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Evaluation of the Effectiveness of an Exemplar Equestrian Air Jacket against Crush Injuries

David Hynd, Matthew Muirhead, Jolyon Carroll, Alistair Barr and Jonathan Clissold

Abstract Horse rider fatalities have occurred during the cross-country phase of three-day eventing when horses have fallen and landed on their riders. There are safety jackets available for horse riders, which are designed to inflate and offer protection when the rider falls from a horse, but the effectiveness of these 'air jackets' against crush injury from a falling horse is not well understood. TRL and British Eventing tested an exemplar air jacket to estimate its protective capacity and provide baseline data on the forces applied by a falling horse. Four tests were performed with an equine cadaver. In two tests, one with an air jacket and one without, the horse was dropped onto an instrumented Hybrid III ATD. In two further tests, the horse was dropped onto an array of 123 load cells with a measurement area of approximately 1 m x 2 m. The results indicated that the air jacket could have a beneficial effect in reducing the likelihood of a severe injury being sustained in an accident where a horse falls on a rider. However, with or without the air jacket, there was a high probability of a severe injury being sustained by a rider in the loading condition created for these tests.

Keywords Air jacket, cross-country, equestrian eventing, equine cadaver, personal protective equipment (PPE).

I. INTRODUCTION

Like other sports, horse-riding has its risks. However, one area that's often deemed to be particularly dangerous is cross-country riding. Over recent years there have been a number of fatalities resulting from horses falling on riders during the cross-country phase at events. British Eventing figures reveal that between July 2013 and June 2014 there were 45 falls on British Eventing cross-country courses in which the horse was caused to somersault by the way it impacted the fence. Not only can these falls put the rider at risk from injury when hitting the ground but, worse still, they can result in the horse falling onto the rider, causing death or serious injury. In fact, in 2013/14, 16 of these falls resulted in serious injuries, with one fatality.

There are existing safety jackets for horse riders, which are designed to inflate (like an airbag in a car) and offer protection when the rider falls from a horse. Questions have been raised about the potential of these air jackets to prevent injuries and fatalities in somersault fall scenarios, with some stakeholders calling for air jackets to be made compulsory. To date, however, the effectiveness of air jackets at protecting against injuries from a horse falling on a rider has not been well understood.

In order to promote understanding of this issue and to identify a better way to safeguard riders, a test programme was performed to establish the effectiveness of air jackets in protecting against crush injuries. The study sought to understand both the protective capacity of existing air jackets and the forces applied by a falling horse, so that a suitable test procedure for protective equipment could be developed. The defined objectives of this study were to:

- Test an exemplar personal protective equipment (PPE) from the current market and estimate its protective capacity;
- Provide baseline data on the forces applied by a falling horse, from which a suitable test procedure for PPE could be developed.

II. METHODS

A series of controlled tests was performed at the equestrian surgical facility at the Bristol Veterinary School

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(BVS)¹. A horse (owner donated with informed consent) was euthanised in the surgical facility and testing commenced as soon as possible post-mortem in order to minimise any effects caused by rigor mortis. The horse was sourced from a rescue centre and was being euthanised for medical reasons as part of the normal operations of the rescue centre and BVS, i.e. the horse was not euthanised specifically for this project, although the timing of the euthanasia was co-ordinated to provide a specimen for testing that was as fresh as possible without compromising the welfare of the animal.

Four separate tests were performed in the following test conditions (in order).

1. Horse dropped onto anthropometric test device (ATD) torso (wearing an inflatable air jacket and body protector) – the shoulder of the right side of the horse impacted the ATD.
2. Horse dropped onto ATD torso (wearing a body protector only) – the shoulder of the right side of the horse impacted the ATD.
3. Horse dropped onto force plate (on its left side).
4. Horse dropped onto force plate (on its back).

Figs 1–4 show the test configurations for tests 2, 3 and 4. The order of the tests may have been significant given the increasing time elapsed from the moment of euthanasia and the potential for damage to occur to the equine subject in each impact. No obvious signs of damage were observed throughout the testing, though no imaging techniques were used to confirm this.



Fig. 1. Lower view of Test 2 (non-inflatable body protector only).



