HOW EFFECTIVE ARE AVALANCHE AIRBAGS? FIELD TESTS OF AVALANCHE SAFETY EQUIPMENT

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ABSTRACT: Avalanche transceiver – shovel – probe. This still is the standard equipment recommended for touring in the backcountry. More and more, off-piste and backcountry recreationists carry additional avalanche safety gear such as avalanche airbags. In a series of field tests with four artificially triggered avalanches, we compared the effect of additional safety equipment. We measured burial depth and visibility of dummies equipped with two different brands of avalanche airbags (ABS and Snowpulse), the avalanche ball and of dummies with no additional equipment. The burial depth of dummies equipped with an airbag was significantly lower compared to dummies which carried an avalanche ball or no additional equipment. Moreover, based on a qualitative validation the airbag systems were rated better than dummies without airbag. Both brands of airbags and the avalanche ball were visible in all cases on the surface of the avalanche deposits – partly due to the avalanche size and the path topography. Acceleration measurements at the head of the dummies suggest that the risk of injury may be reduced with an appropriate form of the airbag.

1. INTRODUCTION

„Your Whole Life Fits into this Backpack", „Head On Top Technology (H.O.T.)" or „the fastest system to locate buried people in avalanches" – With such slogans additional safety equipment gets presented to backcountry and off-piste skiers. Manufacturers justify these statements by referring to own tests and also to tests which were done by the SLF in winter 1994-1995 (Tschirky and Schweizer, 1997) and 2000-2001. (Kern et al., 2001) showed that in a flowing avalanche a segregation takes part so that larger particles tend to stay closer to the surface than smaller particles. Airbag systems take advantage of this physical process when skiers release a balloon at the moment they get caught by an avalanche. In the last 20 years, a number of commercially available products have been developed. This additional safety equipment complements the standard equipment (Avalanche transceiver, shovel and probe) and is used more and more often in practice. Therefore the magazine "K-Tipp" (a Swiss magazine for consumer protection) wanted to do new field tests with current safety equipment (Cetojevic et al., 2011). SLF developed the test concept and coordinated the field tests that were carried out in winter 2010-2011 near Davos.

2. METHODS

The tests included the airbag systems ABS and Snowpulse (SP) as well as the avalanche ball (LB). The products were carried by full-sized rescue dummies with a weight of 75 kg. In total, four avalanches were released artificially. For the first two avalanches, 8 dummies per avalanche were placed on the slope. After a dummy has been destroyed in the second avalanche, there were only 7 dummies left for the last two experiments. Four dummies in a row were placed by helicopter in the avalanche slope. One row was higher up in the slope, the other row 100 m below (Fig. 1). Each product was placed once in each row and was therefore tested twice per avalanche. Two dummies (one per row) were only equipped with transceiver and no additional equipment (Nix). The dummies in the upper row were equipped additionally with an acceleration logger attached to the back of the head. These loggers recorded the three dimensional acceleration at a rate of 1600 Hz. To protect the logger, these dummies carried a helmet.

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Figure 1: One row of four dummies placed in the avalanche slope. The order of the safety equipment was changed each time.

Figure 2: Position of the two rows with 4 dummies each in the avalanche slope.

Towards the end of February 2011 the conditions were ideal to trigger avalanches. During a dry and cold period from 26 January onwards the surface of the snow cover had transformed into facets with low cohesion. This weak layer was covered by 20-30 cm of new snow on 21-22 February. Accompanying northwesterly winds additionally loaded the northeast-facing slopes near the Flüelapass above Davos. The tests were carried out on 26 February and 1 March 2011. Table 1 describes the four triggered avalanches. The fracture line of the avalanches was in steep, rocky terrain and could not be visited and characterized in detail due to a lack of time. The fracture depth was more than 1 m. The outline of the debris was measured with a GPS-based laser rangefinder. The position of the dummies was determined before and after the avalanche release by GPS (Fig. 3).

At all four avalanche sites the terrain was similar without sudden changes in terrain features and slope angle. There were hardly any possibilities for the debris to accumulate in deep trenches or depressions. The avalanche runout zone was thus rather favorable for a victim and not representative for all possible avalanche burial situations. This also reflects in the average burial depth of 53 cm of completely buried dummies in comparison with the long-term mean of 100 cm (Harvey et al., 2002).

