



## TECHNICAL NOTE

N. Ade,<sup>1</sup> R. Stämpfli,<sup>2</sup> and K.-U. Schmitt<sup>3</sup>

# Evaluating Airbag Safety Vests for Equestrian Sports

### Reference

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### ABSTRACT

Thoracic injuries are common in equestrian sports. Advanced safety equipment, including airbag vests, have been introduced to the market to protect this body region. Standard EN13158 ["Protective Clothing—Protective Jackets, Body and Shoulder Protectors for Equestrian Use: For Horse Riders and Those Working with Horses, and for Horse Drivers—Requirements and Test Methods," European Committee for Standardization, Brussels, 2009 (in German)] defines the minimum requirements for conventional safety vests; however, there is currently no standard related to airbag vests for equestrian sports. The aim of this study is to investigate the applicability of a draft motorcycling standard [prEN1621-4, "Motorcyclists' Protective Clothing Against Mechanical Impact. Part 4: Motorcyclists' Inflatable Protectors—Requirements and Test Methods," Deutsches Institut für Normung e.V., Berlin, 2010 (in German)] for equestrian airbag vests. Based on EN13158 and prEN1621-4, airbag vests for equestrian sports were tested. In addition to the tests outlined in the above standards, the pressure induced by the inflating airbag on the thorax was measured and the sound level of the deploying airbag was recorded. The use of airbag vests in conjunction with conventional vests was also investigated. Testing airbag vests in accordance with the existing standards was possible without practical issues. The impact tests indicated that airbag vests were able to absorb higher forces compared to conventional vests. The airbag inflation times were recorded to be between 186 and 260 ms. Trigger forces were measured to be between 150 and 593 N. The maximum pressure on the upper body resulted in 20 to 84 kPa. The bang associated with airbag deployment generated a sound level of 87.3 to 98.4 dB(A). The degree of protection offered by airbag vests was demonstrated by applying the procedures prescribed in existing standards. The draft standard for motorcycling proved to be applicable to equestrian sports. However, regarding the interpretation of the test results, it seems necessary to adapt several threshold values of this standard to account for equestrian-specific parameters.

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<sup>1</sup> Institute for Biomechanics, ETH Zurich, D-HEST, Vladimir-Prelog-Weg 3, 8093 Zurich, Switzerland (Corresponding author), e-mail: nicole.ade@alumni.ethz.ch

<sup>2</sup> Swiss Federal Laboratories for Materials Science and Technology (EMPA), Protection and Physiology, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland, e-mail: rolf.staempfli@empa.ch

<sup>3</sup> Schmitt Kai-Uwe, Institute for Biomedical Engineering, Univ. and ETH Zurich, Gloriastrasse 35, 8092 Zurich, Switzerland, e-mail: schmitt@ethz.ch

## Keywords

protective equipment, airbag safety vests, equestrian injuries, injury prevention, impact testing

## Introduction

Injuries in equestrian sports are of concern as they often exhibit high injury severity. Hasler et al. [1] investigated 365 accidents in horse riding in which two athletes died and 145 sustained injuries with an abbreviated injury scale (AIS) score of 3 or more; 18 % of those injuries were related to the thorax and 12 % concerned the spine. Siebenga et al. [2] also reported a high risk for spinal injuries. Most of these injuries were observed in the lower thoracic region: 58 % of the spinal fractures in their sample occurred at level Th12/L1. In Switzerland, 8410 injuries were sustained in horse riding in 2010: 51 % of the athletes sustained thoracic injuries, and 73 % of the injured were women [3]. In 2011, it was shown that injuries in equestrian sports represent 2.2 % of all sports injuries in Switzerland, but correspond to 3.8 % of the costs related to sports injuries [4]. This can likely be explained by the high AIS severity of the injuries.

Most injuries in equestrian sports result from falls off the back of a horse [5–11]. Although less frequent, hoof kicks have a high potential to cause severe injury because of the high hoof-impact forces involved. The literature reports impact forces up to 10 kN, which can result in fracture of bones and injury to internal organs [12–14].

