Analysis of risk factors for horse falls in eventing cross-country and an investigation of horse/rider stress at eventing competition.

by

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Abstract

Eventing, otherwise known as the 'Equestrian Triathlon', consists of three phases: dressage, show-jumping and cross-country which are completed by a single horse and rider combination. A horse fall during the cross-country phase of eventing carries the highest risk of serious injury and fatality to horse and rider, thus identification of risk factors for horse falls has the potential to improve safety within the sport. Research into other equestrian sports such as show-jumping has identified that stress can affect the performance of horses and riders, thus a further understanding is needed on the stress experienced by both horse and rider at eventing competition. This could be used to inform future research that aims to assess how stress can affect performance at eventing competition and potentially the risk of horse falls during cross-country.

The first study (Chapter Four) aimed to identify horse-, rider- and competition-level risk factors for horse falls during the cross-country phase of one-day eventing competitions in the UK. A total of 749,534 cross-country starts were included in analysis (2005-2015). Univariable logistic regression was utilised to identify variables for inclusion in the final multivariable logistic regression model. Models were constructed stepwise using a bi-directional process and assessed using the Akaike information criterion. Eleven variables were retained in the final model including: class, dressage penalties, horses' number of starts in previous 60-90 days, horse grade, rider sex, horse sex, horse height, number of days since the riders' last start, rider age, number of horse falls in the riders' career and number of horse falls in the horses' career. The class of competition was one of the most important predictors of a horse fall, with risk increasing as the level of competition advanced. The findings support the results of prior studies in addition to identifying previously un-reported risk factors.

For the second study (Chapter Five), a scoping review was conducted. The aim of the study was to review the literature on the validity of heart rate monitors (HRMs) to collect heart rate (HR) and heart rate variability (HRV) data for the assessment of stress in horses. Twenty-four research studies were included within the review. Three of the studies conducted validation tests with a HRM in comparison with the gold-standard electrocardiogram, the remaining 21 studies utilised HRMs in combination with other validated measures of stress (such as salivary cortisol). The study established that HRMs are a valid tool to collect HR/HRV data whilst horses are stationary but that the validity of HRM data declines if horses are moving/exercising. Additionally, the study evaluated methodological techniques and provided recommendations to optimise data collection for the use of HRMs in horses.

The third study (Chapter Six) comprised three aims: to investigate pre-competitive stress experienced by horses and riders at eventing competition, to explore whether there was any association between physiological measures of stress in horse and rider combinations and to investigate riders feeling-states before and after eventing competition. HRMs were used to collect HR/HRV data from 13 horses and 13 riders at eventing competitions. From the raw HRV data, the root mean square of successive differences (RMSSD) was calculated. Rider RMSSD was significantly lower at the cross-country start box than resting at home ($p<0.001$) and at the cross-country warm-up ($p<0.05$). Horse RMSSD was significantly lower at the cross-country start box than resting at home ($p=0.001$), resting at competition ($p<0.001$) and at the cross-country warm-up ($p<0.001$). There was no significant association between horse and rider RMSSD. Riders had significantly higher tranquillity after the competition than before and there was a significant strong positive correlation between rider positive engagement after the competition and horse RMSSD at the cross-country warm-up. Results indicate that the horse and rider both experience high levels of stress at the cross-country start box of eventing competition. Further studies are needed to establish whether stress such as this is beneficial/detrimental to performance and any potential effect on the risk of a horse fall.

This thesis has provided a significant and original contribution to knowledge by providing recommendations from the conducted studies that can be utilised to: (1) implement regulatory changes with the aim of reducing the risk of horse falls during eventing cross-country (Chapter Four), (2) improve the quality of published scientific research by establishing recommendations for appropriate methodology when using HRM devices in horses to collect HR/HRV data (Chapter Five), and (3) inform future research that aims to assess how stress can affect the risk of a horse fall in eventing cross-country by providing preliminary data on the mental stress that horses and riders are exposed to at eventing competition (Chapter Six).

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List of Abbreviations

AIC – Akaike Information Criterion

ANS – Autonomic Nervous System

AUC – Area Under Curve

AWERB – Animal Welfare and Ethics Review Board

BC – Blood Cortisol

BE – British Eventing

BHA – British Horseracing Authority

CCI - Concours Complet International

CIC - Concours International Combiné

DMD – Dorsal Metacarpal Disease

ECG - Electrocardiogram

EIFI – Exercise Induced Feeling Inventory

ERMC – Eventing Risk Management Committee

FEI - Fédération Équestre Internationale

FPR – False Positive Rate

GPS – Global Positioning System

HR – Heart Rate

HRM – Heart Rate Monitor

HRV – Heart Rate Variability

IBI – Inter-Beat Interval

ID - Identification

IQR – Interquartile range

IRT – Infrared Thermography

LCI – Lower Confidence Interval

MER – Minimum Eligibility Requirement

OR – Odds Ratio

PARQ+ - Physical Activity Readiness Questionnaire

PNS – Parasympathetic Nervous System

POMS – Profile of Moods States

RMSSD – Root Mean Square of Successive Differences

ROC – Receiving Operating Characteristic Curve

RSA – Respiratory Sinus Arrythmia

SAE – Serious Adverse Event

SBR – Spontaneous Eye Blink Rate

SC – Salivary Cortisol

SD – Standard Deviation

SNS – Sympathetic Nervous System

STEMH – Science, Technology, Engineering, Medicine and Health

TPR – True Positive Rate

UCI – Upper Confidence Interval

UK – United Kingdom

VO_2 – Oxygen Consumption

Vε - Ventilation

VO_2max – Maximum rate at which the body can effectively use oxygen during exercise

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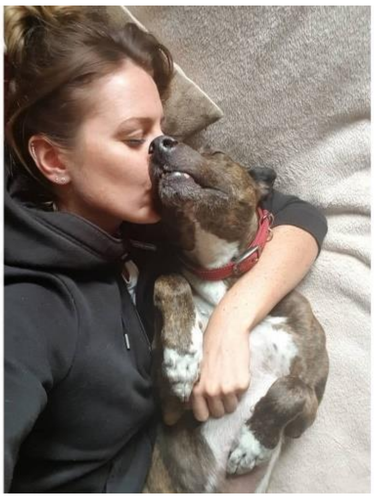
In memory of George.

'There isn't anywhere you can be where I won't be with you'



1. Introduction

Eventing competition appeals to amateur and professional riders all over the world with riders from 23 different countries competing in the sport at the World Equestrian Games 2018, including riders from Japan, Canada, South Africa, Ecuador, Germany, Australia and Brazil. Eventing began as a military fitness test for the cavalry's fitness and suitability (FEI, 2018, April 24). The first recorded eventing competition was held in France in 1902; subsequently becoming an Olympic sport in Stockholm 1912 (Hennessy, 2017), at this time amateur riders from the military were the only people permitted to compete in the sport (FEI, 2018, April 24).

The different phases of eventing were initially designed to simulate challenges that the horses and riders may be confronted with on or off duty in the military as well as comparing the standards of training between cavalries from different countries (FEI, 2018, April 24). Eventing is governed internationally by the Fédération Équestre Internationale (FEI) and in Britain by British Eventing (BE). BE took more than 66,000 entries during the 2019 season, with 520 different cross-country courses that season (BE, 2020, May/June). The BE season runs from March to October and accommodates low-level national to elite level international horses and riders.

There are three phases of eventing: dressage, show jumping and cross-country. The dressage phase is comprised of a series of compulsory movements that are performed by the horse and rider in a specially laid out arena in front of dressage judges. The show jumping aspect is a course of jumps made of coloured poles which can be knocked down if touched with sufficient force, and the cross-country is a course of solid jumps and obstacles that are positioned across undulating and varying terrain. The cross-country element requires the horse to travel at high speed whilst jumping obstacles such as logs, water, ditches and drops.

Eventing was originally set up and organised in what is known as the traditional 'long-format'. The long-format style of eventing was completed over three days and included one day of dressage, one day of speed and endurance, and one day of show jumping. The speed and endurance day for the long-format of eventing included four phases to test endurance instead of the single speed and endurance phase that is used in today's format, the cross-country. The separate endurance phases for the long-format of eventing were, phase A: roads and tracks completed mainly in walk and trot, phase B: galloping over steeplechase fences, phase C: roads and tracks mainly completed in walk and trot, and phase D: the cross-country (Murray et al, 2006b). Riders may have competed more than one horse at a competition, but each horse was required to complete every phase with that rider to acquire a penalty score for the combination. The short format of eventing (endurance phases A-C removed) was introduced in 2004. The reasons behind the change in format are unclear but one of the reported reasons for the change was to improve welfare of the horse, with horses reported to be experiencing extreme fatigue during the long-format (Murray et al, 2006a). Murray et al (2006a) investigated the difference between the physiological demands on the horse of the cross-country phase at long- and short-format events based on anecdotal reports that horses were completing short-format events more tired than for long-format equivalents. The authors found limited evidence that the workload of horses was higher at long-format events than short-format events, although the study only included CCI two-star competition, so it could be that differences would be seen at the higher levels of the sport. No research to date (and to knowledge) has investigated whether there is a difference in the risk of horse falls or horse/rider injury at long- and short- format events. From the descriptive, public data available regarding horse falls at BE events it appears that there has been a reduction in falls since 2004 (although the reduction is not linear as the years progress), however the data is not presented as a percentage of starts so is not very informative (BE, 2015). Additionally, the decline in horse falls could be due to any number of factors and may not be related to the change from long- to short-format eventing.

There are different levels of eventing; as horse and rider gain experience and become more confident at a level they may move up to the next, providing they meet the qualification requirements set out by the governing body. A higher grade of athleticism is required from the horse as the levels ascend, due to more complex moves in the dressage and the increasing height, width and technicality of the jumps, furthermore the distance covered and speed of the cross-country phase increases. The levels of BE range from BE80(T) which is the lowest class, with a maximum jump height of 0.8m, to Advanced which is the highest national level with jumps reaching a maximum height of 1.30m on the cross-country and showjumping course (BE, 2018). The highest level of competition designed by the FEI is CCI5*-L (FEI, 2018, April 24); there are only six of these events in the world, with two of them being held in the UK (Badminton and Burghley Horse Trials), highlighting the leading influence that the UK has on eventing on a global scale.

