snow science

An Up-to-Date Perspective on the Effectiveness of Avalanche Airbags

Story by Pascal Haegeli, Markus Falk, Emily Procter, Benjamin Zweifel, Frédéric Jarry, Spencer Logan, Kalle Kronholm, Marek Biskupic, Hermann Brugger

Over the last five years, the use of avalanche airbags has increased dramatically, both among professional guides and amateur recreationists. While there were only a couple different airbag types on the market ten years ago, backcountry enthusiasts can now choose from a wide range of models produced by at least four different manufacturers. In additional, a few new manufacturers are pushing into the growing market with their own innovative designs.

Avalanche airbags have a tremendous potential to save lives, since they are the only avalanche safety device that can directly prevent or reduce the severity of avalanche burial—the root cause of the majority of avalanche deaths. As a consequence, some avalanche warning centers now recommend airbags as a useful complement to the traditional avalanche safety tool kit of transceiver, probe and shovel. Whereas the underlying mechanism for the effect of avalanche airbags[i] has been validated conclusively using mathematical models and field tests, the precise effect of airbags on avalanche mortality is still being debated. While manufactures like to present airbags as the ultimate avalanche safety device (e.g., "97% survival", "8x safer!"[ii]), prominent avalanche educators try to warn against the 'silver bullet' marketing by highlighting that the number of lives saved per 100 fatalities might only be in the single digits.[iii] Since both sides claim their analyses are based on solid data and rigorous statistics, it is difficult for the layperson to determine what's right and what's wrong. However, an accurate and easily understandable presentation of the true effect of airbags on avalanche mortality is important. According to a study by Christie (2012) from Backcountry Access, survival statistics are the most important reason for airbag purchases among their customers.

A number of independent statistical evaluations have assessed the effectiveness of airbags, the most prominent of them is the analysis by Brugger et al. (2007). However, due to the small number of incident records involving airbags available at the time, the analysis has limitations and the results should be interpreted cautiously. More recently, Shefftz (2012) compared the available ABS airbag involvement data to various avalanche accident datasets to estimate the range of impact airbags might have on avalanche survival. However, this type of comparison also has challenges that limit the resulting conclusions. The goal of this article is to provide an up-to-date perspective on the effectiveness of airbags based on a detailed study we recently published in the journal Resuscitation (Haegeli et al., 2014). In addition to simply presenting the results of the study, we also want to take this opportunity to describe the challenges that evaluations of avalanche safety equipment face in detail. We hope that this information will help backcountry recreationists to assess marketing claims more critically and make better informed choices when deciding whether to add an airbag to your avalanche safety kit or not.

Mortality, mortality difference and mortality ratio

Whenever you read statistics—airbags or otherwise—you should immediately ask yourself the following questions:

- What is the question they are trying to answer?
- Where is the dataset coming from?
- What kind of assumptions were made during the analysis?

Without a clear understanding of this context, the presentation of statistical figures is meaningless, even if number might actually be technically correct.

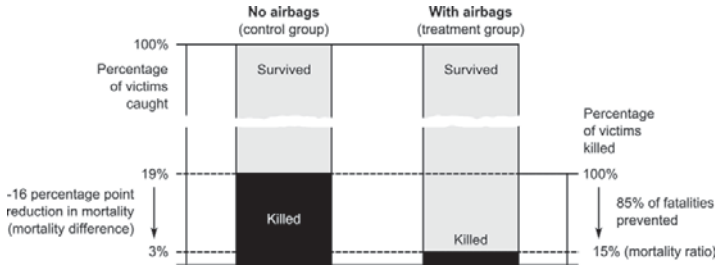

Fig. 1: Mortality difference and mortality ratio illustrated with the results of Brugger et al. (2007)

The first step of examining the effectiveness of any safety device is therefore to specify the question you want to answer. We think that the most interesting questions for the evaluation of avalanche airbags are:

1) How does the use of an avalanche airbag affect my chance of getting killed in a serious avalanche involvement?

2) How many avalanche fatalities could be prevented with the widespread use of avalanche airbags?

The statistical measures used to answer the two questions are the mortality difference for the first question and the mortality ratio for the second question. These two measures are closely related, but they offer different perspectives on the effectiveness of airbags and it is important to clearly understand their differences.

We are using the results of the study by Brugger et al. (2007) to explain the meaning of these two statistical measures in detail. The dataset used by Brugger and colleagues consisted of 1504 avalanche involvements occurring in open terrain in Switzerland and Austria between 1990 and 2005. Thirty-five of the avalanche victims included in this dataset were equipped with airbags during their involvement. Out of 100 victims involved in avalanches without airbags (control group), 81 survived because they did not sustain any fatal injuries and did not get buried or were found and extricated in time (Table 1). This is equivalent to a mortality rate of 19%. Out of 100 avalanche victims equipped with airbags (treatment group) 97 survived, which corresponds to a mortality of 3%.

