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Fédération Equestre Internationale (FEI) eventing: Fence-level risk factors for falls during the cross-country phase (2008-2018)

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Summary

Background: The equestrian discipline of eventing tests athletes' and horses' skill over three phases: dressage, jumping, and cross-country. Falls during cross-country can be particularly serious and result in serious or fatal injury for both horse and athlete. Cross-country course and fence design are crucial contributory factors to safety.

Objectives: To provide descriptive statistics and identify fence-level risk factors for horses competing in Fédération Equestre Internationale (FEI) events worldwide.

Study design: Retrospective cohort study.

Methods: Data were collected for every horse start worldwide in all international (CI), championship (CH), Olympics (OG), and World Equestrian Games (WEG) eventing competitions between January 2008 and December 2018 and univariable logistic regression, followed by multivariable logistic regression were applied. The final model was built in a stepwise bi-directional process, with each step assessed by the Akaike information criterion.

Results: Risk factors were identified at fence level covering aspects of fence design and course design. Ten fence types were at increased odds of a fall occurring compared to square spread fences, and seven types were at reduced odds. Fences with an approach downhill (odds ratio 1.35, 95% confidence interval 1.19-1.52), with landing into water (OR 1.82, CI 1.62-2.01), frangible devices (OR 1.28, CI 1.15-1.41), and later elements of combined obstacles (OR 1.33 CI 1.25-1.42 for the second element, OR 1.21 CI 1.10-1.32 for later elements) were associated with increased risk of falls occurring.

Main limitations: Although the data set covers every international competition worldwide, it does not include national-level competitions.

Conclusions: It is recommended that the most challenging fences are placed near the beginning of the course, and not in downhill or water settings. The complexity of individual elements in combined fences should be reduced. Adopting evidence-based course design is a crucial intervention for reducing the incidence of horse falls and associated serious and fatal injuries to horse and human athletes.

Introduction

The Fédération Equestre Internationale (FEI) equestrian discipline of eventing, also known as three-day eventing, is a multi-phase competition that tests multiple aspects of horse and athlete skill. Each event consists of three phases: dressage, jumping, and cross-country [1]. In protecting both horse and athlete welfare, significant focus must be given to the cross-country phase of eventing, as falls during cross-country can have very serious consequences up to and including the death of both horse and athlete [2,3]. So-called “rotational falls” are a particular concern, defined as when the horse somersaults as a result of hitting a fence. The horse's hindquarters end up significantly higher than its front end and it will land on the landing side of the fence [4]. Despite the sport’s long history, it was not until 1999 that safety in eventing achieved global attention, when five athlete fatalities in the UK that year prompted major reviews of safety [5]. The International Eventing Safety Committee concluded in the year 2000 that “everything should be done to prevent horses falling” [6]. Since then, studies to identify risk factors have primarily focussed on course-level factors during the cross-country phase, as well as behavioural factors on the part of the horse and athlete [7-11]. Until recently, the most recent season for which risk factors for horse and athlete falls during cross-country had been published was the 2002 season. A study of horse-, athlete-, and course-level risk factors covering the period 2008-2018 published in 2021 was the first peer-reviewed publication since 2008 [12]. Factors at the level of event and horse previously reported to be associated with increased risk of falls include higher event level, longer course length or more fences, individual history of falls, and poor performance in the dressage phase [7,12]. Other factors previously reported include the presence of water for takeoff or landing, approach and landing gradients, angle of fence, and approach speed [9,10],

The Barnett report - an audit covering the period 2008-2014 - was published by the FEI in 2016 with statistical analysis of falls and investigation of factors contributing to rotational falls in particular, but the report was not published in a peer-reviewed journal [13]. This report showed that 14.5% of riders who had a rotational fall were seriously or fatally injured, compared to 4.3% of riders who had a non-rotational fall. A report published by the FEI in 2020 found that in the period 2009-2020, 16.7% of riders who had a rotational fall were seriously or fatally injured, compared to 4.8% of riders who had a non-rotational fall [14].

Rule changes have been implemented throughout the last two decades relating to course design, fence composition and competition format, but to date no academic studies have examined the impact of such changes. One prominent example of a rule change was the introduction of frangible fences, i.e. fences that are designed to break and/or deform to help prevent somersault falls that are induced by contact of the horse with the fence [15,16]. The first type of frangible device introduced was the frangible pin, first used in eventing in 2002 [17]. More types of frangible device including MIM clips, which enable a wider range of fence types to be designed as collapsable, were introduced later, and their use has become more popular since 2015. Anecdotally, there is a perception that frangible fences have reduced the number of rotational falls.

The FEI reported in 2021 that the percentage of competition starts resulting in a fall was 5.94% during the period 2005-2008, 5.37% during the period 2009-2013, and 5.38% during 2014-2020 [18]. The same FEI report also showed that in the period 2008-2017, over 90% of falls during FEI eventing competitions occurred at fences during cross-country. In the period 2018-2020, this proportion fell to just under 80% of falls, although there was a change in how fall locations were classified in 2018. Until 2008 it was permitted for athletes who became unseated to simply remount and continue in competition. From 2009 onwards, either a horse fall or an athlete becoming unseated resulted in automatic elimination. Thus it was the case for prior studies, and remains the case in this study, that the primary focus on understanding and aiming to reduce the incidence of falls should be at fences during cross-country.

