Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 2 (2010) 2869–2874

Procedia Engineering

www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

Functionality of back protectors in snow sports concerning safety requirements

Frank I. Michel[a]*, Kai-Uwe Schmitt[b,c], Bendicht Liechti[d], Rolf Stämpfli[e], Paul Brühwiler[e]

[a]*bfu – Swiss Council for Accident Prevention, Hodlerstrasse 5a, 3010 Bern, Switzerland*
[b]*University and ETH Zurich, Institute for Biomedical Engineering, Gloriastrasse 35, 8092 Zurich, Switzerland*
[c]*AGU Zurich, Winkelriedstrasse 27, 8006 Zurich, Switzerland*
[d]*ETHZ, Institute for Biomechanics, Wolfgang-Pauli-Strasse 10, 8093 Zurich, Switzerland*
[e]*EMPA - Swiss Federal Laboratories for Materials Testing and Research, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland*

Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

Abstract

Approximately 13% skiers and 38% snowboarders wore wearing a back protector during the last season in Switzerland. This huge number suggests an ensured functionality of such back protectors. However, there is no specific standard regarding snow sports available. Therefore, the main goal of the study was to get an initial overview about the functionality in terms of potential protective effects of back protectors. The whole project was divided into an athlete survey and an experimental performance test (drop test). The results from the surveys clearly pointed out, that back protectors belong to the most important pieces of protection equipment in snow sports. The related customer expectations emphasize the importance in terms of injury prevention particularly regarding severe spinal column injuries. Concerning the performance test according to the standard for motorcyclists' back protectors EN 1621-2 most of the samples did pass protection level 1. However, considering the test procedure there appears to be a mismatch between customer expectations, injury occurrence and the actual preventive potential of currently available protectors.

Keywords: Snow sports; injuries; back protector; safety standards; material test; survey

1. Introduction

Approximately 23% of all sports injuries in Switzerland occur during alpine skiing and snowboarding [1]. The most frequent injury location during alpine skiing affects the knee (34%) and for snowboarding the region around the shoulder and the upper arm [1]. The amount of injuries of the spinal column varies between 2-10% [2-4]. In this context approximately 10% of these spinal injury patterns are linked to permanent neurological deficits [5,6]. Besides, the Swiss statistics [7], which include all injury cases for people between 16-65 years, report about 6% of spinal column injuries for alpine skiing (counted injury cases from 1987-2006) and about 10% for snowboarding (counted injury cases from 1995-2006). Contrary to the results from Franz et al. [3] the most frequent injured part of the spinal column is related to the cervical spine (alpine skiing: 3.9%; snowboarding: 6.8%) [7]. All registered spinal column injuries were without spinal cord damages. General back and bottom injuries in alpine skiing (4.2%) and snowboarding (7.3%) were mostly contusions. If spinal column injuries as well as general back and bottom injuries are merged, than 10.2% of "back related injuries" can be noticed for alpine skiing and 18.3% for snowboarding respectively [7]. These numbers of "back related injury locations" are important because they are covered by the geometrical dimensions of commercially available back protectors.

The usage of back protectors in snow sports is expected to avoid spinal injuries as well as injuries related to the back in general. Approximately 13% skiers and 38% snowboarders were wearing a back protector during the last season (2008/2009) in Switzerland [1]. This huge number suggests that consumer believe in a protective potential as well as an ensured functionality of

* Corresponding author. Tel.: +41-31-390-2158; fax: +41-31-390-2230
E-mail address: f.michel@bfu.ch.

1877-7058 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2010.04.080

such back protectors. However, there is no specific performance standard related to snow sports available. Several manufacturers are using the standards for motorcycles [8] to test the performance and promote their products. Currently, the market reveals a big variety of products with different technologies and different product design, respectively.

With reference to shock attenuation and impact damping most of the back protectors are "hybrid constructions" and consisting of polymer materials. Depending on the outer (deformation) texture of the back protector it can be differentiated between "soft shell" and "hard shell" protectors in general. Hard shell constructions exhibit a hard and non-deformable outer shell mostly consisting of duromers (thermoset materials) or plastomers. This construction should distribute the force of the impact over a wider area. Underneath the hard outer shell there is mostly a layer of deformable materials consisting of elastomers. In contrast, soft shell constructions offer soft, deformable material layers only. Mostly theses materials are elastomers such as polyurethane (PUR) or ethylene vinyl acetate (EVA) with visco-elastic characteristics. These materials are deformable directly at the point of impact. Additionally, there are back protectors on the market which are integrated in special backpacks designed for snow sports. Moreover, there are protector vests, which offer additional protection for the shoulder and elbow region as well as the chest. However, a back protector for snow sports, which covers also the cervical spine segment, could not be found on the market up to now.