Table 1: Characteristics of the four avalanches

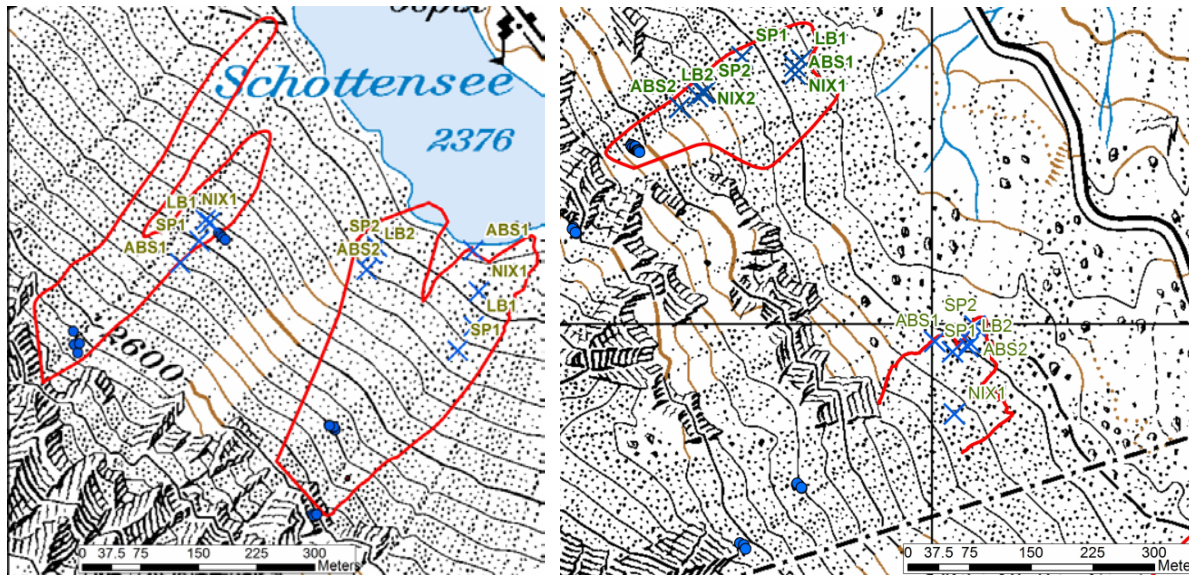| Avalanche no.	1	2	3	4
Date	26 Feb 2011	26 Feb 2011	1 Mar 2011	1 Mar 2011.
Number of dummies caught	4/8	8/8	6/7	7/7
Not caught	all in bottom row	-	LB top row	-
Mean burial depth of dummies without airbags (cm)	18	43	63	45
Difference in elevation dummies were carried down by avalanche (top row/bottom row (m)	120/0	220/60	200/140	200/120

Figure. 3: Outlines of the avalanches 1, 4, 2, 3 (from left to right) and the positions of the dummies before (●) and after (×) the avalanche. Dummies of the upper row before the avalanche are denoted by the suffix '1', the ones from the lower row by '2'. ABS = Airbag ABS, SP = Airbag Snowpulse, LB = Avalanche ball, NIX = without additional equipment.

3. RESULTS

3.1 Burials

The following parameters were recorded from each dummy after the avalanche: Visibility of part of the body and of safety equipment, position of dummy, burial depth of airways, head and body.

The airbag systems ABS und SP as well as the avalanche ball were visible on all avalanche deposits. Mean burial depth and position are summarized in Tab. 2.

The limited number of tests makes statistical comparison of burial depths challenging. Therefore, we performed a bootstrap simulation (Davison et al., 1997) on the basis of the poor data to get reliable mean burial depths and to do meaningful statistical testing. Fig. 4 and 5 show the distribution of the measured airway burial depths of dummies with and without airbags. The larger scatter for the burial depth without airbag is obvious. The 95% confidence interval is between 25 and 63 cm, whereas for burial depths with airbag it ranges from 8 to 26 cm.
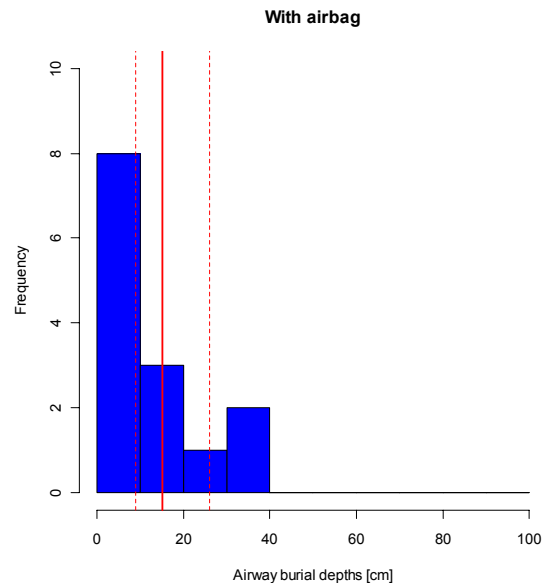