Scientific research in eventing to date has included genetic evaluation of event horses (Stewart et al, 2010), nutritional problems of event horses (Leahy et al, 2010), physiological demands of eventing for the horse (Amory et al, 1993; Ecker & Lindinger, 1995; Vallel et al, 2013) and rider (Roberts et al, 2010), risk factors for injuries to horses (Munsters et al, 2020; Murray et al, 2004) and riders (Ekberg et al, 2011) and risk factors for horse falls in the cross-country phase (Murray et al, 2005, 2006b; Singer et al, 2003). The scale of research that has been carried out in eventing is small in comparison to other equestrian sports such as horse racing. Horse racing is a popular spectator sport in the UK with one of the most reputable races, The Grand National, consistently being one of the top ten most viewed sports events in any given year, reaching a global audience of 8.9 million in 2013 and 2014 (Deloitte and the British Horseracing Authority, 2013). Furthermore, horse racing in the UK contributes £3.4 billion to the economy (Deloitte and the British Horseracing Authority, 2013). Due to its exposure in the public eye, horse racing has been under constant pressure to reduce the risk of injury and fatality to its equine participants, for the sake of animal welfare. The British Horse Racing Authority (BHA); governing body of horse racing in the UK has successfully increased safety in the sport over the last 20 years with the equine fatality rate being reduced by one third during this time (British Horseracing Authority, n.d.). Eventing competitions in the UK are only occasionally shown on national TV networks or reported in main stream media. Injuries and fatalities of horses and riders during eventing is primarily reported using equine specific media outlets, therefore it is possible that the general public are mainly unaware of the sport and its associated risks. The lack of public awareness for eventing likely has an impact on the amount of funding and time available for research within the sport, especially when compared to a high value, worldwide popular spectator sport such as horse racing.

All horse riding is high risk; Nutt (2009) reported that there is a Serious Adverse Event (SAE) every 350 exposures, and around ten deaths a year from horse riding activity in the UK. In comparison, it is projected that there is one SAE from every 1000 exposures to the class A drug Ecstasy, which has received considerable media attention regarding its adverse effects. Frequently reported equestrian related injuries include neck fracture, spinal fracture and head injuries with the potential to lead to permanent spinal injury (paralysis), personality change and reduced motor function (Silver & Parry, 1991; Silver, 2002). O'Brien (2016) stated that eventing is known to be the most dangerous equestrian sport for riders, with 59 rider deaths between 1993 and 2015.

A reduction in risk requires a change in the attitude and behaviour of the people who participate in the activity (Thompson et al, 2015). Sandman's model of risk communication (Sandman, 1993) explains that the cultural combination of "hazard" and "outrage" is a better way to understand risk than simply using probability and consequence of an incident occuring. Sandman (1993) states that "hazard" is the probability of risk, whereas "outrage" is the public's perception of whether risk is being controlled/managed by authorities. Something may be high risk, but if the public "outrage" is not also high, then the authorites may not be sufficiently pressured to manage the "hazard" of risk. Sandman 's (1993) model of risk communication could be used to hypothesise that horse related risk is a high "hazard" (risk) and low "outrage" activity (Thompson et al, 2015). A high level of risk to both horse and rider during eventing is accepted but there is currently a low level of outrage at this risk. If the level of outrage was increased to 'high' then eventing related accidents would become high risk and high outrage and at this point the cultural response would impose crisis management by the governing bodies and strategies would have to change (Thompson et al, 2015). The current high risk/low outrage within the sport encourages complacency and a lack of change. Thompson et al (2015) discusses

Sandman's (1993) approach to risk in relation to horse related risk and recommends that the risk needs to be reduced and the outrage needs to be increased. This will force the government and/or governing bodies within the sport to financially support research or legislate for change to improve safety (Thompson et al, 2015).

Previous research has uncovered some indicators of risk, but more research is needed as serious injuries and fatalities still occur. Eventing is an interspecies sport and as such carries a large number of variables when attempting to conduct research. Due to this, a greater amount of research is needed in different areas of the sport to help develop a picture of potential marginal changes that can be made to reduce risk. It is unlikely that there will ever be one solution to make the sport entirely risk free, so it is vital that research continues to uncover areas where small changes can be made to reduce overall risk.

2. Review of the literature

2.1 Risk factors for horse falls

2.1.1 Risk factors for horse falls in eventing cross-country

Statistically, the highest risk of injury/fatality to the horse and rider during cross-country riding is associated with a rotational horse fall, in which the horse hits and somersaults over a solid obstacle, potentially landing on the rider (Barnett, 2016; BE, 2015). A horse fall is defined in the BE rule book as when *"both the horse's shoulder and its quarters come into contact with either the ground, or the obstacle and the ground, simultaneously"* (BE, 2018). A rider fall is when the rider becomes unseated from the horse, but the horse does not fall. Due to the high percentage risk of serious injury or fatality to both horse and rider involved in a horse fall it is imperative that continued effort is made to reduce the occurrence of horse falls.

Horse falls can be categorised in to rotational (somersault) or non-rotational (non-somersault). Descriptive data available from the FEI (2019, April 1) states that there were 295 non-rotational and 28 rotational horse falls during the 2018 eventing season (1.41% and 0.13% of starters, respectively). Of these falls, 7.12% (n=21) of riders that had a non-rotational horse fall were seriously injured compared to 17.86% (n=5) of riders who had rotational falls suffering a serious injury. For horses, Barnett (2016) reported that 15.64% of rotational and 2.30% of non-rotational horse falls resulted in a serious/fatal injury at FEI events between 2010–2014. Barnett (2016) also considered rider injury and found that 14.53% of rotational and 4.69% of non-rotational horse falls resulted in serious/fatal injury. In comparison to the risks reported in the context of horse falls, the FEI (2019, April 1) reported that only 1.88% of unseated rider falls during the 2018 eventing season resulted in serious injury to the rider; notably, this data includes all unseated rider falls; such as during the dressage, show-jumping, cross-country and elsewhere (such as warm-up areas). Data for unseated riders specifically on the cross-country course and their injury rate is not currently available from the data that the FEI provide, furthermore the FEI do not appear to include any information on horse injuries in their annual reports (FEI, 2021a). Data from comparable years of competition are not available from BE public reports although for the 2014 eventing season, they reported that 28% (n=8) of rotational and 8% (n=19) of non-rotational horse falls resulted in serious injury to the rider (BE, 2015). In contrast, only 1% (n=20) of unseated rider falls resulted in serious injury to the rider (BE, 2015). For the years discussed here, a serious injury in UK eventing competition was defined as "*Rider admitted to hospital as an in-patient either immediately or later as a result of the injuries sustained in the accident, or died more than 30 days after the accident from injuries sustained; or one or more of the following injuries: fracture, internal injury, severe cuts or lacerations, crushing, concussion.*" (FEI, 2019, April 1). A fatal injury is considered as any incident where the rider dies within 30 days of the incident occurring (FEI, 2019, April 1).

Previous risk factors that have been reported to increase the risk of a horse fall over a fence include fence-level factors such as the width (spread) of the fence, the location of the fence (i.e. in water or sited downhill) and certain styles of fences (e.g. corner, square spread), competition-level factors such as events that are run over three days and championship events, course-level factors such as the length of the cross-country and the number of fences, rider-level factors such as rider sex and horse-level factors such as horse age and experience level (Barnett, 2016; Murray et al, 2005, 2006b; Pinchbeck et al, 2002; Singer et al, 2003).

Singer et al (2003) conducted a case-control study using retrospective data to investigate the risk factors for horse falls on the cross-country phase of horse trials and three-day events. Fifty horse falls were identified with 150 unmatched, control jumping efforts (Singer et al, 2003). The risk of falling increased for courses with a greater number of jumps, fences with a ditch in front, fences sited downhill and fences that were jumped later in the course (number of the jumping effort later than 20). In contrast, total number of jumping efforts carried a reduction in risk per every additional jumping effort (Singer et al, 2003). The occupation of the rider was strongly associated with the risk of falling: professional event riders had the lowest risk of falling whereas riders employed full time outside of the horse industry and students had the highest risk of falling. The study by Singer et al (2003) identified key risk factors that may have been useful in developing safer cross-country competition. The findings that courses with a greater number of obstacles and fences sited later on the course had a higher risk of horse falls could suggest that horse and rider fatigue is a factor to consider when designing cross-country courses and preparing horses/riders for competition. These findings, in combination with the findings of certain fence-level factors having an increased risk of horse falls (such as fences with a ditch in front and fences sited downhill) could be used to develop safer protocols on course design, for instance, fences that have been associated with an increased risk of falls are placed nearer the beginning of the course, where the horse/rider is not yet fatigued. This study provided valuable information; however, the sample size was limited (and no power analysis was conducted). Additionally, this study was carried out before the format of eventing changed to short-format so may not reflect the sport in its current form. Future studies would benefit from a comparable design on short-format eventing whilst incorporating a larger sample size.

Murray et al (2005) performed a case-control study to identify variables that were associated with increased or decreased risk of a horse fall on the cross-country phase at event competitions. Data from one-day events and two-/three-day events were split to establish whether significant risk factors varied between the different types of eventing competition. Data were collected for 121 horse falls (cases) at one-day events and 59 cases at two- or three-day events, with 540 matched controls. A case was a jumping effort that resulted in a horse fall, a control was a jumping effort that did not result in a horse fall. Fences with landing in water, horse and rider combinations that had no previous refusals and fences with a spread of two meters or greater were significantly associated with increased risk of a horse fall at both two-/three-day events and one-day events. For one-day events in isolation, fences with a take-off in water, rider's knowledge of their position at the start of the cross-country (particularly riders who were in the lead), riders who received cross-country tuition and fences with a drop landing were significantly associated with increased risk of a horse fall. For two-/three-day events, riders who participated in non-equestrian sport were significantly associated with increased risk of a horse fall. Murray et al (2005) study revealed previously unidentified risk factors for horse falls. Several fence factors were found to have an increased risk of a horse fall such as fences with a landing in water, fences with a take-off in water, fences with a drop landing and fences with a spread of more than two meters which suggests that course design and fence dimensions are important factors when considering horse fall risk. This developed on the findings by Singer et al (2003) where other fence factors noted previously were found to be significantly associated with increased risk of horse falls.