Fig. 2. Rear three-quarter view of Test 2 (non-inflatable body protector only).



Fig. 3. Front view of Test 3 (side impact without ATD torso).



Fig. 4. Side view of Test 4 (back impact without ATD torso).

¹ The testing reported in this paper was approved by the University of Bristol Ethical Review Group with the Veterinary Investigation Number VIN/13/050

ATD preparation

Tests 1 and 2 were performed using a Hybrid III ATD (including the head, neck, thorax, abdomen, pelvis and arms, but not including the legs because these were not loaded during the tests). This ATD was chosen in preference to the THOR ATD because of the expected greater risk of damage to the THOR in this loading condition, and the greater cost of repair to the THOR ATD if damage occurred. In both Tests 1 and 2, the ATD was clothed in a T-shirt and long-johns, and wore a mandatory BETA 2009 Level 3 horse-rider body and shoulder protector, which was labelled as conforming to the requirements of the European Standard BS EN 13158:2009 Level 3. The wearing of a BETA 2000 or 2009 Level 3 protector is mandatory for the cross-country phase of eventing competitions run by British Eventing and therefore no test was performed without a protector. The BETA protector is intended to 'prevent minor bruising that would have produced stiffness and pain, reduce soft tissue injuries and prevent a limited number of rib fractures' [1]. The jacket contained a label explaining the intended function of the body protector and noting that, 'this body protector will not prevent injuries in accidents involving severe torsion, flexion, extension, or crushing of the body'.

In Test 1, the ATD additionally wore an air jacket over the top of the BETA body and shoulder protector. The jacket is inflated using a CO₂ canister and is normally deployed by a lanyard connected to the saddle. For Test 1, the air jacket was deployed immediately prior to release of the horse. It was not possible to measure air jacket pressure in these tests, but the air jacket stays inflated for much longer than e.g. a car airbag because the time between deployment and falling to the ground or loading from the horse can be very variable in equestrian accidents. It was considered that the minimal delay between deployment and impact was representative of the accident situation. In both scenarios chest deflection was used as the standard measure to predict the risk of serious chest injury [2].

Force plate

In Tests 1 and 2 the ATD was supported by a force plate consisting of an array of 123 load cells in an 8 x 16 arrangement, with five of the extreme corner cells removed (see Figs 5 and 6). Each cell was 125 mm x 125 mm in size, giving a total available measurement area of approximately 2 m x 1 m. The load cell array was placed on a bed of sand, which provided a firm, level supporting surface, and was calibrated prior to testing.



Fig. 5. Load cell wall, showing the array of 123 load cells.

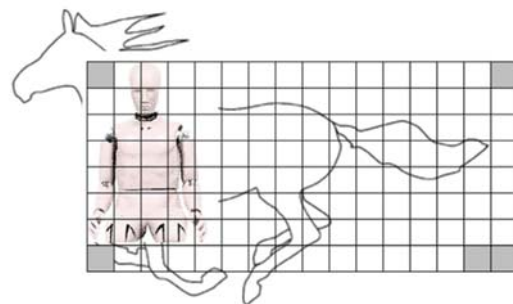


Fig. 6. Schematic of approximate horse and ATD positioning with respect to the force plate.

Test procedure

The equine cadaver was raised into position for each test using a telehandler. The horse was supported using a harness system that was sold as being designed for lifting cattle. The harness supported the torso of the horse such that it was level and stable, and the head was separately supported such that it impacted padding adjacent to the force plate at approximately the same time as the torso impact. The mass of the horse was 487 kg (pre-mortem) and the drop height was 1.2 m above the plane of the load cell wall. This drop height was chosen based on a review of equestrian rotational falls, and limited by the estimated risk of overloading and damaging the ATD.

All tests were recorded with a high-speed camera with adequate lighting for filming at 1,000 frames per second. Force plate and ATD chest deflection data were acquired at 20 kHz and filtered according to SAE J211.

III. RESULTS

Test 1 (air jacket and body protector)

In the first test the equine cadaver was dropped on its side onto the ATD, which was wearing a body protector and inflatable air jacket (as shown in Fig. 7). Data acquisition was initially successful and the force plate and chest deflection data were reviewed on-site, with the peak chest deflection noted. Unfortunately, a subsequent data transfer error resulted in the loss of the data from one of the two data acquisition systems used, and this included the data from the majority of the load cells and from the chest deflection sensor.