Figure 4: Histogram of airway burial depths for dummies with airbag systems. The red line shows the mean of the data, the doted red line is the 95% confidence interval calculated from 2000 bootstrap simulations.
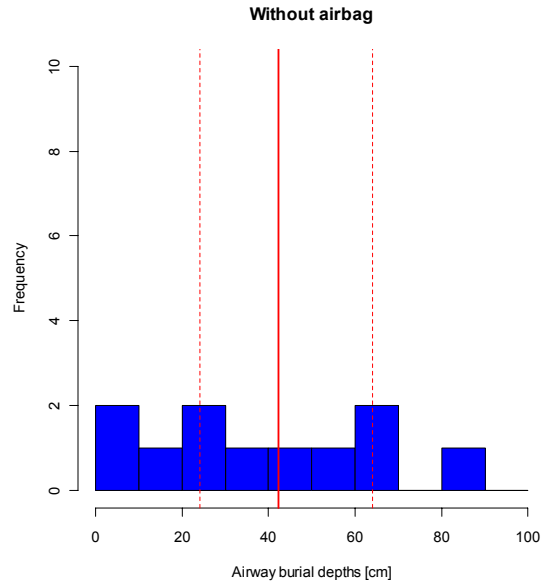
Without airbag

Figure 5: Histogram of airway burial depths for dummies without airbag systems. The red line shows the mean of the data, the doted red line is the 95% confidence interval calculated from 2000 bootstrap simulations.

To check if these differences of burial depths were statistically significant we tested the hypothesis that airbag systems do not reduce burial depths (H0).

We used the non-parametric Wilcoxon test for testing the null hypothesis with the poor amount of measured data. To improve the estimate and confidence interval, it was checked with a bootstrap test whether the difference of mean and median as test statistics for the bootstrap sample was significant. Tab. 3 shows the probabilities (p-values) under the null hypothesis.

Considering p-values of less than 0.05 as statistically significant, the results show that the burial depths were lower for the dummies carrying an airbag system compared to the control dummies. There are no significant differences in burial depths between the two airbag systems ABS and Snowpulse (SP) on the one hand, as well as no significant differences between the avalanche ball (LB) and the dummies without any additional safety equipment (Nix). There was also no correlation between the position of the dummies (upper/lower row) and the tested equipment.

Table. 2: Mean burial depth, standard deviation and position of dummy in the debris.

	Airways (cm)	Head (cm)	Body (cm)	Position of body: back/belly/lateral (counts)
Nix (n=5)	49 ± 31	47 ± 34	51 ± 30	4/1/0
LB (n=6)	37 ± 22	27 ± 24	40 ± 22	3/3/0
ABS (n=7)	12 ± 14	7 ± 15	26 ± 22	3/2/2
SP (n=7)	19 ± 13	7 ± 11	22 ± 22	3/3/1
With airbag (ABS/SP, n=14)	15 ± 13	7 ± 13	24 ± 21	
Without airbag (nix/LB, n=11)	42 ± 26	36 ± 30	45 ± 25	

Tab. 3: p-values of Wilcoxon tests and bootstrap tests concerning the null hypothesis.

	Wilcoxon test	Bootstrap difference mean	Bootstrap difference median
Burial depth airways	0.002	<0.001	0.012
Burial depth head	0.004	<0.001	0.01
Burial depth body	0.025	0.01	0.023

3.2 *Evaluation of burial*

Burial time is crucial for surviving in an avalanche. After 18 minutes, 91% of completely buried people in avalanches are still alive (Brugger et al., 2001). Therefore it is important to minimize the burial time. From this point of view we assigned to each dummy credits for criterions which reduce burial time:

a) 1 credit point if equipment or dummy was visible from far away.
b) 1 credit point if the head was visible
c) 1 credit point if the airways were buried less than 10 cm under the surface.