To reduce injury risk in equestrian sports, different protective equipment is available. Helmets are, for instance, widely used. The use of helmets is often enforced by regulations defined by sports associations. Helmet-wearing rates range from 61 % [15] to 83 % [16]. In contrast, safety vests are less frequently worn. Although there are no detailed data available in the literature, an unpublished survey by the authors shows that of the approximately 2000 participants surveyed only 16 % of the riders wear a safety vest regularly; 31 % reported that a vest is used for certain activities. Reasons for not wearing a vest were mainly related to comfort issues (for example, too stiff or limiting the range of motion), as well as the fact that vests are only required by few regulations [16].

Safety vests for equestrian sports generally make use of damping material (e.g., foam), which is designed to absorb energy at impact. Standard EN13158 [17] defines procedures for mechanical testing and corresponding requirements for such products. However, recently, vests that incorporate an airbag have been introduced to the market. Airbag vests are not covered by the above standard.

Based on observations from other fields such as motorcycling, it might be assumed that airbag technology will be more widely used in the future. In the event of an impact, the airbag

inflates and thus establishes a protective cushion around the thorax. Vests for equestrian sports are usually triggered by a cord that is fixed to the saddle. In case of a fall, the cord pulls the trigger and the airbag is inflated. The gas used to inflate the airbag is included in a cartridge, which is part of the garment. The gas cartridge can be replaced so that the vest can be inflated several times.

Thollon et al. [18] found that the use of airbags in motorcycling has significantly reduced the injury severity. Mechanical tests performed using Post Mortem Test Objects as well as computer simulations showed a reduction of impact forces and thorax compression of up to 80 %. To account for the minimum requirements of airbag garments in motorcycling, a draft standard was developed (prEN1621-4) [19].

Despite the apparent benefit of airbag vests, the potential of airbag-induced injuries should also be considered. This relates to the pressure acting on the body when the airbag is deployed as well as the potential for an acoustic shock caused by deployment. Few studies have been conducted addressing these aspects. Performing tests with (some of the first) airbags in the automotive field, Schaefer [20] recorded pressure peaks on a crash test dummy between 120 and 240 kPa in an upright body position and 270 to 720 kPa in a forward bending position (closer to the airbag). Hodge and Garinther [21] concluded that a pressure of approximately 69 kPa can result in injury of internal organs (e.g., bleeding of the lung). With respect to acoustic trauma, numerous studies indicate that a noise level of 125 dB(A) can result in injury [22–26].

This study investigates the protective potential of airbag vests for equestrian sports. The performance of such products was compared to conventional safety vests for horse riding. The current standard for safety vests in equestrian sports does not cover airbag vests; it is, therefore, important to determine whether the available draft standard for motorcycling can be applied or whether a different standard is required for these airbag vests.

## Methods

### MATERIALS

Eight conventional safety vests (certified according to EN13159, including different safety levels) and five airbag vests were investigated (**Fig. 1**). Two airbag vests consisted of tubular air chambers, which cover parts of the back and the front of the upper body. The remaining three airbag vests contained a single air chamber, which inflated in the back area only (**Fig. 1**, fourth

**FIG. 1**

Two conventional vests, two airbag vests (both inflated) and one combination of an airbag vest on top of a conventional vest (from left to right). All vests are mounted on the test manikin.



picture from the left). The sample was chosen such that all available technologies and the most popular products on the Swiss market were included. Only commercially available vests were assessed.

The samples used for testing and the test matrix are described in **Table 1**. In addition to EN13158 [17], the conventional vest O is certified according to EN1621-2 [27] (testing back protectors for motorcyclists). Airbag vest T is sold as an add-on product to the conventional vest U. In our tests, using a manikin, this airbag vest was therefore assessed in combination with the conventional vest.

