lies in the size and the representativeness of both the study and its control samples. We confirmed that the 30 resorts where the injuries were recorded spanned the same geographic area as all 180 French ski resorts. Among them, the 10 ski resorts selected to study the control population were chosen for their geographic distribution, size, and typology.[9,10] Because of the large number of cohorts, the capacity of the study to detect significant contrasts is very high; thus, the finding of no significant effect of helmet use when comparing patients with TBI and patients with injury to other body parts is a reliable result. On the other hand, some significant but small effects highlighted in the study might have no concrete importance. For instance, the difference in the risk of TBI between individuals at expert and intermediate skill levels (adjusted OR: 0.99, $P<0.001$) may have very limited practical and clinical consequences.

All injuries resulting from a winter sport accident and treated by a physician from the Médecins de Montagne group were recorded. However, some injuries may have bypassed the resort doctors. First, some of the most severely injured patients were transported directly to the nearest hospital by helicopter. These patients represented less than 0.2% of all injuries according to an unpublished study conducted in 2009 in the main French skiing region (Rhône-Alpes, 71% of French skiing days) by Médecin de Montagne and the TRENAU network.[32]

Second, some injured people may not have reported their injuries. In 2000, we conducted a survey (unpublished) to evaluate the rate of this "bypass" in the 10 ski resorts studied: 1276 interviews were conducted on the ski slopes about previous winter sport injuries, and it was estimated that between 12 and 17% of injuries go unreported. However in both cases, we do not know the proportion of head injury among these injuries bypassing our network.

Conclusions

In this study, the effect of wearing a helmet on the risk of TBI and OTHI was evaluated in 2 ways: first, considering the noninjured skiing population; and second, considering skiers and snowboarders involved in a traumatic accident. These case control studies provide controversial findings:

1. Non-helmet–wearing participants were more likely to sustain injuries (TBI, OTHI, and injuries to other body parts) than helmet-wearing participants.
2. When involved in a traumatic event, non-helmet–wearing participants had a greater risk of sustaining OTHI. However, the effect of helmet use on the risk of TBI (and in particular concussion) was not significant.
3. Participants with low skill levels, those aged <26 and >50 years, and snowboarders were at higher risk of head injury. Collisions and accidents in a snow park are more likely to induce head injury than other traumatic accidents.

These results show that head safety is a multifactorial issue within which the helmet plays an important role that justifies its use. This study also poses important questions to the scientific community and to helmet manufacturers about how helmets can be improved to better protect from concussion.

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Author Contributions: Study concept and design (CM, TD, PJA); acquisition of the data: (JDL, JBD, Médecins de Montagne epidemiological network); analysis of the data (NB, SA); drafting of the manuscript (NB, SA); critical revision of the manuscript (CM, TD, PJA); and approval of final manuscript (NB, JDL, SA, CM, TD, JBD, PJA).

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