This article presents the results of a multivariable model incorporating risk factors at the level of the fence, course, and event. The goal of this is to understand which risk factors contribute to increased odds of a horse falling or athlete being unseated at a particular fence or element of combination fence. The main hypothesis was that some combination of fence, course, and event-level risk factors – including fence design, location within the course, and factors such as approach gradient or presence of water - would contribute to the likelihood of a horse falling or athlete being unseated at a given fence. The focus on the data at the fence level, and use of an outcome definition "one or more falls at this fence", allows a greater understanding of how fence and course design impacts horse and athlete safety.

Materials and Methods

The data set used was the FEI's Global Eventing Database. A form of the database is publicly available online [19] – the authors had access to the complete dataset for this study in collaboration with the FEI. The data used in this study consists of every FEI eventing competition held between 1 January 2008 and 31 December 2018. The database is substantial and multifaceted – it contains detailed information about each competition, along with specific information about results, fences, horses, athletes and falls.

Falls are defined for the athlete as "when he/she is separated from the horse in such a way as to necessitate remounting", and for the horse as "when at the same time, both its shoulder and quarters have touched either the ground or the obstacle and the ground or when it is trapped in a fence in a way that it is unable to proceed without assistance or is liable to injure itself" [20]. Under these definitions, horse falls and athlete falls are mutually exclusive events. A detailed fall report form is completed for every fall, so that the circumstances of the fall are recorded as part of the FEI database.

This study investigated the fence- and course-level potential risk factors associated with falls of either type. The data were modelled at the fence level – i.e. every fence at every event was included in the study – and the deleterious outcome studied was a binary variable indicating whether or not there had been at least one fall (athlete or horse) at a fence. Note that 842 fences (10.2% of those that had any falls) had more than one fall occur, meaning the risk of falls may be underestimated for some individual fences in the final model.

Multivariable logistic regression models were constructed in a bespoke code written in R version 4.1.2 (R Foundation for Statistical Computing) [21]. Potential risk factors included in this study, along with category definitions, are shown in Table 1. Note that the variable "event level" was included in this study in the form that it took during the time period studied. Events were assigned a star rating from 1* to 4*, with 4* representing the most challenging competitions. In 2019 the categories were altered – see Table 2 for an explanation of the old and new event level systems. Risk factors included in continuous form were also examined in categorical form, with the best fitting form as assessed using the Akaike information criterion (AIC) included in the final model. Variables were assessed for collinearity during initial data exploration. The first stage of modelling examined each risk factor in turn in a univariable logistic regression model, with a maximum p-value of 0.20 used to select candidates for the final model. Multivariable mixed-effect logistic regression models were constructed using a stepwise bidirectional process (R function "stepAIC") with each step assessed using the AIC, until the best-fitting models were identified [22,23].

Variables rejected at the univariable and multivariable stages were subsequently tested for confounding in the final model [24]. Biologically-plausible combinations of risk factors were tested for second-order interaction and included for assessment in the final model. The final single-level model was tested for goodness-of-fit using the Hosmer-Lemeshow test [22]. Any potential impact of event-level clustering was assessed by the mixed-effect model which included event as a random effect. Power calculations indicated that logistic regression models would have 80% power to detect odds ratios of 1.03 or higher, with 95% confidence, for variables in continuous form. For variables in binary categorical form, the model had 80% power to detect odds ratios of 1.07 or higher, with 95% confidence.

Results

Table 3 shows the descriptive statistics of falls by fence type (diagrams of each fence type are shown in Figure 1) for the full cohort of fences as recorded in the Global Eventing Database. The proportion of fences of each type at which there was at least one fall ranged from 2.4% for fence type D3 (covered ascending spread) to 11.5% for fence type J2 (step down into water).

Of 202,771 horse starts between 1 January 2008 and 31 December 2018, 190,429 started the cross country phase. Of these, 10,519 (5.2%) had a fall recorded – henceforth unless specified, “fall” refers to either an athlete being unseated or a horse fall. Of these falls, 9,358 (89.0%) occurred at a fence during the cross country stage. At fence level, there were 204,399 unique fences used in 6,450 unique FEI competitions during the time period. These data represent a total of approximately 6,100,000 individual jumping efforts, where one jumping effort is one horse attempting one fence. Note that to account for potential modifications year to year, the ‘same’ fence at the ‘same’ event in different years were regarded as being unique. The 9,358 recorded falls occurred at 8,253 fences – 4.0% of all unique fences. The study cohort used for analysis was the 204,399 unique fences with each fence as a unit of observation. Cases were defined as the 8,253 fences at which there was at least one fall recorded. Table 4 shows the final multivariable model. The univariable model results are shown in Table S1.