#### DATA COLLECTION

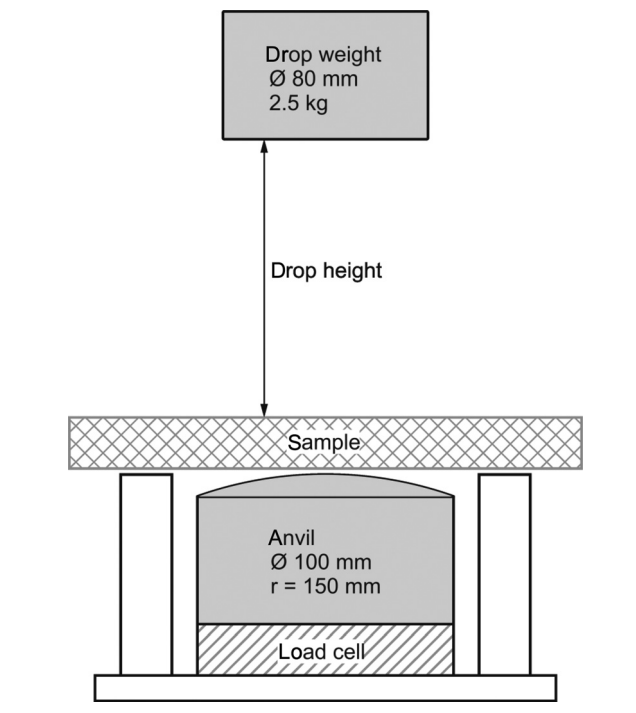
All vests were tested mechanically in accordance with standard EN13158. This included the performance of impact tests in which a mass of  $2.5 \pm 0.025$  kg was dropped on the vest (**Fig. 2**). The standard defines three safety levels that correspond to the impact energy: a product of level 1 can withstand an impact energy of 25 J, level 2 can withstand 30 J, and level 3 can withstand 35 J. The force underneath the vest was recorded by a piezoelectric force sensor (Type 9091, Kistler Instruments, Switzerland), connected to a charge amplifier (Type 5015, Kistler

Instruments, Switzerland) and a computer controlled transient recorder board (Type BE490XE, Nicolet Technologies, The Netherlands) with a sample rate of 40 kHz. One to six tests were conducted per vest (**Table 2**). According to the standard, the maximum force is required to be below 6 kN, and the average maximum force of all tests shall not exceed 4 kN. For the drop tests, all airbag vests were inflated manually. Because the pressure inside a vest as foreseen by the manufacturer was unknown, all airbag vests were inflated to 35 kPa in a first step. Further tests were conducted at 50 kPa and 75 kPa at which the vests were impacted once per pressure step. An air regulator with pressure gauge (Model EARP3000, SMC Corporation, Japan) was used to monitor the vest pressure and keep it constant throughout the test session.

Impact tests were also conducted on conventional vests when worn in conjunction with an airbag vest (**Table 1**). Four impacts were conducted for each of the combinations. Furthermore, airbag vest T was tested together with conventional vest U. Airbag vests P and Q were impacted in the middle of the left front air tube. The remaining airbag vests were loaded in the middle of the air chamber on the back. For each impact, the location was slightly changed ( $\pm 50$  mm) to ensure that the

**TABLE 1** Samples used for testing and the test matrix.

Sample	Product Description	EN13158 [17] Drop Test	prEN1621-4 [19]			
			Intervention Time	Activation Force	Acoustic Shock	Pressure on Body
A	Conventional, level 3	X				X
D	Conventional, level 3					X
E	Conventional, level 3	X				X
F	Conventional, level 2	X				X
G	Conventional, level 3					X
N	Conventional, level 1	X				X
O	Conventional, level 2	X				X
U	Conventional, level 3	X				X
P	Airbag	X	X	X	X	X
Q	Airbag	X	X	X	X	X
R	Airbag [19]	X	X	X	X	X
S	Airbag [19]	X	X	X	X	X
T	Airbag [19]	X	X	X	X	X

**FIG. 2** Test setup for performance of drop tests.

same position was not impacted twice. Conventional vests and the conventional vest when worn in conjunction with an airbag vest were tested at the same locations.