Murray et al (2006b) carried out a prospective, case-control design study with a ratio of three controls per case which were used to test for associations between course-, fence-, horse-, rider- and event-level variables and horse falls. A case was defined as a cross-country jumping effort that resulted in a horse fall and a control was defined as a cross-country jumping effort that did not result in a fall. Three controls were selected for each case and the controls were randomly selected from all successful jumping efforts at the same competition where the case occurred. 166 cases and 470 controls were recorded. Murray et al (2006b) reported overall risk of a horse fall as 3.5 falls/10,000 jumping efforts and found that three-day events were associated with a higher risk of a horse fall than one day events. Fence-level risk factors for horse falls included fences with a take-off or landing in water, fences with good-to-soft or soft-to-heavy ground, non-angled fences that had a spread of more than two metres, and fences with a drop landing. Other risk factors were reported such as horses and riders that had not incurred any refusals, riders that had cross-country lessons, riders that were aware that they were in the lead prior to the cross-country phase and riders who reported that they approached the fence too fast or too slow. This study identified a number of risk factors for horse falls during the cross-country phase of eventing competition. Using larger samples of competition data would have a larger case/control ratio, where the number of control (successful jumping efforts) would be far greater than the number of cases, therefore the findings of the Murray et al (2006b) study may not be truly representative of risk in the sport. Additionally, the ground conditions were a subjective measurement using only the researchers' sight to judge the quality of the ground and does not take into consideration the variety in ground-composition and how this may affect impact firmness, cushioning, responsiveness and grip. Nevertheless, the study highlighted key areas of risk that should be considered by the sport and in subsequent studies.

Barnett (2016) produced two reports on horse falls at FEI events as part of an audit for the world governing body. The first report focused on fence-level risk factors, with the data set including 3,212,036 jumping efforts from competitions during the period 2008-2014. For the multivariable model on fence-level risk factors, the authors state that a smaller dataset was created which included an equal number of cases (jumping efforts at which there had been horse falls) and controls (jumping efforts that did not have any horse falls) and that fences that had multiple falls were presented more than once in the data set. The authors do not appear to have stated the final sample size for the multivariable model, however from the descriptive data provided earlier in the report it could be assumed that there were 1,689 cases (horse falls) and 1,689 controls (n = 3,378). The results of the fence-level study revealed that post and rail, ascending spread, square spread, open and solid corner, brush with ditch, and frangible fences all carried increased risk of a horse fall (in comparison with all other fences). Furthermore, fences with a downhill landing or a take-off and/or landing in water and higher levels of competition were all associated with increased risk of a horse fall. The findings of the fence-level risk factor analysis that was conducted by Barnett (2016) mirrored and expanded upon previous findings. At this point in time (2016), a total of four studies had now reported that fences with a downhill/drop landing were associated with an increased risk of a horse fall (Barnett, 2016; Murray et al, 2005, 2006b; Singer et al, 2003). Furthermore, a total of three studies had reported that fences with take-off and/or landing in water were associated with increased risk of a horse fall (Barnett, 2016; Murray et al, 2005, 2006b), and two had reported that fences with a ditch in-front were associated with increased risk of a horse fall (Barnett, 2016; Singer, 2003). Evaluation of findings relating to specific fence types that are associated with increased risk of a horse fall is challenging due to different methods adopted by researchers. For example, Murray et al (2005, 2006b) considered the length (cm) of the spread in fences, finding that fences with a spread of two meters or greater were associated with increased risk. In comparison, Barnett (2016) reports that certain 'styles' of spread fence are associated with increased risk of a horse fall, such as ascending, or open.

It is clear from the research available that certain overarching factors related to fences are significantly associated with increased risk of a fall. In fact, O'Brien (2016) critically examined different methods of risk calculation in eventing and concluded that the primary locus of risk during cross-country is the jump itself and the action of the horse jumping, subsequently arguing that future research should focus on this. Notably, Murray et al (2005, 2006b) reported that fences with a take-off or landing in water were associated with increased risk of a horse fall 9-10 years prior to the Barnett (2016) study.

Despite this, there does not appear to have been any official action taken by the governing bodies to mitigate this risk, as the finding is still apparent 9-10 years on (Barnett, 2016). In the context of fence-level risk factors for horse falls, the attention of researchers should perhaps focus on how to communicate with the governing bodies to encourage them to take action in consideration of research findings in this area. Research could continue to focus on repeating and updating the studies into fence-level risk factors, however this will be meaningless if the governing bodies do not take action. Research has reported fence-level risk factors with clear similarities in the findings, thus this needs to be addressed by the governing bodies.

The second report produced by (Barnett, 2016) investigated fence-, rider-, course- and competition-level factors from competitions during the period 2009–2014. The data included 76,638 starts (in the cross-country phase of eventing) and 1,180 horse falls, however a smaller data set was utilised for analysis, with a control - case ratio of two to one, respectively (case is a horse fall during cross-country, control is no horse fall during cross-country). The authors do not explain why the data set was reduced in this manner and also do not state the final sample for the multivariable model, however from information provided in the descriptive section of the report it can be assumed that there were 3,540 starts (2,360 controls and 1,180 cases). Corresponding to the fence-level model in the first report, the authors found that fences with a landing downhill, a landing into or out of water (or both) and frangible fences were all associated with increased risk of a horse fall. In fact, within this study, the authors reported that even fences that were associated with water (near to, but not directly into or out of water) also had an increased risk of a horse fall in comparison with fences that were not associated with water. Additionally, Barnett (2016) reported that the risk of a horse fall increased as the level of competition increased. For rider-level variables; male riders were more likely to fall than female riders, riders that were categorised higher (due to MERs at the highest levels) were less likely to fall than lower category riders and riders who had a previous near miss were at a decreased risk of a horse fall than riders that had not had a previous near miss (a near miss was described by the researchers as a previous unseated rider fall where the fence judge had stated that the horse had 'hit the fence hard', thus the fall was potentially a near miss for a horse fall) (Barnett, 2016). Furthermore, additional show-jumping penalties during the 12-month period prior to competition, certain course designers, venues and championship competitions were associated with increased risk of a horse fall. The second report conducted by Barnett (2016) highlighted previously unidentified risk factors for horse falls such as rider sex, level of competition and competition performance (i.e. previous show-jumping penalties and near misses). As these findings had not been reported in previous studies, it would be beneficial for future studies to investigate these factors as this area has received little consideration in comparison with fence-level risk factors.

Although previous studies have provided valuable findings in the context of risk factors for horse falls in the cross-country phase of eventing, these studies have tended to use reduced data sets and as such are not a true reflection of the balance between starts/jumping efforts that result in horse falls and starts/jumping efforts that do not result in horse falls. Research is therefore needed that evaluates all available data for the intended time-periods, which would give a more representative view of the risk factors for horse falls in the cross-country phase of eventing sport.

2.1.2 Risk factors for horse falls in other sports

Research that has aimed to identify risk factors for horse falls in eventing is limited in numbers, however there are studies available that have investigated risk factors for horse falls in other, comparable sports such as steeplechase and national hunt racing. Pinchbeck et al (2002) analysed retrospective data from all steeplechase runs on UK racecourses during 1999. The data set analysed included 8,308 starts with 647 horse falls, with authors reporting horse fall risk as 5.6 falls per 100 starts (Pinchbeck et al, 2002). Risk factors for horse falls included young horses (4-5 years) and horses over the age of 12 (Pinchbeck et al, 2002). Additionally, horses that had not raced in the previous year, increased number of starters, races held in winter months (December-February) and races that were 20-28 furlongs in distance were at an increased risk of a horse fall (Pinchbeck et al, 2002). The results of Pinchbeck et al (2002) study are important to consider when investigating horse falls in eventing. Steeple chase racing is comparable to the cross-country phase of eventing competition as horse and rider partnerships are travelling at speed whilst jumping natural/solid obstacles. There are however differences between the sports; for example, 22-28 furlongs is 4023-5633m, which indicates that 22 furlongs is longer than an Advanced level BE competition (maximum distance is 4,000m); thus, steeplechase races cover a further distance. Additionally, for a sixteen-furlong (3,218m) race in steeplechasing there are only twelve fences, whereas the equivalent distance at an eventing competition would be Intermediate which consists of 26-32 fences. Nonetheless, there are similarities between the sports so racing research should not be disregarded. Pinchbeck et al (2004) conducted a further study on horse falls in steeplechase racing, with a prospective cohort study design that included 2,879 starts and 124 falls. The authors found that horses that walked calmly in the parade ring were associated with a reduced risk of a horse fall in comparison to those that were trotting or presenting other behaviours (Pinchbeck et al, 2004). The findings regarding horses' behaviour in the parade ring in the study by Pinchbeck et al (2004) is less applicable to eventing risk as this circumstance is associated to an aspect of racing that is unique to the sport. Eventing horses are not required to attend a parade ring, however at the top levels of the sport horses are required to pass veterinary inspections which could be comparable to the parade ring in racing. For veterinary inspections in eventing, horses must be lead in front of a veterinary committee (and often a spectator audience is present). It may therefore be useful for future research studies to consider the horses behaviour in these settings at eventing competition to enable assessment of whether there is an association with displayed behaviours and risk of horse falls. Pinchbeck et al (2004) also found that sunshine and rain weather were associated with higher risk of a horse fall in comparison with cloudy weather, which could indicate that the horse is affected by visibility or the ground condition in these different settings. No research (to knowledge) in eventing has analysed whether the weather is associated with risk of horse falls in the cross-country, although Murray et al (2006b) did report that fences with a good-to-soft or soft-to-heavy ground were associated with increased risk of a horse fall. The findings of Murray et al (2006b) and Pinchbeck et al (2004) may be linked, as it is possible that the weather conditions will affect the ground conditions, although it is important to consider that the study by Murray et al (2006b) gathered data on ground-conditions via subjective methods (two observers categorised the ground conditions). Further research that assesses the ground condition in an objective manner and how this affects the risk of horse falls as such in eventing cross-country are needed to further understand this factor.

Thompson and Nesci (2013) carried out a study which used the topic of ‘risk in eventing’ to better understand the horse-human relationship. The authors interviewed 21 riders, with the interviews comprising of sections such as ‘the rider’s horse riding history’, ‘the rider’s thoughts about risk in eventing’ and ‘how risks are mitigated, and safety maximised when riding’. The study findings indicated that riders attributed a good rider-horse partnership to a lower likelihood of risk, with developing familiarity over time (with partnered horse) perceived as a mitigation for risk (Thompson & Nesci, 2013). These findings highlight a unique aspect of equestrianism which is that equestrian sports are inter-species. This separates equestrian sport from other high-risk sports and emphasises the need for research that focuses on this field of study. Thompson and Nesci (2013) also stated that the majority of eventing riders were more concerned for their horse than themselves (in the context of injury); highlighting the complex and unique nature of eventing sport, whereby a partnership between two sentient beings is required. The partnership between horse and rider is especially of interest in eventing sport due to the inherent risks that the sport predisposes to its participants. The rider can choose to engage in the high-risk activity with awareness of the risks, however it would be unreasonable to assume that horses have this awareness.