Table 1: Dataset of Brugger et al. (2007)

	Survived	Killed	Total
Without an airbag (control)	1191 (81%)	278 (19%)	1469
With an airbag (treatment)	34 (97%)	1 (3%)	35
Total	1225	279	1504

Based on the data presented in Table 1, Brugger et al. (2007) showed that that the use of avalanche airbags results in a significant reduction of the mortality by 16 percentage points from 19% to 3% (Fig. 1, left axis). This is the so-called mortality difference. The mortality ratio scales or normalizes the mortality of victims with airbags with the original mortality of victims without airbags (mortality of the treatment group divided by the mortality of the control group; Fig. 1, right axis). In the study of Brugger et al. (2007), the mortality ratio is 15%, which means that out of 100 avalanche victims killed without airbags, 15 would still die even if all were equipped with avalanche airbags. In other words, 85 of 100 fatalities could have been prevented with the use of airbags.

Only relevant cases

To date, the vast majority of analyses on the effectiveness of airbags were based on an airbag involvement dataset that was collected collaboratively by the ABS airbag manufacturer and the WSL Institute for Snow and Avalanche Research SLF. This dataset is almost entirely European and it includes a wide spectrum of incidents ranging from large avalanche with multiple burials to small avalanches where single victims managed to avoid being buried. While all of these cases provide valuable information on airbag performance, not all of them are suited for a statistical analysis of the effect of airbags on mortality. A detailed description of the criteria used to put together the analysis dataset (Were all known airbag incidents included in the analysis or did it only focus on a specific subset?) is of utmost importance when interpreting statistical results.

One of the goals of our study was to collect a larger and geographically more comprehensive dataset that is well suited for truthfully estimating the effectiveness of airbags. Existing records of well-documented avalanche accidents involving at least one airbag user were collected from data sources in Canada (Canadian Avalanche Association), France (National Association for Snow and Avalanche Studies), Slovakia (Avalanche Prevention Center), Norway (Norwegian Geotechnical Institute, Norwegian Red Cross), Switzerland (WSL Institute for Snow and Avalanche Research SLF) and the United States (Colorado Avalanche Information Center). Since airbags are designed to prevent or reduce the severity of avalanche burial, we focused on avalanche involvements with the potential for full burial. This was accomplished by including only incidents with avalanches of a destructive size 2 or larger according the Canadian or American avalanche size classification and including only victims who were seriously involved in the avalanche. This means that they were either seriously involved in the flow of the avalanche or hit by the avalanche from above then partially or completely buried. Victims who were only slightly moved at the edge of the avalanche, managed to remain standing during entire involvement or even ride out of the avalanche were excluded from the dataset as airbags are unable to affect the outcomes of these types of involvements. The resulting dataset consists of 245 incidents with a total of 424 seriously involved individuals. Two hundred and forty-six (58%) of the included victims had an inflated airbag, 61 (14%) had an airbag that was not inflated during the involvement, and 117 (28%) were not equipped with airbags.

Unbiased control group

The accurate assessment of airbag effectiveness requires a reliable control group of victims without airbags. The challenge is that many avalanche incidents with good outcomes (i.e., no fatalities or major injuries) simply never get reported. This prevents us from calculating a reliable base mortality for avalanche involvements. Since both airbag manufacturers and avalanche safety researchers are actively hunting for the information on avalanche accidents involving airbags, it is likely that the reporting rate of non-fatal avalanche accidents with airbags is considerably

Continued on next page ➡

Effectiveness of Airbags

(continued from previous page)

higher. This difference in reporting rates can unintentionally skew the results of statistical analyses on the effectiveness of airbags.

To obtain a control group that is as comparable as possible to our airbag cases, we limited our analysis to only include accidents that involved both users and non-users of avalanche airbags. This allowed us to extract both the treatment group and the control group from the same accidents, therefore avoiding any reporting biases. However, the price for this unbiased control group is a considerably smaller dataset that only includes 35% (106 of 207) of the available records on seriously involved individuals with airbags and is skewed towards larger avalanches with multiple involvements. Remember this when interpreting the final results.

Controlling for other factors affecting mortality: adjusted mortality rates

Airbags are clearly not the only factor affecting your chance of surviving an avalanche involvement. The size of the avalanche, your location when the avalanche releases, the character of the runout zone, whether you get injured and whether you wear an avalanche transceiver all have the potential to affect the outcome of your involvement. Because all of these factors work together, a simple cross table like the one shown in Table 1 is unable to correctly separate the effect of airbags from the other contributing factors.