The number of credit points was higher for the dummies equipped with an airbag system than for the dummies equipped with the avalanche ball or with no additional equipment (Table 4).

Table. 4: Given credits for buried dummies with mean and +/- one standard deviation. If only one or two credits were given, the additional letters indicate which credit points were given.

	Credit points	median
Nix (n=5)	0/0/3/0/0	0
LB (n=6)	2ab/1a/3/1a/1a/1a	1
ABS (n=7)	3/3/3/1a/2ab/3/3	3
SP (n=7)	3/3/2ab/1a/2ab/3/3	3

In the same way as for the burial depths we tested differences between the safety equipment by the given credits. Tab. 5 shows the p-values under the null hypothesis stating that there are no differences between the systems.

From the results in Tab. 5 we conclude that:
- Airbag systems (ABS and SP) were rated significantly better than systems without airbags.
- Airbag systems were rated significantly better than the avalanche ball (LB).
- The rating for the avalanche ball (LB) was only marginally better than for dummies without any additional equipment.

Table 5: p-values of Wilcoxon tests and bootstrap tests of the credit point data.

null hypothesis	Wilcoxon test	Bootstrap-test difference mean
rating for airbag system (ABS and SP) is not higher than for control group (Nix)	0.007	0.002
rating for airbag system (ABS and SP) is not higher than for avalanche ball (LB)	0.02	0.008
rating for avalanche ball (LB) is not higher than control group (Nix).	0.041	0.09

3.2 *Measurements of the head acceleration*

Fig. 6 shows the acceleration which was measured on the dummies back part of the head in avalanche no. 2. Depending on the direction of the impact, the acceleration logger measured at maximum between 16 and 27 times the gravitational acceleration (g). In avalanche no. 2, such high values were measured during some short peaks for all dummies except for the Snowpulse system (SP). Also in the other avalanches, isolated peaks exceeded this threshold.
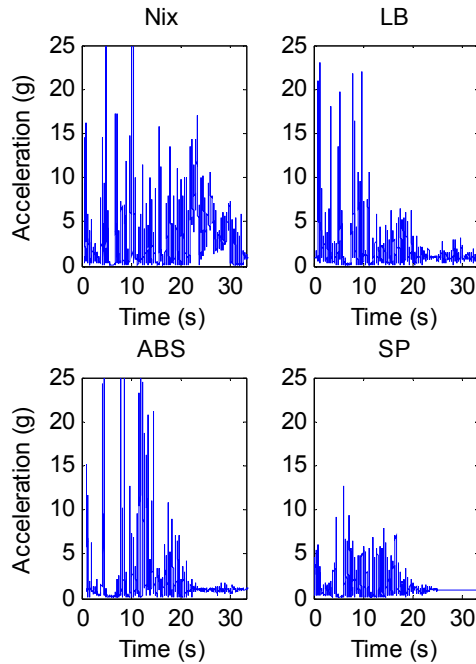
Figure 6: Accelerations measured during avalanche flow (avalanche no. 2).

How dangerous are these accelerations?

The car industry uses expensive dummies where acceleration is measured in the centre of the head. The head is connected with a flexible neck to the body. To describe the severity of a collision, a so-called "head injury criterion (HIC)" is used (Cichos et al., 2008).

$$HIC = \max_{t_1, t_2} \left[\frac{1}{(t_2 - t_1)^{3/2}} \left(\int_{t_1}^{t_2} a(t) dt \right)^{2.5} \right],$$

where the maximum is searched for during a period $(t_2 - t_1) \leq 36$ ms.