The majority of previous research in equestrian sport has focused on estimating the risk of horse riding based on type of injury, frequency of falls and prevalence of injury (Boden et al, 2006; Hitchens et al, 2009; Murray et al, 2005; Singer et al, 2003). Riders’ perception of experiences and risk, and the effects of these factors have received some attention (Beauchamp & Whinton, 2005; Chapman & Musselwhite, 2011; Thompson & Birke, 2014; Thompson & Nesci, 2013) but psychological aspects of the rider such as mood and feelings-states and the effect these have on the horse are still not fully understood, especially in equestrian sports such as eventing.

2.1.3 Risk prevention strategies in eventing

Governing bodies in the UK and internationally have made efforts to increase safety and decrease risk within the cross-country phase of eventing. Foreman et al (2019) created a model of rotational horse falls and described a rotational horse fall as occurring when the horse strikes the obstacle at the shoulder causing the forelimb to hyperextend and the riders' centre of balance to shift forward, which results in a rotating motion of the horse from the point of contact and is typically followed by the horse and rider having rotated fully, landing on the ground. Frangible pins were developed to interrupt the fixed point rotation from the point of impact (as described by Foreman et al, 2019), thus enabling the horse to bring its leg(s) forward and prevent a rotational fall (Kahmann, 2010). To knowledge, there are currently no peer reviewed scientific research studies that have reported the efficacy of frangible devices/fences for reducing the occurrence of rotational horse falls. Several online sources mention research conducted by the Transport Research Laboratory however there does not appear to be any published documentation that details the research that has been done by this institution (Mathieson, 2016, February 15; Walcott, 2003, May 20).

Frangible pins were initially trialled at nine UK events in 2002, with the devices being used where possible, nationwide from 2003 onwards. The use of frangible pins is reported to have a substantial role in reducing the risk of a horse fall, with claims that the frangible devices allow the horse to free its front legs and prevent a rotation, or indeed a horse fall altogether (Hennessy, 2017). The impact that frangible devices has had on reducing serious injury and fatality to horses and riders is yet to be proven in peer reviewed, published research, although Barnett (2016) reported in an audit for the FEI that fences with frangible pins increase the risk of a horse fall. It is discussed that this could be due to the selection of fences that will be built to integrate a frangible device by course designers, chosen due to a perceived increased risk at that style of fence. Frangible pins are intended to decrease the risk of the horse somersaulting over the fence, not to eliminate the risk of a fall completely. The presence of a frangible pin on a fence may also affect the rider psychologically, as they may have decreased concern towards a fence that has a frangible pin and therefore ride the horse over the fence differently, assuming a degree of 'safety' (Barnett, 2016). Other frangible devices and materials have been developed and used in fence design including expanded polystyrene logs (ProLog) and MIM clips (MIM safe NewEra). These devices and materials are all designed to mimic the same function as frangible pins in reducing horse rotation during a fall.

FEI created the 'Eventing Risk Management Committee' (ERMC) with the purpose of investigating new ways to reduce horse falls and horse/rider injury and fatality in the sport. The FEI ERMC states that *"All risk management actions must be aimed to make sure that horses and riders are not exposed to higher risks than that inevitably inherent to the nature of the competition and defined as acceptable to all stakeholders"* (FEI, 2014, February 14). Additionally, the committee lists action plan measures including *"Finalizing and making full use of the potential of the FEI Safety Database."* (FEI, 2014, February 14). Furthermore, minutes from the FEI general assembly 2019 state that as part of their ongoing risk management policy and action plan, the FEI ERMC will be continuing to work with Equiratings® to inform restrictions in athlete participation based on prior performance and decision making for the FEI ERMC, with no further detail offered (FEI, 2019, October 14). Equiratings® claim to offer a service of risk management, whereby data is used to create a ratings system that will 'flag' horses and riders who are most at risk, however there does not appear to be any information available on exactly how this analysis is carried out (Equiratings®, n.d.).

2.1.4 Predicting risk in eventing

Several epidemiological studies have attempted to reveal the main risk factors associated with falls and injuries in eventing, as discussed in Section 2.1.1 (Barnett, 2016; Murray et al, 2005, 2006b; Singer et al, 2003). Epidemiological methods have also been widely used to identify risk factors for injury and fatality during other equestrian sports such as horse racing (Boden et al, 2006; Georgopoulos & Parkin, 2017; Parkin et al, 2004, 2008).

A study that critically examined methods of risk calculation in eventing by O'Brien (2016) concluded that larger data sets need to be used to examine the risks associated with horse falls during cross-country. O'Brien (2016) also states that such data could be used as a basis for future multilevel analysis that may help in determining the many variables that play a part in horse fall risk.

Eventing carries a larger number of potential variables in relation to the environment than horse racing, with horse racing competitions carried out on a 'built for purpose' racetrack that is seldom used for any other activity. Horse racing venues also have a team of maintenance staff whose job is to maintain the ground in between race meets, something that is only seen in top level eventing (such as Badminton and Burghley Horse Trials). Eventing is run over varying terrain, with changes in altitude, tight turns, water and banks just some of the obstacles that the horse and rider partnership must contend with. Due to this it is vital that not only epidemiological data is used in eventing risk factor analysis, but other methods of data collection are used simultaneously to try and create a more in-depth understanding of what increases the risk of a horse fall, something that this study aims to do.

Previous research has identified several different factors can affect the risk of a horse fall, and thus it is recommended that a broad approach is taken when attempting to identify risk factors f or horse falls. The main aspect of the danger of the fence itself comes from the design of cross-country fences and that they are generally fixed (do not collapse/move). Frangible fences have been developed to reduce the risk of rotational falls and the outcome of serious injuries from these falls (however there is an absence of scientific research to confirm that they are successful in doing this). If all fences were made in a completely collapsible design on the cross-country course then it is possible that the risk of horse falls would virtually be eliminated, however, the governing bodies and participants within the sport may not want this as the sport will no longer be the same. It is accepted that the sport carries risk and it is possibly that which motivates the participation of riders in the sport (as well as spectators). The FEI (2014, February 14) state in their FEI ERMC policy and action plan that *"Eventing is a complete all-round test of horse and rider and a tremendous test of horsemanship, but it is also, and will remain, a risk sport."*, perhaps expressing their desire to maintain a certain level of risk within the sport. If many different risk factors are identified, then many small changes could be made to decrease the overall risk of horse falls. The goal to eliminate horse falls entirely is unfounded, but an 'acceptable level of risk' should always be strived for. The difficulty is in defining what this acceptable level of risk is, as it is surely different for the riders, the horses, the public, and the organisers (O'Brien, 2016).

2.2 The demands of eventing

At competition, horses and riders are exposed to various sources of stress, which can have a negative effect on performance, welfare and safety (Peeters et al, 2010). Stress can be experienced by athletes in the context of the stress placed upon their body by the physical activity that is performed, or by psychological means (i.e. mental stress) such as fear, anxiety, or excitement. The stress that horses' and riders' experience can be subdivided into two categories: eustress and distress. Eustress is otherwise known as 'positive stress' and can be useful when competing at sporting competition. An increase in stress and the hormones associated with this phenomenon (such as cortisol) has many desirable effects on horses and riders competing in sport, such as reducing inflammation, movement stimulation and heightened blood glucose concentration (Bartolomé & Cockram, 2016; Filaire et al, 2001). Distress, also known as 'negative stress', is known as such when it causes negative effects on the health of a person or animal, welfare and/or performance (Peeters et al, 2013). Stress at competition can have both positive and negative implications on the performance of the horse and rider. Stress chemicals such as cortisol play an important role in the body; its release can be activated by innate stress or as part of the normal physiological response to exercise (Borer, 2003; Malinowski et al, 2006). During exercise, cortisol is responsible for many critical functions such as the mobilisation of fatty acids, amino acid uptake in the liver, protein catabolism and maintaining vasoconstriction

(Borer, 2003; Malinowski et al, 2006; McKeever & Gordon, 2008), all of which aid in maintaining the continual need for fuel and oxygen during exercise (Borer, 2003; Malinowski et al, 2006). Conversely, stress can have negative effects on the body of horse and rider. For example, excess cortisol production has been reported to increase the risk of mental health disorders (Lee et al, 2010), cardiovascular disease (Dimsdale, 2008), type 2 diabetes (Pouwer et al, 2010) and reduce fertility (Ebbesen et al, 2009) in humans. In horses, long term excess cortisol secretion can have detrimental effects such as inhibition of the immune system, muscle wastage and increased risk of colic (Archer & Proudman, 2006; Bartolomé & Cockram, 2016). Understanding the physiological demands of eventing on both the horse and rider is a vital prerequisite to assessing mental stress in these settings as the body will be affected by both physiological and psychological (mental) stress in response to exercise. Additionally, physiological measures can be used to identify mental stress, therefore it is imperative to be aware of how physical exercise may affect these measures.

2.2.1 Physiological demands of eventing

2.2.1.1 The physiological demands of eventing on horses

Eventing is recognised as a physiologically challenging sport for horses. The cross-country phase requires significantly greater levels of physiological effort than the other two phases (Vallel et al, 2013), with early research in the sport confirming that horses reach the anaerobic threshold during the cross-country (Amory et al, 1993). Ecker and Lindinger (1995) reported that significant water and ion losses occur for the horse during the cross-country phase of eventing, with a rise in these losses as the competition level increases in difficulty. Vallel et al (2013) also stated that horses produce high levels of blood lactate following on from the cross-country phase of eventing, with higher values recorded in higher level competitions (3.27±3.17 mmol/l and 9.45±4.46 mmol/l following intermediate and advanced level cross-country, respectively), in line with the findings of Ecker and Lindinger (1995). The findings of these studies confirm that the cross-country phase of eventing requires extensive physical exertion from the horse.

Many factors can affect the exertional output of the horse during the cross-country phase such as the climate, elevation and the length and ground condition of the course. Geor et al (1995) stated that horse heart rate (HR) was significantly higher during sub-maximal exercise when the climate conditions were hot and humid, when compared to a cool and dry, or hot and dry environment. Respiratory rate was also significantly higher throughout post-exercise recovery for hot, humid and hot, dry conditions compared to a cool, dry climate (Geor et al, 1995). These findings are due to the added thermal load of high temperature and humidity thus increasing heat storage rate and decreasing the rate of heat dissipation during recovery (Geor et al, 1995). Hot and humid conditions are rare within the UK climate, this type of environment will undoubtedly only be experienced by professional level horses and riders from the UK who travel abroad to compete in international competition and are not climatised to these conditions (Marlin et al, 1999; Williams et al, 2002).