To account for the other contributing factors in our analysis, we collected information on a large number of parameters describing the characteristics of the incident, the avalanche and the victims. We then examined the influence of all these factors on mortality simultaneously using a statistical technique called binomial logistic regression analysis. This method allows us to properly identify and separate effects of the individual contributing factors. The results of this analysis were then converted into adjusted mortality rates, which are interpreted in the same manner as mortality rates calculated from cross tables. The interested reader is referred to our paper in Resuscitation to get the full list of parameters included in the analysis and read the full details on the logistic regression analysis.

What did we discover?

The results of our analysis support the finding that airbags significantly reduce the mortality in serious avalanche involvements, but the effect is lower than previously reported. The analysis revealed that airbags affect mortality only indirectly through their influence on victims' grade of burial.[iv] Other factors affecting grade of burial are avalanche size (the larger the avalanche the higher the likelihood of a critical burial) and whether the victims sustained a major traumatic injury during the involvement (higher likelihood of critical burial with major injury).[v] The adjusted risk of critical burial is 47.0% for victims without airbags or with non-inflated airbags, and 20.1% for users with inflated airbags.

Mortality is subsequently determined by grade of burial, avalanche size and major traumatic injuries. The adjusted mortality is 43.8% for critically buried victims and 2.9% for non-critically buried victims. The adjusted mortality with and without an inflated airbag can now be calculated by multiplying the adjusted risk of critical burial with respect to airbag use and the adjusted mortality with respect to critical burial as illustrated in Fig. 2.

While the mortality without inflated airbags is 22.2%, the mortality with inflated airbags is 11.1%. This results in an adjusted mortality difference of 11 percentage points (95% confidence interval is -4 to -18 percentage points) and an adjusted mortality ratio is 0.5 (95% confidence interval is 0.3 to 0.7).

This means that out of 100 victims without airbags seriously involved in avalanches similar to the ones included in the analysis dataset 22 are killed and 78 survive because they did not sustain any lethal injuries, did not get buried during their involvement, or were found and extricated in time. Out of 100 victims equipped with inflated airbags, only 11 would have been killed. In other words, an additional 11 victims would have survived due to the airbags, which means that half of all fatalities could have been prevented. These effects are significant, but they are not as good as previously reported (-11 percentage points versus -16 percentage points in Brugger et al., 2007). Furthermore, the mortality of airbag users is significantly higher than previously reported (11% versus 3% in Brugger et al., 2007). While this difference is partially due to the fact that our analysis focused on larger avalanche accidents with multiple involvements, it clearly highlights that airbags do not guarantee survival under all circumstances. Even if all victims in the present dataset were equipped with inflated airbags, one of every nine victims would have died.

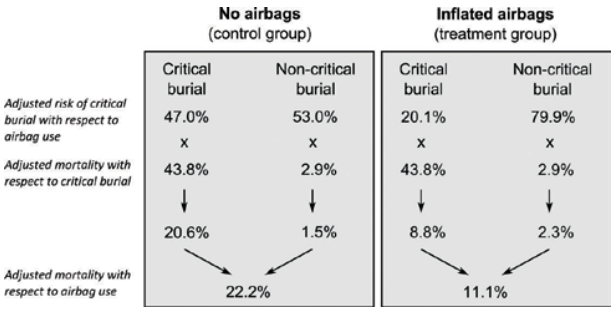

Fig. 2: Calculation of adjusted mortality with respect to the use of inflated airbags.

What about non-inflations?

So far we have examined only the benefit of inflated airbags. In other words, the 11 percentage point decrease in mortality represents the best case scenario when airbags are properly deployed and inflate as designed. However, past studies have repeatedly highlighted non-inflations as a serious problem for the performance of airbags. To examine non-inflations, we used all available records of airbag users including ones from accidents that only involved single users. The resulting dataset consisted of 307 records from 245 accidents. The overall non-inflation rate within this sample was 20% (61 of 307), which is very close to the rate reported by Brugger et al. (2007). This non-inflation rate reduces the 11 percentage point decrease in mortality from inflated airbags to roughly 9 percentage points (i.e., 80% of 11 percentage points). This clearly highlights that non-inflations still pose a considerable threat to the airbag performance.