At event level, compared to competitions in 2016, 2017, and 2018 combined, fences in competitions between 2008 – 2015 were at increased odds of being associated with a fall (odds ratio 1.11 [95% confidence interval 1.06 – 1.17]). Fences in events at 3* or 4* level were more likely to have been associated with a fall than fences in 1* and 2* events, at odds ratio 1.09 (1.03 – 1.15) for 3* events and odds ratio 1.59 (1.42 – 1.79) for 4* events. An increase in the number of cross country starters was associated with increased odds of a fall occurring, with field sizes at or above the 75th percentile (42 horse starts) at odds ratio 2.00 (1.95 – 2.05) compared to field sizes at or below the 25th percentile (12 horse starts).

At fence level, higher fence numbers (i.e. further from the start of the course) were associated with increased odds of a fall occurring at that fence. Fences at or above the 75th percentile (fence number 17) were at odds ratio 1.14 (1.10 – 1.19) compared to fences at or below the 25th percentile (fence number 7). Fences that were part of combined obstacles – i.e. jumping efforts with multiple individual fences – were more likely to be associated with a fall than isolated, non-combined fences. Compared to fences that were not part of a combined obstacle, element A of a combined fence was associated with an odds ratio of 1.15 (1.08 – 1.22), element B was at odds ratio 1.33 (1.25 – 1.42), and element C or later were at odds ratio 1.21 (1.10 – 1.32) for a fall to occur at that fence.

Compared to fences which had a level or uphill approach, fences with a downhill approach were associated with an increased odds of a fall, with odds ratio 1.35 (1.19 – 1.52). Similarly, in comparison to fences which had a level landing gradient, fences with a downward landing were associated with an increased odds of a fall (1.42 [1.32 – 1.54]), while fences with an uphill landing were associated with reduced odds (0.80 [0.70 – 0.93]). Fences which had a landing into water were associated with an increased odds of a fall compared to fences without a water landing, at odds ratio 1.82 (1.65 – 2.01). Fences which were defined as being 'associated with water' (which included fences with take-off from and landing into water, and fences with neither factor) were associated with an increased odds of a fall, at odds ratio 1.46 (1.34 – 1.59). Fences that were part of an optional route for a particular obstacle were at greatly reduced odds of a fall (0.23 [0.19 – 0.28]). Fences which were frangible were associated with a greater odds of a fall (1.28 [1.15 – 1.41]). Fences that were portable were at reduced odds of a fall than permanent fences(0.94 [0.89 – 0.99]).

Seventeen fence types were found to have significant associations with the likelihood of falls occurring. The reference fence type used was C – square spread, one of the more common fence types. Compared to type C fences, type G3 fences – corner with solid walls and solid top (2.44 [2.20 – 2.72]), type G2 – corner with 'post and rail' walls and solid top (2.09 [1.72 – 2.55]), type E4 – brush with ditch in front (2.02 [1.75 – 2.34]), type H2 – trakehner with cross rails on top (2.00 [1.09 – 3.67]) were at least twice as likely to be associated with a fall, and type K fences – a water obstacle (colloquially known as a 'splash') with no physical fence – were at most reduced odds of a fall occurring (0.38 [0.22 – 0.64]).

Two second-order interactions terms were retained in the final model. Fences for which the approach and landing gradients were both downhill were at a total odds ratio of 1.50 (1.05 – 2.15) of a fall occurring, compared to fences with level gradients at approach and landing. Fences which were associated with water and which had an upwards gradient on the landing were at a total odds ratio of 1.64 (1.02 – 2.63) for a fall occurring, compared to fences that were not associated with water and that had a level landing gradient.

No confounding was detected between retained risk factors and those rejected at any stage of model-building, with none of the model estimates of risk factors retained in the final model changing by more than 10% upon the inclusion of any of the rejected risk factors. The inclusion of event as a random effect accounted for 18% of the variance in the final model and altered the model coefficients of one risk factor by more than 10% – the odds ratio of 'fence is portable' in the mixed-effects model was 0.94 instead of 0.93 in a fixed effects-only model. No evidence of a lack of fit for the final model was found with the Hosmer-Lemeshow goodness-of-fit test, which returned a p-value of 0.3.

Discussion

Risk factors at event-level and fence-level were found to be statistically significantly associated with the likelihood of a fall (of a horse or athlete) occurring at each individual fence. A summary of the fence-level results is shown in Table 5.

Later years included in the data were associated with lower odds – this could be related to rule changes over that time period such as alterations to event format and course design including fence design, or changes to the minimum eligibility requirements for qualification. Event levels at 3* and 4* must naturally include longer courses with more fences, and more challenging obstacles [20]. Therefore, it should perhaps be expected that fences in those events are more likely to have falls occur at them compared to fences in 1* and 2* events, even accounting for the fact that better quality horses/combinations are competing at the higher levels. It is nevertheless important for athletes stepping up to higher levels, to know how much greater the risk is for their new level of competition. Larger field sizes were more likely to result in falls occurring at the fence level simply because there would be more opportunity for falls (i.e. more jumping efforts on the day) compared to smaller field sizes. It could also be the case that competitions with more competitors were more likely to have poorer ground conditions e.g. damage to the footing either side of fences, in particular where the ground was softer after wet weather. It was reported by Murray et al. that competitions where the ground conditions were soft/heavy were more likely to have falls occur compared to where there were firm ground conditions [10].