Assessment of Salivary Cortisol (SC), HR and Heart Rate Variability (HRV) has been utilised for horse (Parker et al, 2010; Munsters et al, 2013, 2014), and rider (Lewinski et al, 2013) exercise physiology research. Blood Cortisol (BC) concentration can indicate mental stress levels (Cayado et al, 2006; Fazio et al, 2008) as well as reflecting a physiological response to exertion (Kedzierski et al, 2014). The high correlation between BC and SC concentrations found in horses supports saliva sampling as a useful technique for the measurement of cortisol release (Kedzierski et al, 2013; Peeters et al, 2011). SC has also been utilised to identify stress of horses and riders during show-jumping, where it is reported to increase (Becker-Birck et al, 2013; Peeters et al, 2013). In fact, it has been reported that horses with a higher SC increase at show-jumping competitions perform better, however riders with increased SC are reported to receive more penalties (Peeters et al, 2013). The study by Peeters et al (2013) included 20 riders who had all ridden competitively, the horses and riders all jumped the same course of jumps. It is possible that the higher SC concentrations found in horses in this study at the time of competition were due to the natural physiological response to exercise and therefore explains why this did not negatively affect the horse's performance. In contrast, the increased SC concentrations found in riders may have been due to psychological stress, possibly brought on by performing in front of spectators (Lewinski et al, 2013), and thus could be the reason that the rider's performance was negatively affected. The cortisol response in riders may have been indicating distress, and in the horses, eustress. Lewinski et al (2013) stated that horse and rider SC concentrations increased significantly during riding whilst performing high level classical dressage movements. The study also reported that horse and rider SC changes were simultaneous and that all of the horses and riders were trained to a high level, indicating that experience does not equal less stress (Lewinski et al, 2013). The study by Lewinski et al (2013) highlights that there is an association between horse and rider stress during some styles of riding, although this information is not currently available for eventing competition. The effects that horse and rider stress have on each other may be an important factor when investigating risk during eventing cross-country, if a rider is increasingly stressed due to psychological worry/concerns then this could affect the way they ride and ultimately put both horse and rider at risk if performance is detrimentally affected.

Stressors are present for the horse before, during and after competition which can cause a physiological and potentially psychological (behavioural) response. Stressors may include physical exertion/exhaustion, transport, temporary stabling, noise, spectators, and rider ability/stress (Lewinski et al, 2013; Peeters et al, 2013; Schmidt et al, 2010a, b, c, d). It is vital to consider the internal and external stressors that may affect the horse at competition when attempting to quantify physiological or mental stress. Previous research has found that travelling causes an increase in SC and HR, and a decrease in HRV in horses, suggesting that travelling causes a stress response (Schmidt et al, 2010a, b, c). Eventing competitions are distributed in all different areas of the country, riders may travel their horses 1-12 hours for competitions all over the UK; some will travel and compete on the same day and others may travel and stable the horse at temporary accommodation nearby or on site of the competition. The rider's choices of length of travel and stabling arrangements will undoubtedly affect the horse's stress, fatigue and psychological state. Although there are apparent stressors for the horse during eventing competition, limited research has been published on the subject. Research that measures the stress experienced by horses at competitions may aid in understanding the levels of stress that the horse experiences and how this can be manage d, to improve performance and safety. Ultimately, the potential detrimental effects on the body from physiological or psychological stress are the same as an increase in circulating glucocorticoids (such as cortisol) will occur in response to both physiological and psychological stress. We therefore have a duty to ensure that the stress that we expose horses to during sports like eventing does not cause them harm, but before we can do that we need to assess the level of stress that they experience at these events.

2.2.1.2 The physiological demands of eventing on riders

The physiological demands specific to the event rider during cross-country are scarcely documented in published, peer reviewed research articles. Roberts et al (2010) reported that the energy expenditure of female horse riders during the cross-country phase of a one-day eventing competition were similar with values seen during female basketball, weightlifting and wrestling. Additionally, blood lactate values following the cross-country phase of competition for female riders was comparable to athletes following a 100m sprint and speed skating (Roberts et al, 2010). These findings indicate that the exertion level of a rider during cross-country reaches the anaerobic threshold, offering evidence that cross-country riding is physiologically demanding for the rider and therefore comparable to other high intensity sports. It is not known how rider level of physiological exertion affects the horse, and how these factors affect performance. Additionally, rider fitness is not currently checked or monitored during eventing competition, so there could be wide variation in the fitness levels of these athletes.

Roberts et al (2010) stated that riders exhibited a significant loss in body mass after completing all three phases of eventing competition, with two of the sixteen subjects in the study experiencing a loss in body mass of over 2.5%. Loss in body mass following exercise could indicate that the riders had become dehydrated due to the redistribution of body fluids (Roberts et al, 2010). Nielsen et al (1981) stated that loss of body mass by 2.0% or more can result in a 45% decrease in performance ability. These findings suggest that riders competing in eventing are at risk of reduced performance in the cross-country as they may struggle to concentrate and perform with the appropriate physical strength; potentially putting themselves and the horse at an increased risk of an injury and/or horse fall. This risk may be particularly increased with riders who are riding several horses at eventing competition in one day. Devienne and Guezennec (2000) studied oxygen consumption (VO_2) ventilation (V_E) and HR in five riders during a show jumping training session and found that jumping a course of jumps significantly increased VO_2 and HR. In discussion, Devienne and Guezennec (2000) suggest that a good aerobic capacity is a factor required for riding performance and competition. Fitness training carried out by riders may adequately prepare riders to cope with loss of body mass and intense aerobic activity, however fitness regimes adopted by riders is not currently reported in the literature. Professional riders who ride several horses per day on a regular occasion may be at lower risk than amateur riders who do not usually exert their bodies in this way as the professional riders are doing this type of training more often (as they are competing more). An assumption could therefore be made that professional riders are better conditioned to the exercise intensity and are therefore more fit for the sport. The findings of previous research on the physiological demands of riding on the human athletes highlight that horse riding is demanding. The findings of Roberts et al (2010) are particularly important as they demonstrate that eventing is extremely physiologically demanding on the rider. Further studies are needed to identify the stress response of riders at competition and how this can affect their physiological exertion. This would enable future research to consider how this can affect performance and thus the risk of a horse fall during the cross-country phase. Additionally, similar to horses, prolonged and excessive stress can have detrimental effects on rider health (Dimsdale, 2008; Ebbesen et al, 2009; Lee et al, 2010; Pouwer et al, 2010), so it is vital that we begin to understand the stress that the rider is exposed to during eventing competition.

2.2.2 Methods for measuring physiological response of horse and rider

Physiological measures can be used to assess the workload of horses and riders during exercise, such as lactate, HR, HRV, VO_2max, cortisol and water and ion loss (Ecker & Lindinger, 1995; Kirsch et al, 2020; Roberts et al, 2010; Serrano et al, 2001, 2002; Younes et al, 2016). Additionally, several of these measures can be utilised to assess mental (psychological) stress of horses and riders. Physiological measures that can be used to assess mental stress of horses and riders will be evaluated here.

2.2.2.1 Salivary cortisol

Salivary Cortisol (SC) has been used successfully in previous research to assess psychological stress in horses and humans (Meyer et al, 2015; Yarnell et al, 2013). Koolhaas (2008) reported that in normal competition circumstances, animals will be influenced by a circadian cortisol pattern; the concentration of cortisol is typically higher in the morning and lower in the evening. This indicates that

SC may not be a reliable measure of stress during eventing competition due to the difference in time of day that each horse is competing. Additionally, previous studies have reported that competition horses have altered release of cortisol (due to exposure to stress at competitions) and thus may not follow a typical circadian pattern; which would make it difficult to standardise the results even if time of day was controlled for (Bartolomé & Cockram, 2016). Cortisol concentration in saliva can demonstrate stress but it can also be influenced by other factors such as age and sex, these factors can affect cortisol binding therefore they must be controlled carefully to enable relation of salivary cortisol to stress (Peeters et al, 2013). Further limitations for the use of SC in eventing competition are demonstrated by Schmidt et al (2010c), reporting that transport of horses over short and medium distances leads to increased cortisol release, indicative of stress. The degree of these changes is reported to relate to the duration of transport (Schmidt et al, 2010c). Although SC is a validated measure of stress in horses and riders, it may not be the most appropriate method for assessing stress in-field at eventing competitions, due to the limitations of standardising the study in this context.

2.2.2.2 Infrared thermography

Other methods of measuring stress in horses have been established; ocular (eye) surface temperature as measured by Infrared Thermography (IRT) is reported to be an effective method of measuring stress in horses (Valera et al, 2013). Alterations in eye temperature is a recognised stress response in mammals, with the change in eye temperature being caused by changes in blood flow as mediated by the Sympathetic Nervous System (SNS) branch of the Autonomic Nervous System (ANS) (Blessing, 2003). IRT measures these alterations in ocular eye temperature via differences in the radiation of electromagnetic energy in areas surrounding the medial posterior palpebral border of the lower eyelid and the lacrimal caruncle (Bartolomé et al, 2013; Stewart et al, 2007). These areas within the eye contain capillary beds which are innervated by the SNS and respond to changes in blood flow (Bartolomé et al, 2013; Stewart et al, 2007). Previous research has found that eye temperature increases during acute stress responses which is believed to be as a result of increased attention and therefore increased dilation of the blood vessels in the area (Bartolomé et al, 2013; Yarnell et al, 2013). Infrared eye temperature (IRT) has been utilised in several previous research studies for assessment of stress in horses using ocular temperature. For example, Yarnell et al (2013) found that an increase in salivary cortisol concentration was significantly correlated with an increase in eye temperature (obtained with IRT), in their study that assessed the stress response of horses to a sham clipping procedure. This method requires the infrared images to be taken in a consistent and controlled environment as previous studies noted that noticeably different temperatures were measured seconds apart, due to the horses head moving to a slightly different angle (Ijichi et al, 2018a; Squibb et al, 2018). Indeed, recent studies have suggested that ocular eye temperature (using IRT) should be taken in a controlled environment where specific measurements from the horses head can be followed (such as poles on the ground), to ensure correct data capture (Ijichi et al, 2020). For this reason, this measure is not well suited for in-field testing at competition such as eventing due to the external stimuli that the horses are exposed to in this situation, which may make it a challenge to obtain accurate images.