Airbag vests were further tested according to draft standard prEN1621-4 [19]. In particular, the intervention time and the pull force needed to activate the airbag were determined. Intervention time is defined as the time span starting at activation until the maximum volume of the airbag is reached, i.e., the time from activation until the airbag is ready to be impacted. The airbag vests were mounted to a manikin and then activated manually. All tests were recorded by two high-speed cameras (KODAK EKTAPRO HS Motion Analyzer, Model 4540, up to 4500 fps). The point in time when the

maximum volume was reached was estimated by analyzing the video sequences. The pull force that was required to activate the airbag was recorded by two multi-axis force and torque sensors (Type MC2.5, Advanced Mechanical Technology, AMTI, Watertown, MA), connected with two six-channel signal conditioners (Type Gen5, AMTI, Watertown, MA) and set to a sample rate of 240 Hz. The force and torque sensors were integrated into the manikin. The first sensor was installed between the lower part of the manikin and the stand, the second sensor between the upper and lower body part of the manikin, situating it in the lumbar spine between the vertebrae L3 and L4.

All experiments were evaluated as described in the draft standard prEN1621-4.

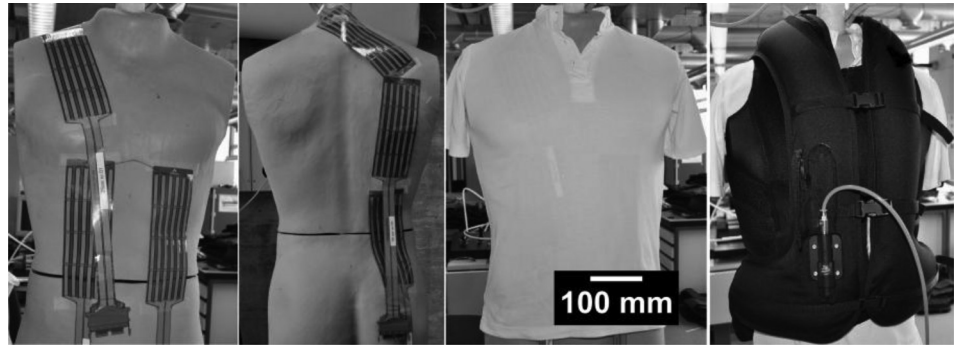
In addition to the standardized test procedures, a sound level measuring device was installed (Type Voltcraft SL-100, Conrad Electronic, Germany) to record the acoustic shock when the airbag deployed. Furthermore, the pressure on the body induced by the inflating airbag was determined using a manikin equipped with six pressure sensors (Tekscan Sensors: F-Scan System, Sensor Type: 9811E, Tekscan, South Boston, MA) at different regions on the upper part of the body (Fig. 3). Each sensor has a matrix of 6 by 16 cells, covering an area of 76 mm by 203 mm. The pressure sensor data was recorded at 120 Hz using the F-Socket research software (Version 6.51, Tekscan, South Boston, MA). The position of the sensors was chosen so that the airbag vests covered the sensors. Each airbag vest was tested once by deploying the airbag via the gas cartridge. Airbag vest P was tested in combination with the conventional vests, which were used in this study (except conventional vest U), and airbag vest Q was combined with conventional vest O. Because of limited size adjustability of the vests, further combinations were not possible. For combined measurements (as well as the tests of airbag vests P and Q alone), the airbags were filled manually to 35 kPa. Data was collected over a 10-s period during which the pressure was kept constant.

**TABLE 2** Impact locations on the conventional vests that were used in drop testing.

Sample	Impact 1	Impact 2	Impact 3	Impact 4	Impact 5	Impact 6
A	Middle back	Back, above shoulder blade	Back, below shoulder blade	Low back	Middle front	Front, ribs
E	Low back	Middle back	Back, between protection panels	Front, lower ribs	Back, shoulder blade	Front, between protection panels
F	Upper back	Middle back	–	–	–	–
N	Upper back	Back, between protection panels	Front zip	Front Velcro	–	–
O	Upper back	Low back	Chest protect	Laterally rib protect	–	–
U	Back, on protection panel	Back, between protection panels	Front zip	Front Velcro	–	–

**FIG. 3**

The test manikin equipped with the Tekscan sensors (*front and back view*), a thin shirt was put over the sensors and the vests were mounted as *top layer* (from *left to right*).