Several of the results of this study are consistent with those reported in earlier studies. Associations between increased likelihood of falls and (i) fences later in the course, (ii) elements (in particular mid and final elements) of combined fences, and (iii) certain fence types were reported by Singer et al. [7]. That study was a case-control study which found in a multivariable model that ascending spread fences (fence type D in the present study) were less likely to be associated with falls than fences that were not ascending spread type. That study also found that fences with a ditch in front were more likely to be associated with falls compared to fences without a ditch in front. Another case-control study demonstrated an association between water approach/landing and increased likelihood of falls [9]. An association between jumps with drop landings and increased likelihood of falls has also previously been detected [8,9].

Fences with higher numbers – i.e. located later in the course – were generally more likely to have falls occur at them compared to fences earlier on the course. This could be the result of fatigue for both athlete and horse – the longer the course, and more obstacles that they have overcome, the more likely that fatigue could contribute to a mistake being made. Additionally, fences later in competitions would naturally have fewer jumping efforts made over them compared to fences earlier in the competition, due to the attrition of retirals/falls/eliminations for some competitors earlier in the course. This means that the odds ratio reported here is likely to be an under-estimate of the true odds ratio for fences located later in the course. Fences that were part of combined obstacles were more likely to have falls occur at them than isolated, non-combined fences. Fences which were described as being element B – i.e. the second fence in the combination – of a combined obstacle were at the highest odds ratio compared to fences that were not combined. This reflects the additional complexity of combined obstacles – horse and athlete have to carefully approach each stage, and in the event of a successful but slightly misjudged jump over element A, for example, they could have little time to recover before attempting to jump element B.

The setting around a fence was found to have significant impact on the likelihood of a fall occurring at the fence, in several aspects of the course design. A downward slope on the approach to or landing from a jump was associated with increased odds of a fall. When approaching down a hill, controlling the centre of balance of the horse is more challenging and precisely identifying the point of take off more difficult. As for landing, it is possible that a downwards slope after a jump could require significant adjustment of horses' bodies in order to continue in their stride, thus making such a jump more difficult than on flat ground. It could also be more likely that a horse could slip on a downwards landing compared to a flat landing. Fences which have their landing into water or otherwise are associated with water have the extra difficulty of the ground not being visible to the horse or athlete – as well as any other challenges that the water would add, for example to pacing and positioning on approach and while jumping, as well as potential alterations to the kinematics of the horse's movement [25,26].

Fences on optional routes – found to be at reduced odds of a fall occurring - are by design less challenging than those on the direct route through an obstacle. However, the data showing which branch of a fence containing an optional route was chosen by competitors were not available. For example, a fall that occurred at an optional fence would be recorded for that specific fence, but the number of successful jumping efforts (controls) at the same fence was unknown. This is unique to optional route fences because specific route choice is not recorded for successful jumping efforts. Fences that are frangible rather than solid are perhaps more likely to be misjudged as the athlete thinks they 'can get away with' clipping it and may approach the fence with less caution. It could also be that course designers intentionally build more challenging fences when they know they will be including a frangible device. Portable fences are perhaps smaller and slightly less challenging compared to permanent fences.

Some fences are designed to be very challenging for horses and athletes, and this was reflected in the likelihood of falls occurring at certain fence types. The fence type with the highest proportion of falls – 11.5% of J2 fences had at least one fall occur – was not statistically significant in the final model. At the univariable stage J2 fences (step down into water) were associated with increased odds of a fall occurring compared to C type fences (square spread), at odds ratio 3.74 (3.20 – 4.38), and p-value <0.001. This implies that other fixed effects that were retained in the final model account for some of the risk associated with J2 fences. Further investigation revealed that 86% of type J2 fences were in the category 'yes' for the risk factor 'landing into water'. Consequently, in the final model the variable 'landing into water' was retained while type J2 fences were excluded. One curious aspect of this is that according to the FEI fence design document [27], type J2 fences are described as a 'step down into water'. It might reasonably be expected that 100% of such fences would be recorded as having a landing into water, but in the available data 14% of J2 fences were not recorded as such. Accurate data recording is critical for future studies and risk management and this should be a key message to those responsible for reporting and recording these data.

The headline FEI statistics on falls, along with the similarities between prior work which was completed using a selected cohort of case-control data from the 2000, 2001 and 2002 seasons [7-11], and this study which covers the full cohort of data from 2008-2018 indicate that it is difficult to conclude that some aspects of Eventing cross-country course design have become safer – at least in terms of reducing falls – since the International Eventing Safety Committee (IESC) reported its findings in 2000. When considering the Barnett report [13], this study has identified some of the same risk factors including event level, fence types A1, E4, G1, G3, downhill landings, association with water, and frangible fences.