2.2.2.3 Heart rate and heart rate variability

Heart Rate (HR) is the number of heart beats per minute whereas Heart Rate Variability (HRV) is the variation in time intervals between successive heart beats (Shaffer & Ginsburg, 2017). HR can be a useful tool to indicate arousal in a non-exercising setting (Vrijkotte et al, 2000), however HRV can provide a more representative assessment of mental stress (Stucke et al, 2015). The majority of previous equestrian studies that have utilised HR have done so to assess workload for horses in sport (Betros et al, 2002; Kirsch et al, 2020; Lorello et al, 2017; Serrano et al, 2001, 2002; White, 1995). For example, Kirsch et al (2020) investigated the physiological demands of cross-country competitions at different levels of eventing and found that mean HR was significantly higher at four-star level compared to two-star level. Additionally, the authors found that horses with 75% Thoroughbred blood had four beats per minute lower HR than warmblood horses, perhaps indicating that the warmblood horses were inferior in their cardiovascular ability. Nevertheless, the study highlights the way in which assessment of HR can be utilised for assessment of physiological demands.

HRV testing is a non-invasive way of measuring ANS activity in response to acute and chronic stress in horses (von Borell et al, 2007) and humans (Castaldo et al, 2015). There are several different parameters (i.e. calculations) of HRV that can be utilised, with von Borell et al (2007) stating that HRV parameters are some of the most superior non-invasive measures of ANS activity in response to psychophysiological stress/arousal. In most HRV parameters, a reduction in values indicates an increase in stress. HRV has been widely used in equestrian research to assess mental stress/emotional state of horses in a variety of settings including: prior to, during and after transport (Schmidt et al, 2010a, b, c, d), in response to ridden performance (Von Lewinski et al, 2013), during competition (Becker-Birck et al, 2013), in response to riders of different experience level (Ille et al, 2013), during training (Kinnunen et al, 2006; Physick-Sheard et al, 2000), during novel object tests (Munsters et al, 2012) and in response to pain (Rietmann et al, 2004). Additionally, HRV has been widely used to assess mental stress/emotional state of humans in a variety of settings including: acute response to skydiving (Dikecligil & Mujica-Parodi, 2010; Meyer et al, 2015), stress in surgeons and surgical trainees (Georgiou et al, 2017), stress in firefighters (Ebersole et al, 2020; Gomes et al, 2013) and pre-competitive anxiety in sport (Ayuso-Moreno et al, 2020; Mateo et al, 2012; Morales et al, 2013; Oliveira-Silva et al, 2018).

Previous research has utilised HR and HRV to assess the training response of eventing horses however no research to date (to knowledge) has assessed HRV at eventing competition. Becker-Birck et al (2013) measured salivary cortisol and HRV in horses in response to dressage and show-jumping competitions over a 3-day period and found that the HRV was significantly lower on day two and three of the competition. The authors reported that the demands of the competition increased each day, so the findings may reflect a cumulative stress response in the horse (Becker-birck et al, 2013). Fenner et al (2016) investigated the effect of nosebands fitted with increasing tightness on the stress response of horses and found that HRV significantly decreased (in comparison with baseline) in horses whilst wearing the tightest noseband, indicating a stress response to this treatment. Previous studies have also included the rider in their assessment of HRV; Von Lewinski et al (2013) used HRV in the horse and its rider to investigate different responses to a rehearsal and a public performance and found that HRV was significantly lower in riders during the public performance, indicating an increased stress response in the riders due to public spectators. The authors found no difference in HRV between the rehearsal and the public performance in the horses, indicating that horses were not affected by any stress associated with being spectated. In summary, HRV is a useful tool to assess autonomic activity in horses and riders and therefore can be used to measure mental stress in response to a variety of situations. HRV has not been used (to knowledge) to assess mental stress at eventing competition, thus this would be beneficial for future research to consider.

There are a variety of methods for analysing HR and HRV in horses and riders. Electrocardiogram (ECG) is the gold standard for these measures but requires expert knowledge to use, is expensive and require the use of multiple leads which may not be suitable to use for in-field settings due to potential interference with the horse/rider. Performance analysis companies such as Polar (Polar Electro Öy, Finland) have developed equine specific, wearable technology that can record HR/HRV during exercise; known as Heart Rate Monitors (HRMs). The validity of HRMs for recording equine HR/HRV has been investigated, with studies reporting that the HRM devices demonstrated good correlations with ECG whilst horses were in a stationary setting (e.g. tethered, or loose in a stable), however the validity of the data declines with increased movement (such as being loose in a field or during ridden exercise) (Ille et al, 2014b; Lenoir et al, 2017; Parker et al, 2010). Similar devices have also been developed for use in humans and have been validated for their accuracy of recording HR/HRV in both stationary (Giles et al, 2016), and exercising settings (Caminal et al, 2018). The use of HRV for assessment of stress in horses has been subject to scrutiny, as although the measure is well reported as a valid tool to assess ANS activity in horses, the accuracy of the measure is dependent on correct methodology in the context of data collection and handling (Stucke et al, 2015; von Borell et al, 2007). It is evident that there are inconsistencies across studies that have used HR/HRV to assess stress in horses and furthermore, there have been no review studies to date which have evaluated the literature on the validity of HRM devices to collect HR/HRV data in horses (Stucke et al, 2015; von Borell et al, 2007). A review of the literature that assesses the validity of HR/HRV as obtained by HRM devices and the appropriate data collection and handling methods that should be used as such, would therefore be beneficial.

2.2.3 Rider mood and feeling-states

The psychological demands of eventing for the rider is not thoroughly understood. Psychological factors of sport are often discussed in the context of the pressure of winning or placing and the pressure of performing well in front of others. Social Facilitation is the heading used in Psychology to describe the effect others have on the performance of an individual in sport. There are two branches to social facilitation; audience effects (a crowd being present) and co-action effects (competing with others, indirectly or directly) (Uziel, 2007). Audience effects may have a part in rider mental state at eventing competition. Although at the lower levels of eventing a crowd is rare, it is possible that certain individuals may provoke an audience effect in riders, such as a trainer/coach, family member or other known riders who are spectating. Co-action effects may affect eventing riders' mental state as although they do not compete side by side to other competitors, they do have a presence and carry out each phase following on from one another. Lewinski et al (2013) reported that the presence of spectators caused significant increases in rider heart rate; however, there was no effect on the horse's heart rate. This finding suggests that riders' experience psychological stress due to the presence of spectators (audience effects). Riders may feel more stressed in the presence of spectators due to wanting to perform well in front of trainers/horse owners or entice sponsorship. Additionally, riders may experience higher levels of stress in the presence of spectators as they may be concerned that the spectators will affect the performance of the horse (Lewinski et al, 2013). Spectator turnout during eventing competition is hugely varied, with national level competitions having an attendance of as little as 100 spectators, in comparison to international level competition such as Badminton horse trials, boasting a spectator attendance of up to 200,000. Spectator attendance during cross-country competition is unique as the course is spread out over a 1-10km area of land, so even large numbers of spectators will spread out between fences.

Hennessy (2017) found that 40% of all falls in eventing involved a horse that was competing for the first time at the level and 24% involved a rider that was competing for the first time at the level, highlighting the importance of correct preparation and training of horses and riders before progressing up the levels. British Eventing enforce Minimum Eligibility Requirements (MERs) which outline a minimum of competition completions/results that a horse and rider must obtain before they are eligible to enter into the next level of competition. BE enforces MERs purely as a safety measure and to ensure that horses and riders are sufficiently prepared and skilled to enter into a higher level of competition. The presence of increased risk at first time at the level as reported by Hennessy (2017) highlights that the MERs are not satisfactorily reducing risk in these instances. Although a horse and rider may be physically capable and prepared for the level (as is proven by obtaining the MER), it could be that the rider is under psychological stress or an alteration in mood/feeling-states when moving up a level, which could have the potential to affect their performance. Horses being at higher risk during this transition may highlight the importance of careful cross-country design. Course designers need to ensure that the course is challenging enough to set up riders for the next level, but not so challenging that when horses and riders step up it is too difficult and therefore dangerous. Assessment of the feeling-states of riders in response to eventing and more research on course design is necessary to answer these questions. 'State' is typically used to describe a temporary emotion/feeling, whereas 'trait' is typically used to describe a more chronic or enduring emotion or feeling (Kantor et al, 2001). In the context of sport, feeling-states are used to assess how emotional state is altered following a certain activity (i.e. how has the activity altered the persons emotional state?) (Winston & Dolan, 2004). Wolframm & Micklewright (2011) stated that riders who feel emotions such as anxiety may have tense muscles and increased respiratory or heart rates (whilst mounted) which could be detected by the horse as danger and thus invoke a fight or flight response. Understanding the emotions and feelings that riders experience at eventing competition would be the first step towards future research where we can assess how these feelings/emotions affect performance and therefore risk of horse falls.

2.2.3.1 Methods for assessing rider mood/feelings-states

Rider mood/feelings before, during and after eventing competition are not well documented in research. Matsuura et al (2015) carried out a study on the short-term effects of horse trekking and exercising with a riding simulator on ANS activity of participants. Using the Profile of Mood States (POMS) questionnaire they found that the exercise significantly lowered the riders' anxiety (Matsuura et al, 2015). The POMS questionnaire is a useful tool to investigate participant mood before/after exercise, but it is time consuming due to its length (60 questions), due to this it may not be suitable for assessing rider mood at competition, due to time constraints. Exercise induced feelings questionnaires such as POMS have been used and validated in sports research such as Dressage (Wolframm et al, 2010), Tennis (Covassin & Pero, 2004) and Triathlon (Parry et al, 2010). The Exercise-Induced Feeling Inventory (EIFI) is an alternative questionnaire that was developed by Gauvin & Rejeski (1993) and has been used in research to profile participants' mood before and after exercise. The EIFI consists of twelve questions that relate to four distinct subscales: Positive Engagement, Revitalisation, Tranquillity and Physical Exhaustion. Gauvin and Rejeski (1993) validated the questionnaire and stated that it has good internal consistency and is sensitive to exercise interventions, making it ideal for a study such as this.

2.3 Horse-rider relationship

The relationship between anxiety and performance has been previously studied. In sport, anxiety (arousal) is typically separated into cognitive and somatic; cognitive anxiety is defined as *"negative expectations, worries, and concerns about oneself, the situation at hand, and potential consequences"* whereas somatic anxiety is defined as *"the perception of one's physiological arousal."* (Schoen et al, 2017). Wolframm and Micklewright (2010) included 22 riders in their study which investigated the effect of the intensity and direction of anxiety and self-confidence on performance at a dressage and show-jumping competition. Riders were required to complete the Competitive State Anxiety Inventory-2 Revised immediately before beginning each competition. Results revealed that dressage performance scores were positively correlated with cognitive anxiety intensity in the rider, suggesting that riders who felt higher levels of cognitive anxiety immediately prior to the dressage test were associated with achieving higher (better) scores (Wolframm & Micklewright, 2010). Additionally, there was a positive correlation for riders who rated the horse as 'active' and the riders' own somatic anxiety intensity during show-jumping, indicating that riders who perceived their horse to be active were associated with higher levels of somatic anxiety immediately before the show-jumping competition. Wolframm and Micklewright (2010) suggest that the relationship between arousal in the rider and performance in the horse are indicative that the rider's self-confidence and perception of the horse's temperament is an important factor in competition performance.