Fig. 7. ATD wearing body protector and air jacket positioned on the load cell array prior to Test 1.

A contour plot of the peak force measured during the test on each of the load cells for which data is available is shown in Fig. 8. In the context of the Figure, the horse's head is in the top left-hand corner and the ATD is laid top to bottom along the fourth column, with the torso around the third row (see Fig. 6 for a comparison). Although only part of the dataset for this test is available, it shows part of the region covered by the ATD torso, with peak forces of around 4.5 kN. The measured peak chest deflection for this test was 66 mm, which corresponds with an 81% risk of receiving a severe chest injury.

The force measured on each load cell during the first 300 ms is shown in Fig. 9. This shows two cells as recording peak forces of just over 4 kN, with other cells experiencing a peak of no more than around 2 kN. This suggests that under the two most heavily loaded cells, the peak pressure was in the region of 256 kN/m². The duration of the impact can be seen to be around 200 ms.

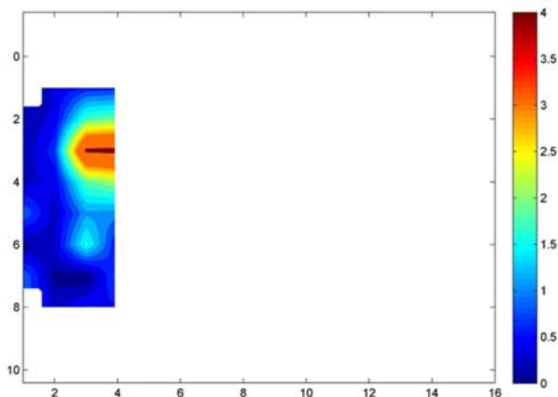


Fig. 8. Contour map of peak forces (kN) for Test 1.

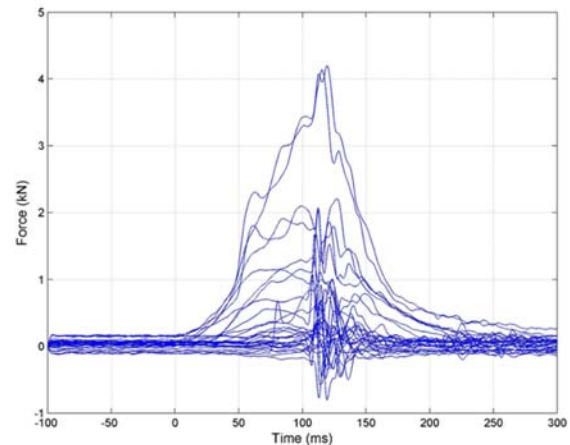


Fig. 9. Force-time for individual load cells for Test 1.

Test 2 (non-inflatable body protector only)

The second test was a repeat of the first, but without the air jacket on the ATD, although the body protector remained (as shown in Fig. 10). A contour plot of the peak forces measured, in the same format and orientation as Fig. 8, is presented in Fig. 11.



Fig. 10. ATD wearing body protector only, positioned on the load cell array prior to Test 2.

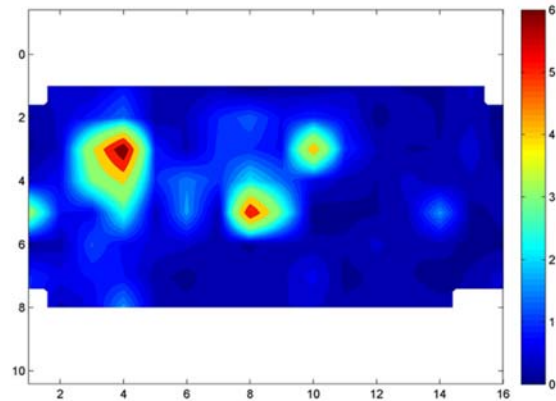


Fig. 11. Contour map of peak forces (kN) in Test 2.