The main goal of the present study was to get an initial overview about the functionality in terms of potential protective effects of back protectors with reference to the prevention of back and spinal injuries during alpine skiing and snowboarding.

2. Methods

The whole project was divided into an athlete survey and an experimental performance testing of back protectors.

2.1. Athlete Survey

In total 3263 skiers and snowboarders participated in the survey. Data collection was partly based on personal interviews on the slope (n=1550) in 20 Swiss skiing regions during the winter season 2008/2009. Additionally, a standardized questionnaire was developed and used for an on-line survey (n=1713). In addition to questions regarding the wearing habits of personal safety equipment, special product oriented data such as product preferences and reasons for buying were determined.

2.2. Laboratory Test

The performance test comprises a drop test accordingly to the standards for motorcycles [8]. The experiments were carried out with a prescribed impactor (drop mass of 5kg and predefined geometrical dimensions, free falling impact) which resulted in an impact of 50J kinetic energy (Fig. 1). The measuring equipment consisted of a load cell sensor (Kistler®, Typ 9091, measuring range 0-1200kN), a charge amplifier (Kistler®, Typ 5015A) and a transient recorder (Bakker, Typ BE490, 12Bit). The data were recorded with a sampling frequency of 100kHz within a time period of 20ms. The distance between the drop mass and the sample was 100cm (drop height). Dissenting from the EN 1621-2 [8], instead of five impacts only three impacts per test sample at different locations were conducted [9]. This deviation from the EN 1621-2 [8] was done since only one protector was available and further test trials with varying parameters such as drop heights were planed.

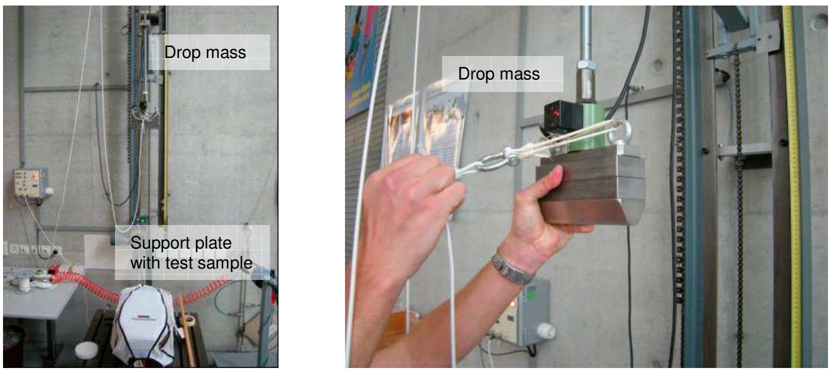

Fig. 1. Drop test device accordingly to EN 1621-2: Left: Drop test device with support plate/test block (steel anvil) including load cell sensor; Right: Positioning of the drop body

The samples were pre-tempered at 20 ± 2°C for 24h before testing. The data were collected at the same temperature of 20 ± 2°C and a humidity of 65 ± 5%. This scenario was in accordance to the EN 1621-1 [9].

The evaluation accordingly to the EN 1621-2 of the aforementioned described test procedure assesses the damping characteristics of a back protector due to direct impact. The measured "remaining impact force" (Fig. 5) represents the resultant force measured with the load cell sensor positioned below the sample and the support plate (Fig. 1).

A total of twelve back protectors differing in design, material and covered body regions were investigated (Fig. 2). Additionally, a backpack with a sweater made of cotton in it, was included in the test series for comparison.