What are the causes for these non-inflations? Information on suspected causes was available for 52 cases:

60% deployment failures by users
12% maintenance errors (e.g., canister not attached properly)
17% device failures (i.e., performance issues that resulted in design and/or production revisions)
12% destruction of airbag during involvements

Relative to the total number of users, the rate of airbags destroyed in involvements was 2% (6 of 307) and the rate of device failures was 3% (9 of 307).

To better understand the reasons causing users not to deploy their airbags, we examined the dataset for relationships between non-deployment and any relevant victim or involvement characteristics. Since we did not detect a significant relationship between deployment rates and avalanche size, non-deployments do not seem to be the result of more violent involvements. However, we found that the non-deployment rate is significantly lower among avalanche professionals (e.g., guides, ski patrollers, avalanche technicians) than recreationists (5% versus 14% respectively). This suggests that familiarity with airbags and their deployment procedures may considerably improve the effectiveness of these devices.

How about risk compensation?

Risk compensation is a common concern when weighing the pros and cons of avalanche airbags. Are users going to feel less vulnerable when wearing an airbag and therefore expose themselves to a higher level of avalanche hazard? While there is no empirical evidence to date on risk compensation behaviour with respect to airbag use, it is a well-studied phenomenon in other areas. Hedlund (2000) offers a summary of existing evidence on risk compensation with respect to road safety initiatives. He states that while risk compensation does occur—even though not consistently—it generally does not eliminate the safety gains from the programs, but only reduces the size of the expected effect. It would be extremely difficult to collect the necessary data to properly quantify the effect of risk compensation on the effectiveness of airbags. However, Hedlund (2000) provides an interesting personal list of four characteristics of safety equipment or initiatives that make risk compensation more likely:

1) Is the piece of safety equipment obvious? Do I even know it is there?

2) Does the piece of safety equipment affect me negatively, physically and/or mentally?

3) Does the effect of the piece of safety equipment directly relate to the motivation and objective of my activity?

4) How much control do I have over my actions? Can I even change my actions if I want to?

Airbags seem to generally score highly on all of these characteristics:

1) It is difficult to forget the fact that you are carrying an airbag as they require frequent attention.

2) Airbags are expensive and heavy, and handling them during a trip can have its challenges.

3) If your primary reason for going into the backcountry is to ski challenging terrain, the benefits of airbags are perfectly aligned with your objective; if you are simply going into the backcountry to enjoy nature and calm, the effect of airbags is much less connected to your goals.

4) While amateur recreationists have complete freedom and control over their actions, avalanche professionals are likely more restricted due to company procedures and policies or professional best practices.

Based on this list of characteristics, it can be assumed that that risk compensation behaviour is likely among airbag users, particularly among recreationists who are interested in pushing their physical and athletic limits.

While our study does not provide any information regarding the presence of risk compensation behaviour with airbags, the results of our analysis offer some insight about the possible consequences of risk compensation behaviour. The parameter estimates from the binomial logistic regression analysis on critical burial indicate that the risk reduction gained from the use of an airbag is roughly equivalent to the risk increase from being involved in an avalanche of one size class larger. This means that personal safety benefits from airbags are quickly nullified if individuals use them to justify increased exposure to terrain where larger avalanches are likely.

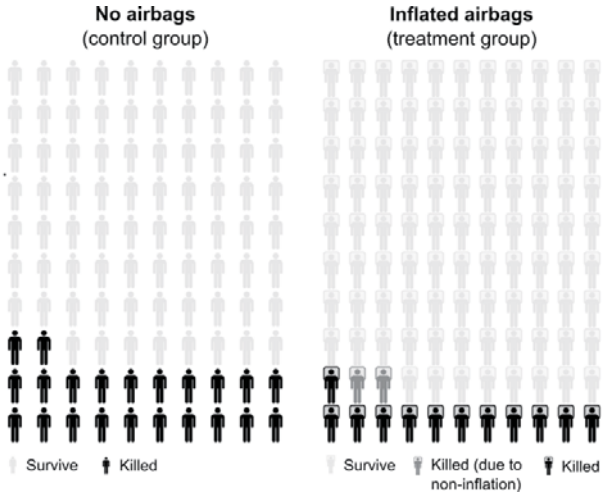

Fig. 3: Effect of airbags on the mortality of victims seriously involved in avalanches.

Limitations

Clearly stating the limitations of an analysis is important when presenting statistical results. In our analysis of the effectiveness, the sample of airbag user records was substantially smaller than the complete dataset (201 records were excluded out of 307 total) to ensure an unbiased control group. The resulting dataset was therefore skewed towards large avalanches with multiple involvements. Furthermore, the dataset had a lower percentage of avalanche professionals and a higher percentage of victims located in the track or runout when the avalanche was triggered. Remember these limitations when interpreting the mortality statistics presented in this article. While the mortality among airbag users in the excluded records (i.e., smaller avalanches, single involvements) is smaller than in the analysis dataset, it is unclear how the effect of airbags shown in the present analysis transfers and contributes in relation to the reduced mortality from smaller avalanche and other differences.