Little is known about the effect that a rider's heart rate has on the horse heart rate. Preliminary studies have investigated the effect that humans with different stress levels have on resting horses' heart rate whilst standing in a stable. Merkies et al (2014) said that horses appeared less stressed in the presence of humans that were afraid of horses and humans that were physically exerted, than humans that were comfortable with horses and physically calm. Results suggest horses are not negatively affected by humans who are stressed or uncomfortable (Merkies et al, 2014). The authors suggested that this finding could be due to the horses being accustomed to riders who were physically exerted or stressed as they were used in a riding school environment and thus were familiar with humans in this state. It is also important to note that the sample size was small and did not meet the intended size from *a priori* power analyses, so the findings should be interpreted as preliminary (n=16 humans, n=10 horses) (Merkies et al, 2014).

The horse-human relationship is widely discussed in research but is difficult to objectively quantify. The relationship as perceived by the rider between themselves and their horse could be influential for the rider's decision making. Haigh and Thompson (2015) found that some riders identify a good relationship between themselves and their horse as an indication of reduced risk, supported by findings of Thompson and Nesci (2013). Riders who have a strong sense of 'trust' in their relationship with their horse may not feel the need to utilise recommended safety equipment whilst handling/riding their horse, putting themselves at increased risk of serious injury. Considering that riders perceive the relationship between themselves as an important factor in the context of risk, it would be beneficial for research to assess whether horse and rider mental stress is correlated; which could be done using physiological measures of stress (to test for associations/correlations between matched horse and rider values). It could be that when the rider is under intense physiological or psychological stress, that this could affect the horses mental stress levels. The relationship between horse and rider needs further research to reveal if they affect one another and how this in turn could affect performance and thus risk.

3. Overview of the thesis

3.1 Analysis of risk factors for horse falls

There were 59 reported rider deaths in the discipline of eventing between 1993-2015 (O'Brien, 2016), Highlighting the dangers of the sport. A number of previous research studies have identified that fence-level risk factors are associated with the risk of a horse fall however limited consideration has been given to other factors such as the previous history of the horse and rider.

In Chapter Four, I will investigate risk factors for horse falls in the cross-country phase of one-day eventing competitions in the UK. This chapter is designed as such due to existing knowledge that a horse fall during the cross-country phase of eventing carries the highest risk of injury and fatality to the horse and rider. Previous research has identified key risk factors for horse falls in the cross-country phase of eventing however this has included in-field data collection which understandably restricts sample size, and in some cases, sample sizes have been greatly reduced from the data that is available. A study which includes all data available for the intended study period and the intended sample (i.e. one-day events) may be more representative of the risk factors for horse falls within the sport. Additionally, results from a study such as this will reflect a more representative balance between cases (cross-country starts that result in a horse fall) and controls (starts that do not result in a horse fall). Within this chapter, novel methods are applied as described in research into risk factors for horse injury/fatality in horse racing (Boden et al, 2006; Georgopoulos & Parkin, 2017; Parkin et al, 2004, 2008). The data available for risk of injury/fatality in the racing industry is larger in comparison to what is available for risk of horse falls (or injury/fatality) in eventing sport. Thus, adopting the novel techniques that have been developed for risk factor analysis in the racing industry may aid in developing research within the eventing industry. Due to this, the analysis conducted in Chapter Four is presented with broad aims, as it is expected that new risk factors may be identified due to this being the first study to encompass all the data that is available for the intended study periods.

Further research is needed to develop and expand upon the findings of previous studies on risk factors for horse falls, this will aid in providing a stronger argument for the governing bodies to act on and acknowledge the findings of scientific research. This study intends to identify risk factors for horse falls so that the information can be disseminated to the sport governing bodies and appropriate action can be taken with the aim of reducing the incidence of horse falls and improving safety within the sport. Action taken from BE regarding this new information may include rule changes or altered MERs.

It is imperative for the continuation of the sport of eventing that increased safety measures are actively sought by researchers and governing bodies in unison. It is paramount that the public judgement of the welfare implications to horses competing in the sport is positive. A reduction in falls during cross-country would likely reduce horse and rider injury, potentially saving human and animal lives and improving the reputation of the sport in the public eye.

3.2 The use of HRM devices to collect HR/HRV data in horses

To date (to knowledge), there are no available studies that have reviewed the literature on the use of HRM devices in horses to assess stress and welfare. Despite this, studies are continually published that utilise these devices for this purpose (Becker-Birck et al, 2013; Ijichi et al, 2019; Ille et al, 2013; Kinnunen et al, 2006; Mott et al, 2021; Squibb et al, 2018; Von Lewinski et al, 2013). In Chapter Five, I conduct a scoping review of the available literature on the reliability and validity of HRM devices for assessing HR/HRV in horses. Previous studies have conducted validation tests with HRMs and the gold-standard ECG (Ille et al 2014b; Lenoir et al, 2017; Parker et al, 2010), however the results and methods of data collection and handling are varied. A review study would therefore be beneficial to critique and evaluate the findings on the validity of HRM devices to inform future study design and procedure. For this review, I consider studies that utilise HR/HRV with other validated measures of stress (such as salivary cortisol concentration) which enables a more in-depth assessment of whether the devices are suitable for collecting HR/HRV data that can successfully identify stress in horses. Furthermore, the inclusion of the wider field of research enables critique of the methods used in different studies and evaluation of whether these are correct as per recommendations from experts in the field and prior review studies. A review such as this will aid in developing standardised methods for using HRM devices to collect reliable HR/HRV data and will inform future studies of appropriate methodology.

3.3 Stress of horse and rider at eventing competition and riders' feeling-states

In Chapter Six, I collect HR/HRV data from horses and riders during different time-periods at eventing competitions in the UK. Theoretical principles of the horse-rider relationship informed the choice to monitor both horse and rider, which would enable objective investigation of any association between horse and rider physiological measures of stress. Time-periods were selected to demonstrate basal values at 'home' and at competition, which would permit tests of difference with the other two time-periods. The other time-periods were selected in consideration of previous research, that the cross-country poses the highest risk of injury/fatality to the horse and rider. These time-periods were prior to the cross-country (at the cross-country warm up and at the cross-country start box) but followed on from the other two phases of competition (dressage and show-jumping). The study was designed in this way to enable assessment of possible pre-competitive anxiety/stress in the horse or rider, directly related to the cross-country. Previous research in horse sport has considered the effect of stress on performance. Despite this, the stress that horse and rider experience at eventing competition has never been assessed. Due to this study being the first to assess stress of horse and rider at eventing competition, the findings are predicted to be preliminary, but will add a significant and original contribution to knowledge that future studies can build upon.

The mental state of riders at eventing competition is not currently understood, however in other fields of study (such as show-jumping) has been found to significantly affect performance. Therefore, during the data collection for Chapter Six, I used the EIFI to collect data on riders' feeling-states on arrival at competition and after all three phases of competition were complete. It is predicted that the riders' feeling-states may be associated with the level of stress that the horse or rider will experience, thus collection of this data enables investigation of this notion. If riders' feeling-states are significantly associated with their (or their horses) physiological measures of stress, then interventions could be introduced to riders to help them mitigate these emotions. In consideration of previous literature which has reported high levels of stress to affect performance, this may be beneficial in reducing the risk of horse falls. The psychology of the rider during eventing has had little research focus to date. Thus, this is a further novel aspect of this study.

4. Risk factors for horse falls during the cross-country phase of one-day eventing competitions in the UK (2005-2015)

4.1 Introduction

Eventing is a high-risk sport, the cross-country phase in particular poses risk of injury/fatality to both horse and rider (Singer et al, 2003). Between 2010-2020 there were 20 rider fatalities globally due to horse falls in the cross-country phase of eventing competition, with five of these deaths occurring in 2016 alone (O'Brien, 2016).

There is a lack of studies that have investigated risk factors for horse falls in the cross-country phase of eventing competition, with most being published more than 15 years ago (Murray et al, 2005, 2006b; Singer et al, 2003). Previous studies have identified risk factors for horse falls during cross-country (Chapter Two, Section 2.1.1), however changes to the sport have occurred since these studies were published. For example, the introduction and increased use of frangible devices; rule changes such as speed and length of the course at differing levels and the introduction of novel safety devices such as air jackets for riders. It is therefore necessary to carry out updated studies on potential risk factors due to changes in the sport. Furthermore, recent studies have investigated risk factors for horse falls in FEI eventing competition and have reported some previously unidentified risk factors such as falls being more likely to occur at fences with frangible devices during FEI competitions (Barnett, 2016). The study by Barnett (2016) was not published in a peer-reviewed journal however it is important to note that the work was supported by BE and the FEI and included collaboration with several experienced academics, who have previously published research of this nature, which indeed raises the merit of the study.

Frangible pins were introduced in 2005 and subsequently listed as mandatory on all suitable fences from 2006 onwards (BE, n.d.). BE state that frangible pins reduce the risk of a rotational horse fall, due to the rail dropping which allows the horse to move its leg forward to prevent rotation (BE, n.d.). They also state that frangible pins can prevent the horse from falling but are first and foremost designed to prevent rotational style falls. According to data published by BE, rotational falls carry the highest risk of serious/fatal injury to the rider, with 28% of rotational horse falls that occurred in the 2014/15 season resulting in serious injuries, compared with only 7% of non-rotational falls having the same outcome that season (BE, 2015).

Due to the limited research available on horse falls in eventing it is prudent to observe the findings of research in comparable equestrian sports such as horse racing. Recent studies into horse racing have tended to focus on risk factors for horse injury and fatality as opposed to horse falls. Boden et al (2007a) reported an increased risk of fatal injury for racehorses who had started in a flat race 21 to 60 days prior to the current start. Furthermore, a study into jump racing found that horses who had started at least once in the previous 14 days to the current start had an increased risk of fatality (Boden et al, 2007b). On the contrary, Lyle et al (2011) found that an increased frequency of starts within the 30, 60, 90, 180 and 365 days prior to the current start (in both jump and flat racing) were associated with decreased risk of sudden death in thoroughbred racehorses, while Georgopoulos and Parkin (2017) stated that the more starts in flat racing a horse had in the most recent 2-3 months prior to a race, the lower the risk of limb fracture. Additionally, Georgopoulos and Parkin (2017) found that the longer the horse has been away from competition the higher its risk of fracture in a new start at competition would be. Studies that have found increasing number of starts prior to the race as protective have typically attributed this to the notion that healthy horses (e.g. fit and free of injury) are more likely to be racing (Boden et al, 2007b; Lyle et al, 2011). Studies that have found that increased number of prior starts increases risk of injury/fatality have attributed this to those horses potentially having a lower level of fitness, accumulation of sub-clinical injury or exercise induced hypertrophy (predisposing these horses to arrythmias) (Boden et al, 2007a; Lyle et al, 2011).