In this test the peak forces were again measured in the region of the ATD torso, but the forces themselves were higher than in the first test, with peak measurements around 7 kN. Another area of relatively high impact can be seen from the impact of the horse's belly region, with peaks of around 5 kN.

For this test the chest deflection measurements are shown in Fig. 12. The peak chest deflection recorded was 77 mm. This level of chest compression would be expected to be associated with a 94% risk of sustaining a severe chest injury. Therefore, assuming that the horse drops were performed in a repeatable manner, the air jacket had the effect of reducing the peak deflection value from 77 mm to 66 mm, and reducing the probability of receiving a serious chest injury from 94% to 81%.

The force measured on each cell in the first four columns of the array during the first 300 ms is shown in Fig. 13. This shows the peak force in one cell being as high as 7 kN, with the next highest forces recorded around 4 kN. The duration of the impact can again be seen to be around 200 ms.

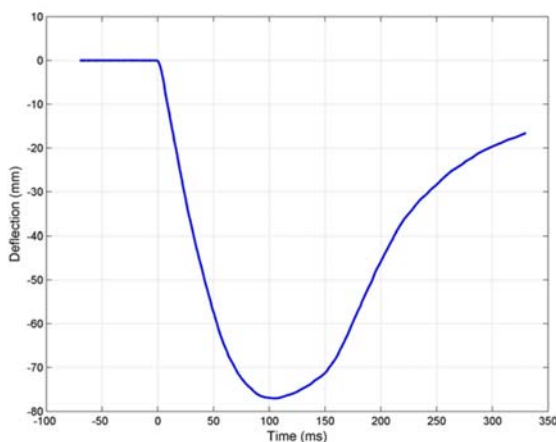


Fig. 12. Chest deflection measurements for Test 2.

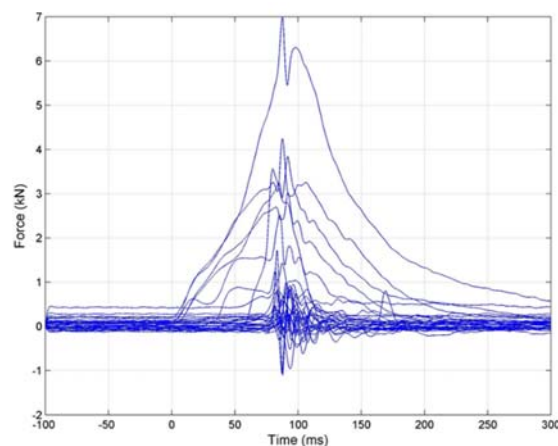


Fig. 13. Force-time for individual load cells for Test 2.

Test 3 (side drop)

The contour map showing the peak forces recorded by each cell for Test 3, where the equine cadaver was dropped on its side directly onto the load cells without an ATD in place, is given in Fig. 14. Another approximate overlay schematic for this set-up is shown in Fig. 15. This reveals a very localised peak force (around the pelvis of the horse) of around 15 kN.

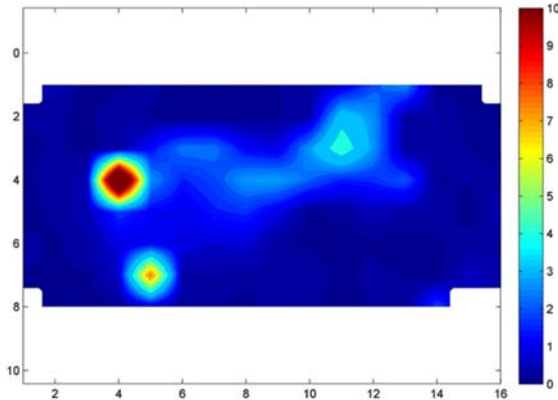


Fig. 14. Contour map of peak forces (in kN) in Test 3.

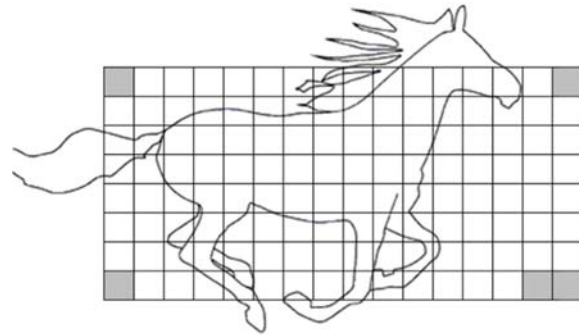


Fig. 15. Schematic of approximate position of horse with respect to the force plate, Test 3 (no ATD torso).