The results from this work arethe first step towards building a 'risk profile' or 'score' for each cross-country course and could contribute to further grading of cross-country phases of events within different levels of competition, helping to inform athletes as to the expected difficulty of the course on which they are about to compete. Course risk profiles can be used to support the development of horses and riders and be included in qualification criteria to progress to higher event levels. These results also motivate a discussion about whether safety could be a higher priority in course design. It would not be desirable to look at these results and say, for example, that jumps in or out of water, corner, and trakehner fences should no longer be used. Rather, it should be considered whether it might be possible to design around these more challenging fences. For example, it would be more appropriate to ensure that very challenging fence types generally are not over represented in the second half of cross-country courses such that the effect of fatigue (identified as a potential explanation for falls at later fences in this study and previously [7]) is not exacerbated by a very difficult fence design. Where feasible, the inclusion of more optional routes on cross-country courses would contribute to reducing the overall 'difficulty rating' of the course. An awareness of the risk factors identified here can inform course design – e.g. through policy and course design documents - that aim to reduce the incidence of athlete and horse falls, while also maintaining the level of challenge that stakeholders would expect to see. Participants in equestrian sports recognise that there is inherent risk involved, especially when riding at speed over solid obstacles during cross-country. An increased focus on safety for both horse and athlete with the goal of minimising inherent risks as far as possible will also positively impact public perception of the sport, and bolster the social licence of eventing in the public eye [28]. This is a particularly important time for stakeholders to focus on the social licence to operate, both in the broader context of equestrian sports and for the particular case of eventing [29].

More than two decades after the IESC report urged "everything should be done to prevent horses from falling", an improved understanding of the true level of risk posed by a particular set of fences on a specific course could form the focus of further risk reviews. Grading of courses, based on the risk profile of all fences, would be a useful next step to help inform athletes about the level of risk to which they would be exposing themselves and their horse. In combination with validated horse and athlete risk profiling, course grading would reduce the risk of serious injury associated with this challenging Olympic sport.

Authors' declarations of interest

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias content of the paper.

Ethical animal research

Not applicable: data provided by a sports regulator were analysed.

Informed consent

Not applicable.

Data availability statement

The data that support the findings of this study are available from [third party]. Restrictions apply to the availability of these data, which were used under license for this study. Data are available [from the authors/at URL] with the permission of [third party].

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Authorship

E. Bennet contributed to study design, study execution, and data analysis and interpretation. E. Bennet had full access to all the data in the study and is responsible for data integrity and accuracy of the analysis. H. Cameron-Whytock contributed to study execution, and data analysis and interpretation. T. Parkin contributed to study design, and data analysis and interpretation. All authors contributed to the preparation of the manuscript and gave final approval to the manuscript.

Figure 1: Diagrams of all fence types in use for the cross-country phase of FEI Eventing competitions between 2008-2018. This figure is adapted from the FEI fence types diagram document [27].

Table 1: Potential risk factors included for consideration in the multivariable logistic regression model. Categorisation shows the form chosen after testing both continuous and categorical variants, for those risk factors which were originally continuous.

Risk factor	Categorisation	Notes
Year	Categorical	Collapsed into two categories: 2008-2015 and 2016-2018
Event level	Categorical	1*, 2*, 3*, or 4*. Olympics and World Equestrian Games were included in 4*.
Event format	Binary	Long format (CCI) or short format (CIC)
Fence number	Continuous	Scaled such that a unit increase in the model variable corresponds to an increase of five in fence number
Fence element	Categorical	If a fence is part of a combination, indicates at which element the fall happened
Fence type	Categorical	Fence type according to course design guidelines (reference)
Optional route	Binary	If the fence is part of an optional route
Fence is frangible	Binary	If the fence is frangible i.e. has some moving parts which are designed to yield when collided with
Fence is portable	Binary	
Take off from water	Binary	
Landing into water	Binary	
Associated with water	Binary	N.B. there is an incomplete overlap between "takeoff from", "landing into", and "associated with" water
Approach to jump	Categorical	Describes the ground level before the jump
Landing after jump	Categorical	Describes the ground level after the jump
Number of cross country starters	Continuous	Scaled such that a unit increase of the model variable represents an increase of 10
Course length	Categorical	
Course level	Categorical	N.B. there is an incomplete overlap between course level and event level (above)
Effort count of entire course	Continuous	The total number of jumping efforts - combined fences are counted as one jumping effort
Number of individual fences on entire course	Continuous	The total number of unique fences - usually greater than the corresponding effort count
Total jumping efforts made at this event	Continuous	The number of fences multiplied by the field size of cross country starters

Table 2: The event level categorisations used in this study were those in place up until 2018. In 2019 the FEI redesignated all event levels. This table shows the old and new categories to aid readers in interpreting the event levels used in the study. Note that these categories include sub-designation of short or long format (CCI or CIC respectively in the pre-2019 system) – event format was included in the present study as a separate risk factor.