Although there is no direct correlation between the HIC and the expected injury, it is considered as a measure of possible harm (Marjoux et al., 2008).
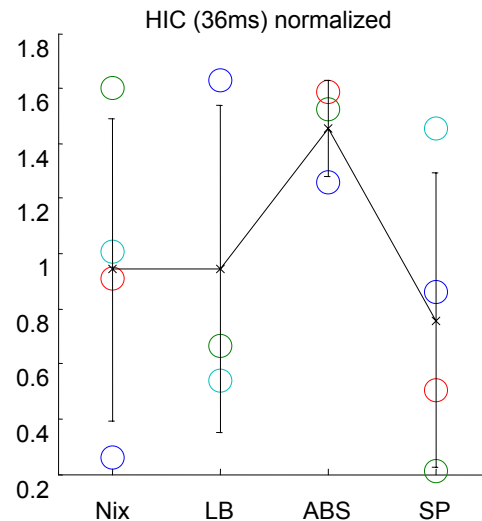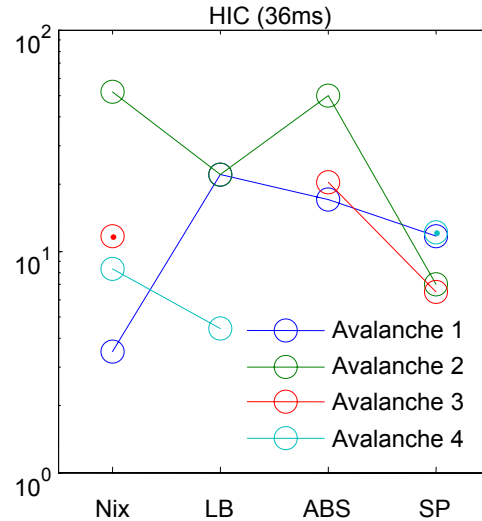

Figure 7. HIC calculated from the acceleration data (top). The bottom graph shows the HIC normalized by the mean acceleration of all dummies per avalanche. The vertical lines show one standard deviation of the data.

In our tests the head was fixed rigidly to the body. Therefore, the acceleration data would have to be corrected by the ratio body head to body mass. This would give approximately 15 times higher acceleration values. Due to the construction of our dummies, the injury risk could not be determined absolutely. Therefore we confined ourselves to a relative comparison between the tested systems. The top panel of Fig. 7 shows the HIC-values for all four avalanches. Due to technical reasons there was

no data measured for the avalanche ball in avalanche no. 3 and for the ABS airbag in avalanche no. 4. The values scatter strongly and are highest for avalanche no. 2. To compare the results among all avalanches, the HIC values were normalized by the mean HIC per avalanche (Fig. 7, lower panel). The dummies without additional equipment (Nix) and the ones with the avalanche ball (LB) had similar force on the head, whereas the force for the ABS airbag was higher and the one for the Snowpulse airbag lower. However, to draw any sound conclusions, more measurements would be necessary. Theoretically, the higher force for the ABS airbag can be explained: People with airbags stay closer to the surface of the avalanche where the velocity is highest (Kern et al., 2004). If you get caught by an avalanche from above, as in the tests, you stay at the turbulent front of the avalanche with the highest stresses. This also applies to the Snowpulse airbag, but the different shape of the airbag seems to protect the head and reduce the acceleration.

The impact on the airbags is large enough to nearly tear off the backpack from the body. We often observed the breast strap to be right below the chin of the dummies after the avalanche release. The use of leg loops is therefore recommended although not often used in practice and also not in our tests.

3. CONCLUSION

For the first time since 10 years, tests were done with additional avalanche safety equipment available on the market. In four typical avalanches for backcountry and off-piste skiers, we tested the avalanche balloon packs ABS and Snowpulse as well as the avalanche ball. The results show that dummies with airbag systems were buried significantly less deep than dummies with the avalanche ball or without any additional equipment. The airways of dummies without avalanche balloon packs were buried 42 cm on average with a 95% confidence interval from 25 to 63 cm. The mean burial depth of dummies with airbag systems was 15 cm with a 95% confidence interval from 8 to 26 cm. There were no significant differences of burial depths between the two airbag systems ABS and Snowpulse.

The avalanche runout zone was rather favorable for a victim as specific terrain features which would promote deep burials did not exist. The four avalanches triggered for the tests are therefore not representative for all avalanche burial situations. Still they allowed finding differences between the tested systems.

Furthermore, we evaluated each burial with a rating system. The airbag systems performed best since they both increased the visibility as well as reduced the burial depth significantly. The avalanche ball was also always visible after each avalanche, only the dummies without any additional equipment where not visible in 4 out of 5 burials.

Preliminary results suggest that the only difference between the two airbag systems ABS and Snowpulse may be the force acting on the head as indicated by the acceleration measurements. With the ABS airbag system the head seems to be more exposed to accelerations than with the Snowpulse system.

5. ACKNOWLEDGEMENTS

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