Figure 16, showing the force-time histories of the cells in the first four columns, highlights the peak force as being restricted to one cell. It also shows the impact covering a shorter time period of around 75 ms, which is expected given that the impact in Test 3 was directly with the hard surface of the load cells.

Time histories for all of the load cells in Test 3 can be viewed in Fig.17, where it may be noted that the total force over the entire measurement plate was around 70 kN.

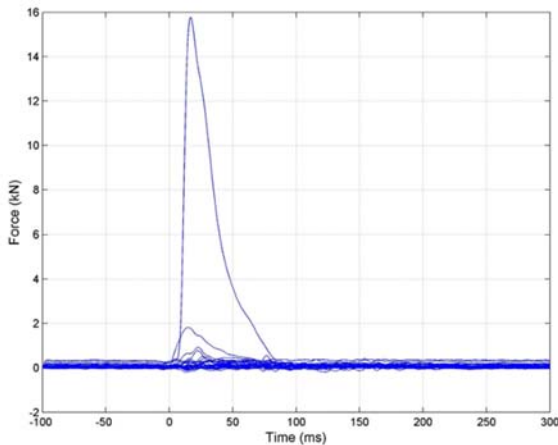


Fig. 16. Force-time for individual load cells for Test 3.

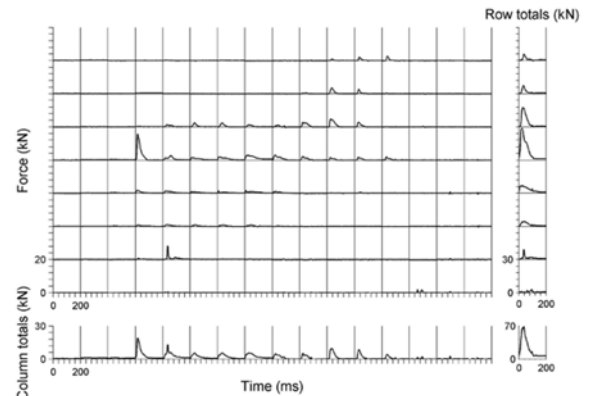


Fig. 17. Force-time for load cells for Test 3.

Test 4 (back drop)

In the fourth test the equine cadaver was dropped directly onto the load cells on its back. A contour map of the peak forces (see Fig. 18) shows two distinct peaks corresponding to the horse’s shoulder region and haunch. The peak forces recorded in these locations were around 12 kN and 17 kN, respectively.

The force-time information for the cells in Test 4 can be gleaned from Fig. 19. The overall force across the cells is around 70 kN, as in Test 3.

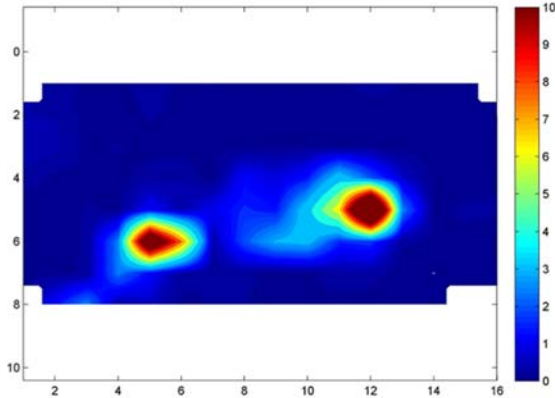


Fig. 18. Contour map of peak forces (in kN) in Test 4.