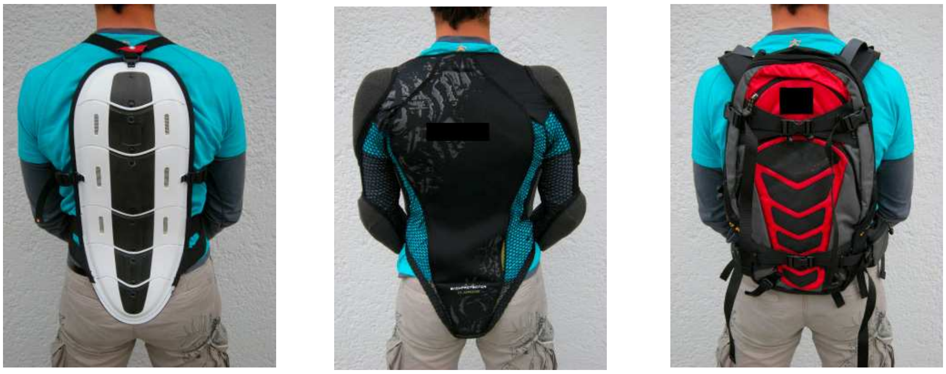

Fig. 2. Selected test samples; Left: Test sample E - hard shell protector; Middle: Test sample A - soft shell protector; Right: Test sample K – special snowboard backpack with integrated back protector

Table 1 provides an overview about the tested back protectors. To the time of investigation not each model was available in size M. Therefore the tested samples varying in size. In addition to the snow sport specific models one back protector was exclusively designed for motorcyclists (sample J, Table 1.).

Table 1. Description of test samples

coding	construction	application	size	mass [g]	thickness [mm]	approximately costs [€]
A	soft shell	snow sports	M	n.s.	23	313
B	soft shell	snow sports	M	683	23	200
C	pack	snow sports	24 liter	1 500	22	133
D	soft shell	snow sports	L/XL	740	21	199
E	hard shell	snow sports	L/XL	700	26	213
F	daypack	snow sports	20 liter	1 550	45	20
G	soft shell	snow sports	L	870	24	267
H	soft shell	snow sports	164-188	560	23	146
I	hard shell	snow sports	L	600	30	70
J	hard shell	motorcycle	L	n.s.	23	53
K	pack	snow sports	25 liter	1 700	28	153
L	hard shell	snow sports	L	850	17	99

3. Results

3.1. Athlete Survey

The data regarding the wearing habit of protection equipment in snow sports (Fig. 3) clearly point out that the snow sport helmet represents the most frequent used piece of protection equipment for both ski and snowboard. Already the second rank, however, back protectors were named whereas snowboarders wear this piece of protection equipment clearly more often compared to skiers.

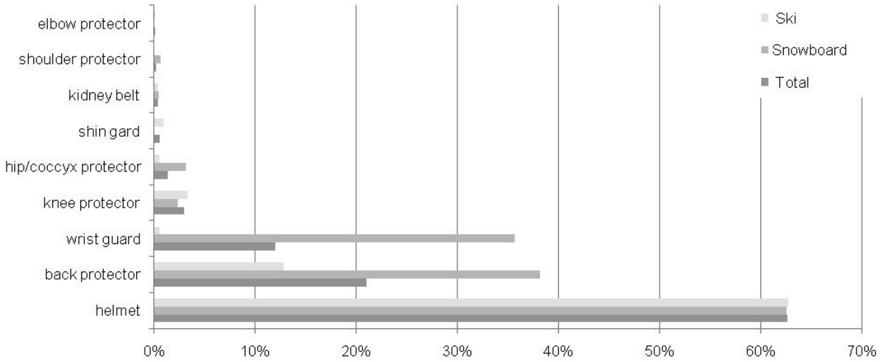

Fig. 3. Wearing habit of protection equipment in snow sports, multiple response possible (n=1550; season 2008/2009)

The personal "on slope interviews" regarding the reasons for wearing a back protector clearly emphasize the aspect of "injury prevention" (67%) followed by "safer feeling" (17%) and "occurrence of spinal/back injury in the past" (7%).

The "internet survey" revealed that 76% of the responders belief that the back protector offers particular protection against spinal vertebral fractures, injuries to the spinal cord (49%) and contusions (42%) as well as lacerations/stab wounds (42%) (Fig. 4).