Categorisation 2018 and earlier	**Categorisation 2019 onwards**
Olympics and World Equestrian Games Special category	**Olympics and World Equestrian Games** Special category
CCI4*	CCI5*-L (long)
CCI3*	CCI4*-L (long)
CIC3*	CCI4*-S (short)
CCI2*	CCI3*-L (long)
CIC2*	CCI3*-S (short)
CCI*	CCI2*-L (long)
CIC*	CCI2*-S (short)
New introductory level	CCI* (unified) Not compulsory for qualifications

Table 3: Descriptive statistics of falls by fence type, in FEI eventing competitions between 2008-2018.

Fence type	Fences	Fences with at least one fall (%)	Fence type definitions
Total	204399	8253 (4.0%)	
A0	1850	97 (5.2%)	A: Post and rails
A1	8893	428 (4.8%)	
A2	2142	90 (4.2%)	
A3	3475	111 (3.2%)	
A4	936	37 (4%)	
B1	5653	229 (4.1%)	B: Palisade
B2	1879	85 (4.5%)	
C1	6713	228 (3.4%)	C: Square spread
C2	10761	356 (3.3%)	
C3	17345	585 (3.4%)	
D1	2816	80 (2.8%)	D: Ascending spread
D2	5117	136 (2.7%)	
D3	19021	466 (2.4%)	
D4	5868	172 (2.9%)	
E1	9467	400 (4.2%)	E: Brush
E2	12923	462 (3.6%)	
E3	4306	199 (4.6%)	
E4	3612	252 (7%)	
E5	464	17 (3.7%)	
E6	2992	86 (2.9%)	
F1	24133	1173 (4.9%)	F: Round
F2	17614	565 (3.2%)	
G1	2172	157 (7.2%)	G: Corner
G2	1801	122 (6.8%)	
G3	7394	600 (8.1%)	
H1	5871	283 (4.8%)	H: Trakehner
H2	180	12 (6.7%)	
H3	253	13 (5.1%)	
J1	67	3 (4.5%)	J: Step
J2	1707	197 (11.5%)	
J3	2208	119 (5.4%)	
J4	3884	108 (2.8%)	
J5	4977	147 (3%)	
K	330	15 (4.5%)	K: Water ('splash')
L	3722	161 (4.3%)	L: Ditch
OTHER	1301	43 (3.3%)	
UNKNOWN	552	19 (3.4%)	

Table 4: Multivariable model results for the outcome "at least one fall at this fence". Cases were fences at which a fall of any kind was recorded. Risk factors with a p-value of less than 0.05 were retained in the final model. Among categorical variable levels, a * denotes the reference category.