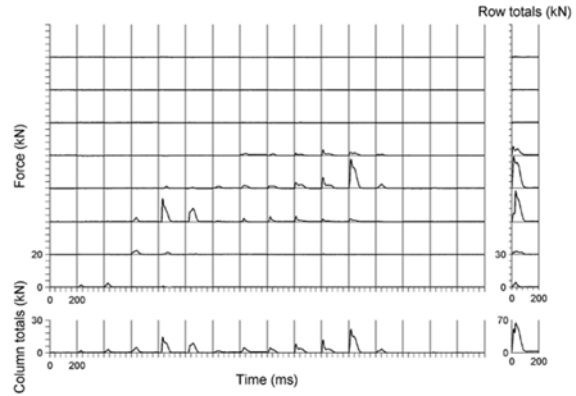


Fig. 19. Force-time for load cells for Test 4.

Summary of results

The key findings with regard to the behaviour of the body protectors around the ATD torso are shown in Table I.

TABLE I
PEAK CHEST DEFLECTION AND SEVERE INJURY RISK FOR ATD TORSO

	Peak chest deflection (mm)	Injury risk (% risk of severe chest injury)
Air jacket + body protector	66	81
Body protector only	77	94

The air jacket was shown to slightly reduce the compression of the ATD’s chest and therefore the predicted risk of severe thorax injury. This means that it could have a beneficial effect in reducing the likelihood of a severe injury being sustained in an accident where a horse falls onto a rider. However, with or without the air jacket, there was a high probability of a severe injury being sustained by a rider in the loading condition created for these tests.

IV. DISCUSSION

Improving safety of riders has been high on British Eventing’s agenda for a number of years. The results of the present study revealed that while air jackets may have some safety benefits, fatal and serious injuries are still highly likely to occur should a horse fall directly onto a rider.

While the results provide an initial indication of the effectiveness of air jackets, there are a number of areas that require further exploration. The ATD used in the tests represented the average height and weight of a 45-year-old male, and results may vary for riders of different statures and ages. For example, risks may be slightly lower for younger riders, but substantially higher for older riders due to the fact that bone condition changes with age. It is expected that the risk of receiving a serious chest injury in these tests would be likely to approach 100% for older riders with or without the air jacket. It may be that there are combinations of loading condition and rider for which this design of jacket is unable to offer meaningful protection.

To put this into context, for car occupants involved in a crash, a younger occupant's probability of death is 1.36 times greater with rib fracture than without, and an older occupant's probability of death is 2.14 times greater with rib fracture than without [3]. For car occupants, the risk of death for a younger occupant with 50% probability of serious rib fracture is 18%, compared with 57% for older occupants. Although not directly applicable to the crush loading investigated in the present study, this is indicative of the likely increased morbidity for older riders for a given injury risk.

It should also be remembered that these tests involved one loading condition, with a relatively low drop height. Other loading conditions may be more or less severe, with concomitant differences in the injury risk. The exemplar equine cadaver was also relatively light in comparison with a typical eventing horse; a heavier horse or greater fall height would be expected to increase the risk of severe chest injury.

Several tests were performed with the same specimen and it was not possible to determine whether there was any degradation of the specimen from test to test (for instance, fractures that would reduce the stiffness of the specimen). This introduces some uncertainty to the results.

One element not assessed in the present study was whether the air jacket protects the rider in the initial ground contact, prior to crush loading from the horse. If so, then there could be a benefit in that the horse would be less likely to land on an injured, and therefore weakened, rib cage. This may particularly be the case with partial crush loading, where the horse doesn't fall as directly or severely onto the rider as the ATD in the present study.

Tests on other designs of air jacket (or other PPE intended to reduce the injury risk) using other specimens would not be directly comparable with these test results. If comparative data is required for different PPE designs, then a more consistent test object would be required, such as a mechanical surrogate for an equine cadaver. The measurements made in these tests provide baseline data that could be used to develop such a test tool.

V. CONCLUSIONS

Results from the tests showed that the air jacket slightly reduced the compression of the ATD's chest and subsequently the predicted risk of severe chest injury from 94% to 81%. This means that it could have a beneficial effect in reducing the likelihood of severe injury from a horse falling onto a rider. However, there is still a high probability of riders sustaining a severe injury, even when wearing the air jacket. So while the air jacket may provide some safety improvements, it is unlikely to prevent fatalities should a horse fall directly onto a rider.

Data have been generated with regard to the forces applied by a falling horse. These data may form a baseline from which a suitable test procedure for PPE could be developed.

VI. ACKNOWLEDGEMENTS

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