### DATA ANALYSIS

All force and pressure data were processed with Matlab (Version R2011a, The MathWorks, Natick, MA). Force data from the impact tests were smoothed by a fourth-order Butterworth filter with a cut-off frequency of 6 kHz. The data of the pressure sensors were filtered with a rotationally symmetric Gaussian low pass filter of size three by three and standard deviation 0.5. The program was also used to determine the pressure distribution on the sensor strips and to localize the area where the maximum pressure value was detected. To calculate the

maximum force, the resulting force of the three directions (x, y, and z) was used. MS Excel software (Excel 2010, Microsoft Corporation) was used to analyze the pull force required to deploy the airbag vests.

### STATISTICAL ANALYSIS

Statistical analysis was performed using the software SPSS Statistics (SPSS 20.0, SPSS, Chicago, IL). Normal distribution of data was tested using the Kolmogorov–Smirnov test. A student's *t*-test for independent samples (95 % confidence interval) was

**TABLE 3** Results of tests using airbag vests.

	Airbag Vest Sample				
	P	Q	R	S	T
Intervention time, ms	241 <sup>a</sup>	218 <sup>a</sup>	260 <sup>a</sup>	252 <sup>a</sup>	186
>> Threshold: 200 ms					
According to prEN1621-4					
Activation force, N	150	593 <sup>a</sup>	265	172	292
>> Threshold: 300 N					
According to prEN1621-4					
Noise level, dB(A)	90.2	98.4	87.5	87.4	87.3
>> Threshold: 125 dB(A)					
According to Hohmann [26]					
Maximum pressure on body (kPa) and corresponding body region	44 (shoulder region)	84 (neck)	68 (shoulder region)	67 (shoulder region)	20 (lumbar region)
Maximum pressure on body (kPa) and corresponding body region in combination with conventional vest	54–150 (neck and shoulder blade)	184 (neck)	Not measured	Not measured	Not measured
Drop test, level 1 (35 kPa)	6.70 <sup>a</sup>	0.34	0.23	0.20	0.24
>> Threshold: 6 kN according to EN13158 (50 kPa)					
Peak force, kN (75 kPa)	0.44				
Drop test, level 2 (35 kPa)		6.45 <sup>a</sup>	0.25	0.25	0.26
>> Threshold: 6 kN according to EN13158 (50 kPa)					
Peak force, kN (75 kPa)	0.33	0.37			
Drop test, level 3 (35 kPa)			0.28	0.25	0.28
>> Threshold: 6 kN according to EN13158 (50 kPa)					
Peak force, kN (75 kPa)	0.35	0.44			

<sup>a</sup>Indicates a value higher than the corresponding threshold value given in the draft standard prEN1621-4 [19] or standard EN13158 [17], respectively.

used to analyze the differences in mean force values to compare the performance of conventional vests with and without additional airbag vests. The same test was chosen to analyze differences in mean pressure values when using combinations of conventional and airbag vests. An  $\alpha$  level of 0.05 was used for all statistical tests.

## Results

Airbag safety vests are the focus of this study. The results of the various measurements related to airbag vests are summarized in **Table 3**. The results of the drop tests using conventional vests are included in **Table 4**. It should be noted that according to our tests some of the conventional vests did not achieve the threshold values prescribed in EN13158 [17]. The results of the drop tests for combinations of conventional vests and airbag vests are also shown in **Table 4**.