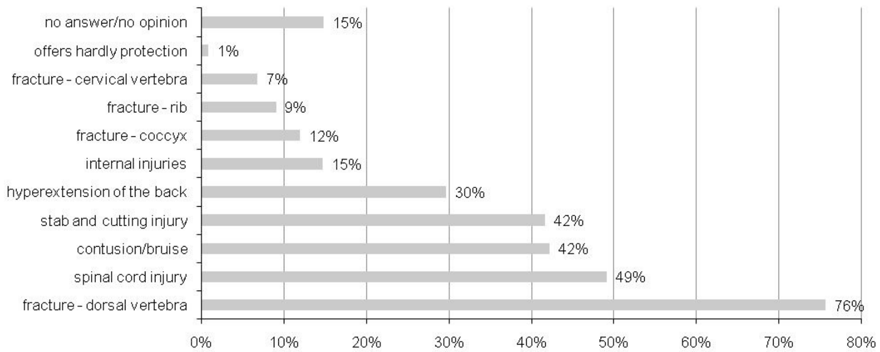

Fig. 4. Customer expectations for injury prevention concerning back protectors (n=1713; season 2008/2009)

3.2. Laboratory Test

Regarding the material test ten out of the 12 test samples passed the protection level 1 ($AveF_{peak} < 18kN$, $MaxF_{peak} < 24kN$) accordingly to the standards for motorcycles EN 1621-2 [8] and thus fulfill the minimum requirement (Fig. 5). However, even the backpack (coded as F in Fig. 5) filled with a sweater meets the requirements for protection level 1 as well. Only six test samples fulfill the requirements concerning protection level 2 ($AveF_{peak} < 9kN$, $MaxF_{peak} < 12kN$). It seems that "soft shell protectors" reveal better damping characteristics than “hard shell constructions”.

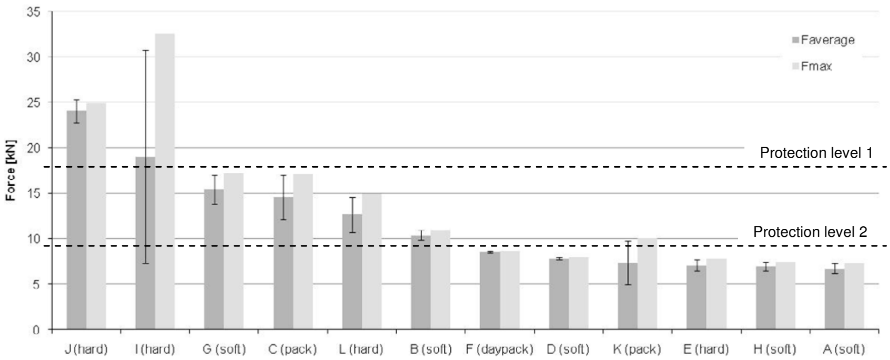

Fig. 5. Remaining impact force accordingly to EN 1621-2 [8]

4. Discussion and conclusion

The results from the two surveys clearly point out, that back protectors belong to the most important pieces of protection equipment in snow sports. The related customer expectations emphasize the importance in terms of injury prevention particularly regarding severe spinal column injuries. Therefore, wearing of back protectors are recommended from different sides [3]. However, back protectors hardly protect the spinal column or the back in general when an axial force to the spine is applied (e.g. as happens in a head-on impact) [8]. Furthermore the influence of back protectors with respect to torsional movements of the trunk is limited [8].

Regarding the material test accordingly to the EN 1621-2 [8] ten out of the twelve test samples did pass protection level 1. However, it remains to be discussed whether the loading scenario used is suitable in the context of snowboarding or alpine skiing. Particularly a mismatch between customer expectations, injury occurrence and loading applied as part of the performance test becomes apparent.

From these findings three major issues arise:

- Is it appropriate to apply the standard for motorcycles also on protective gear for snow sports?
- What other "safety functions" – besides damping - should a back protector for snow sports offer?
- How is the relation between snow sport specific spinal/back injury mechanisms and the resultant biomechanical parameters?

The processing of these three basic topics will contribute to fill the gap between the desired customer requirements, injury occurrence and the functionality of back protectors concerning injury prevention. The development of an international standard for back protectors in snow sports can be an option to ensure a reasonable level of protection and thus be of benefit for consumers. Such a possible standard should try to cover all relevant protections aspects. The work of Engsberg et al. [11], who developed an testing concept for spinal cord and brain injury protection in regards to motorcycling and horseback riding might serve as a first indicator in that respect.

5. Outlook

The development of test procedures for snow sport specific safety equipment should also consider the climate conditions such as temperature. Kleindienst and co-workers [12] could figure out that EVA materials are strongly temperature dependent. Especially temperatures below 0°C lead to changes of the material hardness. The dampening properties as well as bending characteristics of EVA material becomes harder and stiffer.