Risk factor	Cases (%)	Controls (%)	Odds Ratio	95% confidence interval	p-value
Event Year					
2016 - 2018*	2428 (3.7%)	63360 (96.3%)	1.00	-	-
2008 - 2015	5825 (4.2%)	132786 (95.8%)	1.11	1.06 - 1.17	<0.001
Event Level					
Level 1 or 2*	6067 (3.9%)	150821 (96.1%)	1.00	-	-
Level 3	1811 (4.2%)	41721 (95.8%)	1.09	1.03 - 1.15	0.004
Level 4	375 (9.4%)	3604 (90.6%)	1.59	1.42 - 1.79	<0.001
Number of cross country starters					
Per additional ten horses	Median = 24 Min = 0[a]	IQR = 30 Max = 142	1.26	1.25 - 1.27	<0.001
Fence number					
Per additional five fences	Median = 12 Min = 1	IQR = 10 Max = 38	1.07	1.05 - 1.09	<0.001
Element of combined fence					
Not Combined*	3513 (3.4%)	101275 (96.6%)	1.00	-	-
Element A	1915 (4.6%)	40054 (95.4%)	1.15	1.08 - 1.22	<0.001
Element B	2203 (5.1%)	40692 (94.9%)	1.33	1.25 - 1.42	<0.001
Element C or other	622 (4.2%)	14125 (95.8%)	1.21	1.10 - 1.32	<0.001
Fence type					
C* (Square spread)	1231 (3.4%)	35441 (96.6%)	1.00	-	-
A0 (Post & rails)	97 (5.2%)	1753 (94.8%)	1.32	1.06 - 1.64	0.01
A1	428 (4.8%)	8465 (95.2%)	1.15	1.02 - 1.30	0.02
A2-4	238 (3.6%)	6315 (96.4%)	0.91	0.79 - 1.06	0.2
B1 (Palisade)	229 (4.1%)	5424 (95.9%)	1.02	0.88 - 1.18	0.8
B2	85 (4.5%)	1794 (95.5%)	1.49	1.19 - 1.88	<0.001
D1 or D4 (Ascending spread)	252 (2.9%)	8432 (97.1%)	0.84	0.73 - 0.97	0.01
D2	136 (2.7%)	4981 (97.3%)	0.73	0.61 - 0.88	<0.001
D3	466 (2.4%)	18555 (97.6%)	0.69	0.62 - 0.78	<0.001
E1 (Brush)	400 (4.2%)	9067 (95.8%)	0.96	0.85 - 1.08	0.5
E2, E3, E5, or E6	764 (3.7%)	19921 (96.3%)	0.90	0.82 - 0.99	0.04
E4	252 (7%)	3360 (93%)	2.02	1.75 - 2.34	<0.001
F1 (Round)	1173 (4.9%)	22960 (95.1%)	1.00	0.92 - 1.10	>0.9
F2	565 (3.2%)	17049 (96.8%)	0.77	0.69 - 0.85	<0.001
G1 (Corner)	157 (7.2%)	2015 (92.8%)	1.91	1.59 - 2.30	<0.001
G2	122 (6.8%)	1679 (93.2%)	2.09	1.72 - 2.55	<0.001
G3	600 (8.1%)	6794 (91.9%)	2.44	2.20 - 2.72	<0.001
H1 (Trakehner)	283 (4.8%)	5588 (95.2%)	1.49	1.30 - 1.71	<0.001
H2	12 (6.7%)	168 (93.3%)	2.00	1.09 - 3.67	0.03
H3	13 (5.1%)	240 (94.9%)	1.98	1.13 - 3.50	0.02
J1, J3, J4, or J5 (Step)	377 (3.4%)	10759 (96.6%)	0.78	0.68 - 0.89	<0.001
J2	197 (11.5%)	1510 (88.5%)	1.16	0.97 - 1.40	0.1
K (Water)	15 (4.5%)	315 (95.5%)	0.38	0.22 - 0.64	<0.001
L (Ditch)	161 (4.3%)	3561 (95.7%)	1.10	0.89 - 1.36	0.4
Approach gradient					
Level or Up*	7201 (3.9%)	176813 (96.1%)	1.00	-	-
Down	1052 (5.2%)	19333 (94.8%)	1.35	1.19 - 1.52	<0.001
Landing gradient					
Level*	5701 (3.7%)	147884 (96.3%)	1.00	-	-
Down	2139 (5.7%)	35367 (94.3%)	1.42	1.32 - 1.54	<0.001
Up	413 (3.1%)	12895 (96.9%)	0.80	0.70 - 0.93	0.002
Landing into water					
No*	7044 (3.7%)	184779 (96.3%)	1.00	-	-

[a] Two competitions in the database had zero cross-country starters recorded

Yes	1209 (9.6%)	11367 (90.4%)	1.82	1.65 - 2.01	<0.001
Jump associated with water					
No*	6198 (3.5%)	168850 (96.5%)	1.00	-	-
Yes	2055 (7%)	27296 (93%)	1.46	1.34 - 1.59	<0.001
Jump is on optional route					
No*	8142 (4.1%)	189654 (95.9%)	1.00	-	-
Yes	111 (1.7%)	6492 (98.3%)	0.23	0.19 - 0.28	<0.001
Fence is frangible					
No*	7678 (3.9%)	187758 (96.1%)	1.00	-	-
Yes	575 (6.4%)	8388 (93.6%)	1.28	1.15 - 1.41	<0.001
Fence is portable					
No*	4470 (4.3%)	98770 (95.7%)	1.00	-	-
Yes	3783 (3.7%)	97376 (96.3%)	0.94	0.89 - 0.99	0.02
Interactions terms					
Approach down x landing down			0.78	0.67 - 0.92	0.002
Jump associated with water x landing up			1.40	1.09 - 1.78	0.008

Table 5: A summary of fence-level risk factors identified in the final multivariable model shown in Table 4. Odds ratios are reported in the format odds ratio (95% confidence interval). Fence type diagrams are shown in Figure 1.

Fence-level factor	Reference category	Increased odds of fall	Reduced odds of fall
Approach gradient	Level or uphill	Downhill, 1.35 (1.19 – 1.52)	
Landing gradient	Level	Downhill, 1.42 (1.32 – 1.54)	Uphill, 0.80 (0.70 – 0.93)
Landing into water	No	Yes, 1.82 (1.65 – 2.01)	
Associated with water	No	Yes, 1.46 (1.34 – 1.59)	
On optional route	No		Yes, 0.23 (0.19 – 0.28)
Frangible fence	No	Yes, 1.28 (1.15 – 1.41)	
Portable fence	No		Yes, 0.94 (0.89 – 0.99)
Approach downhill and landing downhill	No and No	Yes and Yes, 1.50 (1.05 – 2.15)	
Associated with water and landing uphill	No and No	Yes and Yes, 1.64 (1.02 – 2.63)	
Element of combined fence	Not combined	Element A, 1.15 (1.08 – 1.22)	
		Element B, 1.33 (1.25 – 1.42)	
		Element C, 1.21 (1.10 – 1.32)	
Fence type	C (square spread)	A0, 1.32 (1.06 – 1.64)	D, 0.84 (0.73 – 0.97)
		A1, 1.15 (1.02 – 1.30)	D2, 0.73 (0.61 – 0.88)
		B2, 1.49 (1.19 – 1.88)	D3, 0.69 (0.62 – 0.78)
		E4, 2.02 (1.75 – 2.34)	E, 0.90 (0.82 – 0.99)
		G1, 1.91 (1.59 – 2.30)	F2, 0.77 (0.69 – 0.85)
		G2, 2.09 (1.72 – 2.55)	J, 0.78 (0.68 – 0.89)
		G3, 2.44 (2.20 – 2.72)	K, 0.38 (0.22 – 0.64)
		H1, 1.49 (1.30 – 1.71)	
		H2, 2.00 (1.09 – 3.67)	
		H3, 1.98 (1.13 – 3.50)	