The mean impact force of the conventional vests in conjunction with the airbag vests were all significantly lower than the mean forces derived from testing the conventional vests alone (for all  $t$ -tests for independent samples:  $p < 0.001$ ). Conventional vests that did not comply with the current criteria set out in the standards benefited the most from the combination with an airbag vest, i.e., the largest reduction of the impact force was observed (79 % to 94 % for mean values). **Figure 4** shows an example of a force recording over time for three test settings: a conventional vest, an airbag vest, and a combination of an airbag and a conventional vest.

Airbag vests R and S showed similar results during the pressure testing on the manikin because of the fact that the design of these two vests is very similar. In comparison, airbag

vest T, which is also similarly built but which was tested in combination with conventional vest U, showed on average a reduction of only 28 %. Airbag vest P was combined with all conventional vests for the tests on the manikin fitted with pressure sensors. For all combinations, the maximum pressure was detected in the neck, except for the combination of airbag vest P with the conventional vest G, where the maximum force was measured in the area of the shoulder blade. Conventional vest O generated a peak pressure of 150 kPa when in combination with airbag vest P. However, this result is the result of an artifact in the pressure data, which could not be corrected. The mean pressure values of most combinations (conventional and airbag vest) that were recorded using the six sensor stripes were significantly higher compared to the mean values of the airbag vest R at 35 kPa (N:  $p = 0.023$ , O:  $p = 0.031$ , F:  $p = 0.001$ , G:  $p = 0.012$ , D:  $p = 0.004$ ) except for two combinations of the airbag vest P with two level 3 vests (A:  $p = 0.192$ , E:  $p = 0.060$ ) as well as the combination of airbag vest Q and the conventional vest O (level 2,  $p = 0.627$ ).

## Discussion

A selection of commercially available airbag vests all designed for equestrian sports were tested. For comparison, a selection of conventional safety vests were also included in this study. This selection considers vests of different safety levels according to EN13158 [17]. Generally, the design of the airbag vests differs from conventional vests in the sense that a smaller area of the thoracic surface is covered by protective material. This needs being considered when defining impact areas to be tested. Only areas covered by an airbag tube can actually be tested to avoid

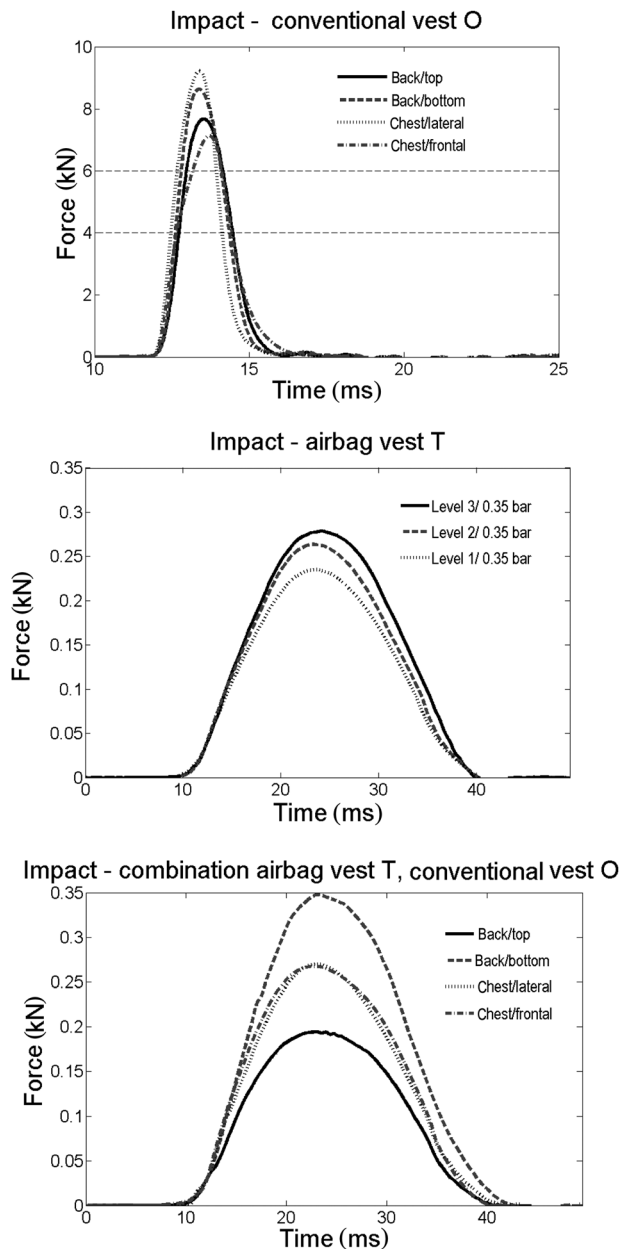
**TABLE 4** Results of the impact tests comparing conventional vests and combinations of conventional vests with airbag vests.