Independently, it is worth to consider additional test procedures for chest/thorax and shoulder as well as elbow protection equipment. This could be valuable due to the aforementioned injury statistics and a possible product oriented supplement of back protectors. Such products e.g. a protector vest (Fig. 2) are already on the market and well known in other sports like downhill cycling. Moreover, product ideas, which cover the cervical spine segment, also represent an approach.

A further topic for both appropriate performance testing procedure as well as product idea incorporates considerations regarding a "functional grading" of back protectors. Such functional grading considerations should not limited to anthropometrical dimensions of the back in terms of ergonomic requirements (e.g. requirements regarding the protected area) [8] but rather imply functional criterions such as human development including bony growth [13] as well as gender dimorphism particularly in the context of bone stiffness and impact attenuation.

A product differentiation regarding the preferred setting (e.g. on piste vs. off piste vs. park & pipe) are also conceivable and requires different functional implementation.

References

[1] Niemann S, Fahrni S, Hayoz R, Brügger O, Cavegn M. *STATUS 2009: Statistics on non-occupational accidents and the level of safety in Switzerland*. Bern: bfu - Swiss Council for Accident Prevention; 2009.

[2] Yamakawa H, Murase S, Sakai S et al. Spinal Injuries in Snowboarders: Risk of jumping as an integral part of snowboarding. *The Journal of Trauma.* 2001;**50**(6):1101–1105.

[3] Franz T, Hasler RM, Benneker L, Zimmermann H, Siebenrock KA, Exadaktylos AK. Severe spinal injuries in alpine skiing and snowboarding: a 6-year review of a tertiary trauma centre for the Bernese Alps ski resorts, Switzerland. *Br J Sports Med.* 2008;**42**(1):55–58.

[4] Ackery A, Hagel BE, Provvidenza C, Tator CH. An international review of head and spinal cord injuries in alpine skiing and snowboarding. *Inj. Prev.* 2007;**13**:368-375.

[5] Prall JA, Winston KR, Brennan R. Spine and spinal cord injuries in downhill skiers. *The Journal of Trauma: Injury, Infection, and Critical Care.* 1995;**39**(6):1115–1118.

[6] Wakahara K, Matsumoto K, Sumi H, Sumi Y, Shimizu K. Traumatic Spinal Cord Injuries From Snowboarding. *Am J Sports Med.* 2006;**34**(10):1670–1674.

[7] Michel FI, Niemann S, Brügger O. *Rücken- und Brustprotektoren im Schneesport - Statistische Analyse*. Bern: bfu; 2009.

[8] Normenausschuss Persönliche Schutzausrüstung (NPS) im DIN Deutsches Institut für Normung e.V. *Motorcyclists' protective clothing against mechanical impact - Part 2: Motorcyclists' back protectors - Requirements and test methods; German version EN 1621-2:2003*. Berlin: DIN; 2003. DIN EN 1621-2:2003.

[9] Normenausschuss Persönliche Schutzausrüstung (NPS) im DIN Deutsches Institut für Normung e.V. *Motorcyclists' protective clothing against mechanical impact - Part 1: Requirements and test methods for impact protectors; German version EN 1621-1:1997*. Berlin: DIN; 1997. DIN EN 1621-1:1997.

[10] Schmitt K-U, Liechti B, Michel FI, Stämpfli P, Brühwiler P. Are current back protectors suitable to prevent spinal injury in recreational snowboarders? *Submitted for Br J Sports Med., 2010.*

[11] Engsberg JR, Standeven JW, Shurtleff TL, Tricamo JM, Landau WM. Spinal cord and brain injury protection: testing concept for a protective device. *Spinal Cord.* 2009; **47**(8):634-639.

[12] Kleindienst F, Krabbe B; Westphal K, Grandmontagne M. Temperature influence of varying midsole hardness on functional properties. In E. Hennig, A. Stacoff, H. Gerber (Eds.), *Proceedings of the 5th Symposium on Footwear Biomechanics* (pp. 54-55). Zürich: Laboratory for Biomechanics, Department of Materials, 2001.

[13] Klein P, Sommerfeld P. *Biomechanik der Wirbelsäule - Grundlagen, Erkenntnisse und Fragestellungen*. München Jena: Elsevier - Urban & Fischer; 2007.