Supporting information

Table S1: Univariable logistic regression was carried out for each potential risk factor, with a sieve of $p<0.2$ used to decide candidate risk factors for inclusion in the multivariable model. Risk factors rejected at this stage were tested for confounding against the final multivariable model.

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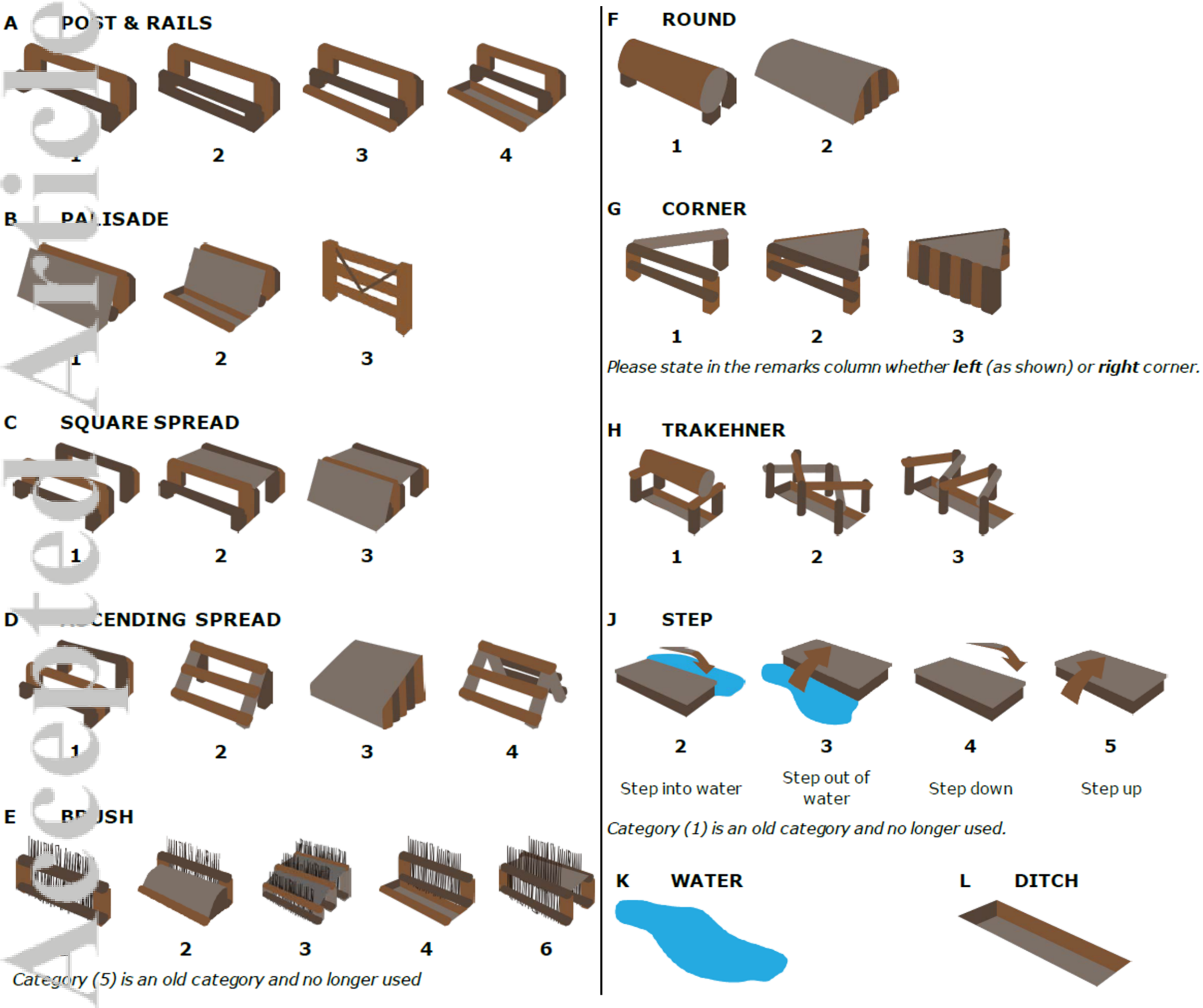

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