Conventional vest	N	O	F	A	E	U
Test level according to EN13158	Level 1	Level 2	Level 2	Level 3	Level 3	Level 3
Baseline, kN	2.98 (2.90 ± 0.07)	9.23 <sup>a</sup> (8.16 ± 0.96 <sup>a</sup> )	>10 <sup>a</sup> (2x > 10 <sup>a</sup> )	3.04 (2.97 ± 0.07)	6.17 <sup>a</sup> (5.81 ± 0.30 <sup>a</sup> )	2.81 (2.71 ± 0.11)
Residual force in combination with airbag vest, kN						
P	1.16 (1.00 ± 0.10)	4.60 (3.58 ± 0.43)	1.80 (1.60 ± 0.16)	1.77 (1.47 ± 0.14)	1.87 (1.76 ± 0.15)	–
Q	0.68 (0.43 ± 0.11)	1.54 (1.01 ± 0.32)	0.58 (0.44 ± 0.15)	0.98 (0.92 ± 0.05)	1.45 (1.32 ± 0.06)	–
R	0.27 (0.25 ± 0.01)	0.33 (0.27 ± 0.03)	0.38 (0.28 ± 0.04)	0.23 (0.23 ± 0.00)	0.27 (0.27 ± 0.01)	–
S	0.25 (0.23 ± 0.01)	0.26 (0.22 ± 0.02)	0.31 (0.27 ± 0.02)	0.22 (0.22 ± 0.00)	0.24 (0.24 ± 0.00)	–
T	0.29 (0.25 ± 0.02)	0.35 (0.27 ± 0.04)	0.34 (0.29 ± 0.02)	0.24 (0.24 ± 0.00)	0.27 (0.26 ± 0.00)	0.27 (0.26 ± 0.01)
Reduction of the impact forces by the combination with an airbag	85 %	87 %	94 %	79 %	88 %	90 %

Note: Values presented are peak values and mean values ± SD.

<sup>a</sup>Indicates a value higher than the corresponding threshold value in EN13158 [17].

**FIG. 4** Force curves over time of a conventional vest with drops on different impact points (*top*), of an airbag vest during different impact energy (*middle*), and a combination of a conventional vest and an airbag vest at an impact energy of 35 J (*below*).



damage to the test instrumentation. Similarly, the pressure acting on the body when the airbag is inflated is concentrated on small areas. Depending on the technology, high-pressure peaks might occur. To prevent airbag-induced injury, the pressure on the body should therefore be checked. The corresponding tests performed in this study used a manikin equipped with pressure sensors. In principle, this technology worked well as it allowed the location of maximum pressure as well as the analysis of the development of the pressure over time to be determined.

Design-specific pressure distribution was observed, for example, indicating pressure peaks in areas where the inflator was positioned. The maximum pressures recorded were well below injurious levels as reported by Schaefer [20] who studied automotive airbags. However, a better basis of reference values is needed to define an overall threshold level for thoracic injury. Considering the pressure rate rather than peak values should also be considered. The peak values recorded in our sample occurred at very different times (after activation). This reflects, of course, the design of the different products. However, maximum pressure values should only be regarded as relevant when they occur shortly after activation, i.e., within a relevant time frame of, for instance, a fall scenario.