Take home messages

What are the most important take home messages from our study?

- Airbags are a valuable safety device, but their impact on mortality is lower than previously reported and survival is not guaranteed.
- For individuals seriously involved in avalanches of size 2 or larger, the use of an inflated airbag reduces the risk of dying from 22% to 11% (Fig. 3). This means that inflated airbags will save about half of the victims who would have otherwise died.
- Non-inflations remain the most considerable limitation to the effectiveness of airbags. The observed overall non-inflation rate from all causes is 20%.
- If non-inflations are taken into account, airbags reduce the risk of dying from 22% to 13% (Fig. 3) and the proportion of saved victims is only 41%.
- Sixty percent of all non-inflations are due to deployment failures by the user. Familiarity with deployment procedures and proper maintenance are paramount for ensuring that airbags work properly.
- Personal safety benefits from airbags are quickly nullified if users use them to justify increased exposure to terrain where larger avalanches are possible.

Where to go next?

While our results show that airbags can reduce mortality in serious involvements in general, the analysis does not provide any insight about the benefit of airbags under different circumstances. For example, it would be useful to estimate and compare the effectiveness of airbags in avalanches with smooth runout zones versus avalanches with terrain traps. Another interesting question would be to examine the effectiveness of airbags as a function of the location of the victim when the avalanche was triggered (start zone, track, runout). However, collecting reliable avalanche accident data is challenging and records are often incomplete. We would like to encourage national avalanche safety agencies, international search and rescue associations, airbag manufacturers and researchers to work together to develop standardized data collection protocols to facilitate future studies. In addition, we would like to encourage recreationists to diligently report all types of avalanche involvements to the local avalanche warning services. The resulting richer datasets will facilitate more detailed studies that will further improve our understanding of the benefits and limitations of airbags and other avalanche safety devices, avoid misleading statements on the impact of these devices, and help users to make better informed choices. ❄

Acknowledgements

We thank the many individuals who contributed to the collection of avalanche accident information that made this research possible. We would also like to acknowledge Bruce Tremper and Jonathan Shefftz, who provided valuable comments on an earlier draft of this paper.

References

Brugger, H., H.-J. Etter, B. Zweifel, P. Mair, M. Hohlrieder, J. Ellerton, F. Elsensohn, J. Boyd, G. Sumann, and M. Falk, 2007: The impact of avalanche rescue devices on survival. Resuscitation, 75, 476–483.

Christie, S., 2012: Avalanche Airbag Survey: A U.S. Perspective. Paper presented at 2012 International Snow Science Workshop in Anchorage, AK, 361–362 [available at http://arc.lib.montana.edu/snow-science/item.php?id=1700].

Haegeli, P., M. Falk, E. Procter, B. Zweifel, F. Jarry, S. Logan, K. Kronholm, M. Biskupic, and H. Brugger, 2014: The effectiveness of avalanche airbags. Resuscitation.

Hedlund, J., 2000: Risky business: safety regulations, risk compensation, and individual behavior. Injury Prevention, 6, 82–90.

Shefftz, J. S., 2012: Enhanced avalanche survival from airbag packs: Why can we learn from the data? The Avalanche Review, 30, 8–9.

Corresponding Author

Pascal Haegeli is a Canadian avalanche researcher and safety consultant based out of Vancouver, BC. His interdisciplinary research aims to allow backcountry travellers to make better informed choices when heading into avalanche terrain. Pascal is also an adjunct professor at the School of Resource and Environmental Management at Simon Fraser University.

[i] Inverse segregation, also known as the "Brazil nut effect", naturally sorts particles within an avalanche according to size with larger particles being moved towards the surface of the avalanche. Inflated avalanche airbags make avalanche victims, already large particles, even larger particles within the avalanche, which increases their chances to end up on top of the debris before the avalanche comes to a stop. Buoyancy effects, which are used by floatation devices, do not play a role in avalanche airbags.

[ii] https://www.abs-airbag.com/us/abs-survival-principles.html.

[iii] Dale Atkins in the 2011 November issue of Power Magazine (http://www.powder.com/stories/know-boundaries-5/).

[iv] Grade of burial was defined as either critically buried (i.e., head of the victim under the snow and breathing impaired) or non-critically buried (i.e., unobstructed airways).

[v] Traumatic injuries are considered major if the injured requires hospitalization.