Intervention time, i.e., the time from activation until the airbag is fully inflated and ready to be impacted, was estimated based on high-speed video recordings. This methodology represents a limitation as it is difficult to determine the point in time when the airbag is ready to use. Modifying the garment for test purposes such that a pressure sensor is integrated to measure the time from activation until a defined pressure is reached might be an option for improvement. Generally, for most products, the intervention times recorded were slightly higher than 200 ms as defined in the standard for motorcycling. This time seems acceptable when assuming a fall from the back of a standing or even jumping horse as the baseline scenario.

The activation force (pull force) of the air vests showed a wide range, from 150 to nearly 600 N. When bearing in mind the range of motion required for riding, it can be argued that the pull force should not be too low to prevent unintentional activation. An unintentional activation of an airbag could create a dangerous situation as the rider will be limited in his or her freedom of movement for a few seconds shortly after activation. Assuming a larger falling height in equestrian sports than in motorcycling, a somewhat higher pull force than for motorcycling seems appropriate. Furthermore, the threshold of the pull force should take into account the target group of a certain product (e.g., if designed for children) as it is related to the mass of the athlete.

Measuring the noise level related to airbag deployment revealed values well below threshold values published for ear injury in humans [22–26]. Therefore, it seems not mandatory to include noise level measurements into a standard. Generally it is recommended to design airbag vests such that the noise level is as low as possible, as this also reduces possible side effects such as frightening the horse, particularly in the case of an unintentional deployment.

Airbag vests are not designed to protect against axial spinal loading (e.g., when hitting the head) or in circumstances that do not result in an activation of the airbag (e.g., a hoof kick). As demonstrated in the drop tests, the airbag vests used in this study showed the potential to reduce the force of a direct impact in a comparable or even more efficient way than conventional

vests. The technology allows absorption of impact energy in a suitable way. An airbag vest can therefore protect from injuries because of direct loading of the thorax (including the back). By the applicable standards it is not defined when the inflated airbag is to be impacted by the drop mass. In our setup, the airbags were inflated manually to certain pressure levels. As the design pressure of the individual products was unknown, different levels were chosen. As the results demonstrate, the pressure does have a significant influence on the impact properties of the product. To be able to perform such impact tests on airbag vests, a more specific test procedure must be defined to address the impact area, i.e., the specific area on the vest that is tested, and the pressure of inflation at time of impact testing.

Further tests were conducted in which conventional and airbag vests were combined. Conventional vests, particularly those offering a higher safety level, are apparently regarded as uncomfortable, but such vests have the obvious benefits that they offer protection also in situations not riding the horse and they cover a larger area of the upper part of the body. Thoracic injury because of a hoof kick could be mitigated by a conventional vest, but not by an airbag vest, as this technology requires to be triggered before its protective potential becomes available. Airbag vests, in contrast, allow a larger degree of movement when riding and might therefore be perceived as more comfortable.

## Conclusion

Combining the advantages of padding and airbag technology was demonstrated to have a significant potential to further reduce loading on the thorax of a rider in case of an impact. Even using a less stiff level 1 conventional vest resulted in over 80 % load reduction in the drop tests when combined with an airbag vest when compared to the conventional vest alone. Exploring such combinations further seems, therefore, an interesting approach to offer protection and simultaneously increase acceptance of safety vests by increasing comfort. The recommendation to wear an airbag vest in combination with a level 3 conventional vest, of course, will not increase comfort. Generally, the current standards for safety vests in equestrian sports [17] as well as the draft standard for motorcycling airbag vests [19] can be applied, but adaptations seem necessary.

## Practical Implications

- The outcome of this study provides a basis for discussing the adaptations of the current standards to cover airbag vests in equestrian sports.
- Airbag vests for equestrian sports exhibit a good protective potential with regard to thoracic injury. However, they do not offer protection in the instance of axial spinal loading (e.g., when hitting the head) or in circumstances

that do not result in an activation of the airbag (e.g., a hoof kick).

- Combining the technologies of airbag vests and vests using padding further reduced the impact force significantly.

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