In 2007, for ease of comparison between studies it was recommended that 30-day periods should be analysed for horse racing risk, following on from the 'Havemeyer Foundation Symposium' (Parkin, 2007). The findings into number of starts prior to the current start in racing is complex, with studies finding contradictory results. It is clear however that prior starts consistently have an effect (whether that is protective or detrimental) on the risk of injury/fatality in racehorses as the variable is often retained in final multivariable models. This methodological approach would be beneficial when considering horse falls in eventing as it would be reasonable to assume that a portion of the injuries that have occurred in horse racing are as a consequence of the horse falling; although the mechanism of the injury occurring is not often stated in the studies. Thus, it could be that the risk factors for horse injury in racing are in-fact also risk factors for horse falls. Inclusion of this variable in eventing horse fall research is therefore valuable and may reveal previously unknown risk factors. In consideration of this it was decided to create new variables to include within the data analysis of this study in line with those used in horseracing risk factor studies such as the one conducted by Georgopoulos and Parkin (2017). The previous number of starts at competition were calculated for each horse and each rider individually and as a team; phases of 30, 60 and 90 days were selected as suggested by Parkin (2007) within racing risk factor analysis, also supported and used by Georgopoulos and Parkin (2017) and Boden et al (2007b).

4.1.1 Aims, objectives and hypothesis

The aim of the study was to provide descriptive statistics and identify horse-, rider- and competition-level risk factors for horse falls in the cross-country phase of eventing competition in the UK. The objective was to analyse eleven years of eventing data (2005-2015) for possible risk factors that are associated with an increased or decreased risk of a horse fall. The hypothesis was therefore that a combination of horse-, rider- and competition-level factors would influence the overall likelihood of a horse fall during the cross-country phase of one-day eventing competitions in the UK.

4.2 Materials and methods

All research was approved by the appropriate ethics committees at the University of Central Lancashire:

Science, Technology, Engineering, Medicine and Health (STEMH) ethics

Reference: STEMH 483

Date approved: 15.08.2016

4.2.1 Reconciling course, fence, competition, and incident information

4.2.1.1 Study design

It was initially planned that files relating to different information regarding competitions would be reconciled, which would provide further variables for analysis of risk factors for horse falls. These data files are explained here, and the reconciliation process is described.

4.2.1.1.1 Sample selection/study period

See Table 4-1 for files collected from the British Eventing Database. Data was filtered at the point of obtainment from the governing body to include data subsequent to the year 2004 (BE advised that data quality was most reliable from this year onwards). Frangible pins were trialled in the 2002 season and various research publications have analysed risk prior to this change in fence design.

Table 4-1: Files collected from British Eventing.

Excel File	Rows	Columns
Course Details	4,662	15
Fence Details	130,959	47
Incident Details	18,465	81
Competition Data	856,587	27

4.2.1.1.2 Course details

The course details file has information on the course's location, length, optimum time and number of jumping efforts. The Technical Advisor and the Course Designer are responsible for gathering this information at competition. The full list of information available in the course details file can be seen in Appendix I.

4.2.1.1.3 Fence details

The fence details file includes information on the cross-country course such as the type, style, height, width and location of the fences used in each course. Ground condition before and after the fence and any details about take-off/landing into water are also noted. The full list of information available in the fence details file can be seen in Appendix II.

4.2.1.1.4 Incident details

The incident details file has any information relating to a rider or horse fall at competition. This data set includes a description of the incident, the type of incident and the time and place of the incident. Details on injury severity and attendance of medical/veterinary staff are also included. The full list of information available in the incident details file can be seen in Appendix III.

4.2.1.1.5 Competition details

The competition data file has information on competition results for horses and riders. This consists of their demographic data, their scores during the competition and the level, location and final results of the competition. BE use an online database to record all results of competition. The data that is input into the database is collected at competition by judges or volunteers. At competition, officials display live scores and results so that competitors and spectators can follow the competition standings. The full list of information available in the competition details file can be seen in Appendix IV.

4.2.1.2 Available data

4.2.1.2.1 Dressage

Dressage judges are responsible for the dressage score which is given verbally and then transcribed by a 'dressage writer'. This information is then given to the officials at the competition as soon as possible to allow for live scoring throughout the competition. The Dressage judge must be an accredited coach or a competitor who has competed at a certain level of British Dressage or BE competition. The qualifications required for the dressage judges increase to a higher standard as the level of competition rises. Requirements for dressage judges are adapted year by year in the BE rules so these guidelines may have changed throughout the years of competition recorded in the retrospective data analysis. The dressage judge will mark each movement out of ten. These scores are then added together and converted into a penalty score – a lower penalty score will result in a better placing within the competition. Penalties can also be given in dressage for: first error of course (two penalties), second error of course (four penalties) and a third error of course will result in elimination (BE, 2018).

4.2.1.2.2 Show-jumping

The show-jumping phase is overseen by a judge drawn from the British Show-jumping panel of judges. This judge will decide on any penalties incurred by the horse and rider combination during the show-jumping round. Jumping penalties are given in the show-jumping phase for: knocking a fence down (four penalties), refusing at a fence (four penalties), second refusal at a fence (eight penalties) and turning a circle in between fences (four penalties) (BE, 2018). Show-jumping time penalties are given for every commenced second in excess of the time allowed (BE, 2018).

4.2.1.2.3 Cross-country

The cross-country is overseen by the cross-country steward. The cross-country steward is responsible for supporting the fence judges, timekeepers and any other cross-country officials appointed by the organiser. Fence judges are responsible for recording penalties obtained by a horse and rider combination at appointed fences. Fence judges may work alone or in pairs and may be given one or several fences to monitor, provided that each is clearly visible to them. There are no qualification requirements to be a fence judge and the majority work at competition on a voluntary basis. Fence judges record any penalties incurred at a fence on a score card. Score cards are collected intermittently at competition and taken to officials to allow scores to be displayed.

Cross-country jumping penalties are given for: first refusal, run out or turning a circle in front of a fence or between a combination (20 penalties), second refusal, run out or turning a circle in front of a fence or between a combination (40 penalties) (BE, 2018). Cross-country time penalties are given for every commenced second in excess of the optimum time (0.4 penalties) and for every commenced second in excess of 15 seconds under the optimum time (0.4 penalties) (BE, 2018).

Penalties from all three phases are accumulated which gives the horse and rider combination their final score. This score will dictate the combination's final position in the competition. Once the penalties from all three phases of competition have been collated and the competition is finished, BE manually update the online database with the scores normally within 24 hours of competition.

4.2.1.2.4 Recording incidents

Falls of horse or rider during any phase of the competition are recorded using a fall report form. It is the fence judge's responsibility to fill out the fall report form if they witness a fall. The fall report form used by British Eventing can be seen in Appendix V. Completed fall report forms are input into digital format at British Eventing head office and kept in an MS Excel database.

4.2.1.2.5 Categorisation of horse fall

Horse falls are categorised in the BE rule book as *"both the horse's shoulder and its quarters coming into contact with either the ground, or the obstacle and the ground, simultaneously".*

4.2.1.2.6 Horse grading and points

Horse grades and points can be seen in Table 4-2. Grade one is the highest grade that can be achieved by a horse. Points can only be obtained for Novice level classes or above.

Table 4-2: Horse grades and points (BE, 2018).

Points	Grade Achieved
0	IV
1-20	III
21-60	II
61+	I

The number of places to which grading points are awarded at a competition is determined by the number of eligible starters in the dressage phase of the class (see Table 4-3). Grading points are awarded to unplaced horses which complete the competition incurring no show-jumping penalties (jumping or time) and no cross-country jumping penalties, this is also known as a 'double clear' round. An extra 50 points are awarded to a horse for completing a competition as a member of a team or nominated individual for Great Britain.

Table 4-3: Points awarded for each class (BE, 2018).

Class		**One Day Event**						**3 Day Event**			
		Novice	Intermediate	Advanced	*	**	***	*	**	***	****
Place	Starters	Points						Points			
1		6	12	24	8	16	32	10	30	110	180
2		5	10	22	7	14	29	9	28	100	17
3		4	8	20	6	12	26	8	26	90	160
4	over 15	3	6	18	5	10	23	7	24	80	150
5	over 19	2	4	16	4	8	20	6	22	70	140
6	over 23	1	2	14	3	6	17	5	20	60	130
7	over 27	1	2	12	2	4	14	4	16	50	120
8	over 31	1	2	19	2	4	12	3	13	40	110
9	over 35	1	2	8	2	4	10	3	13	40	100
10	over 39	1	2	8	2	4	8	3	13	40	90
Double clear round points to unplaced horses		1	2	4	2	4	5	2†	5†	25†	65†
		†Points for completing the competition in the top half of starters but not within the points or prize money									

4.2.1.2.7 Calculated data

Additional variables were created manually in line with methods used for risk factor analysis in horse racing sport. The additional variables were created from the data available and typically related to the horse and rider's previous starts and falls during competition. The calculations for these variables were generated using 'R' software.

Start history

For the cross-country starts available, the previous number of starts at competition were calculated for each horse and each rider individually and as a team, at every current start point. Phases of 30, 60 and 90 days were selected. The same calculation was used to identify a horse, rider or horse/rider combination's first start within the study period.

Days since last start

For the cross-country starts available, the time in days since the last eventing competition start was calculated for each horse and rider individually.

Horse fall history

For the cross-country starts available, the number of horse falls that horses and riders experienced individually and as a combination were created as a new variable. This variable was recorded in periods of the previous 180 days, 365 days and 'career'. Where 'career' is stated, the time-period begins from the first ever cross-country start for that horse/rider recorded within the eleven--year period taken from the database.

4.2.1.3 Data processing

The data were processed using a combination of the software packages Microsoft Access (Version 2008), Microsoft Excel (Version 2008), RStudio (RStudio Team 2017), and STATA (StataCorp, 2017, Release 15). The raw data was not in a suitable format for analysis and required extensive cleaning and sorting.

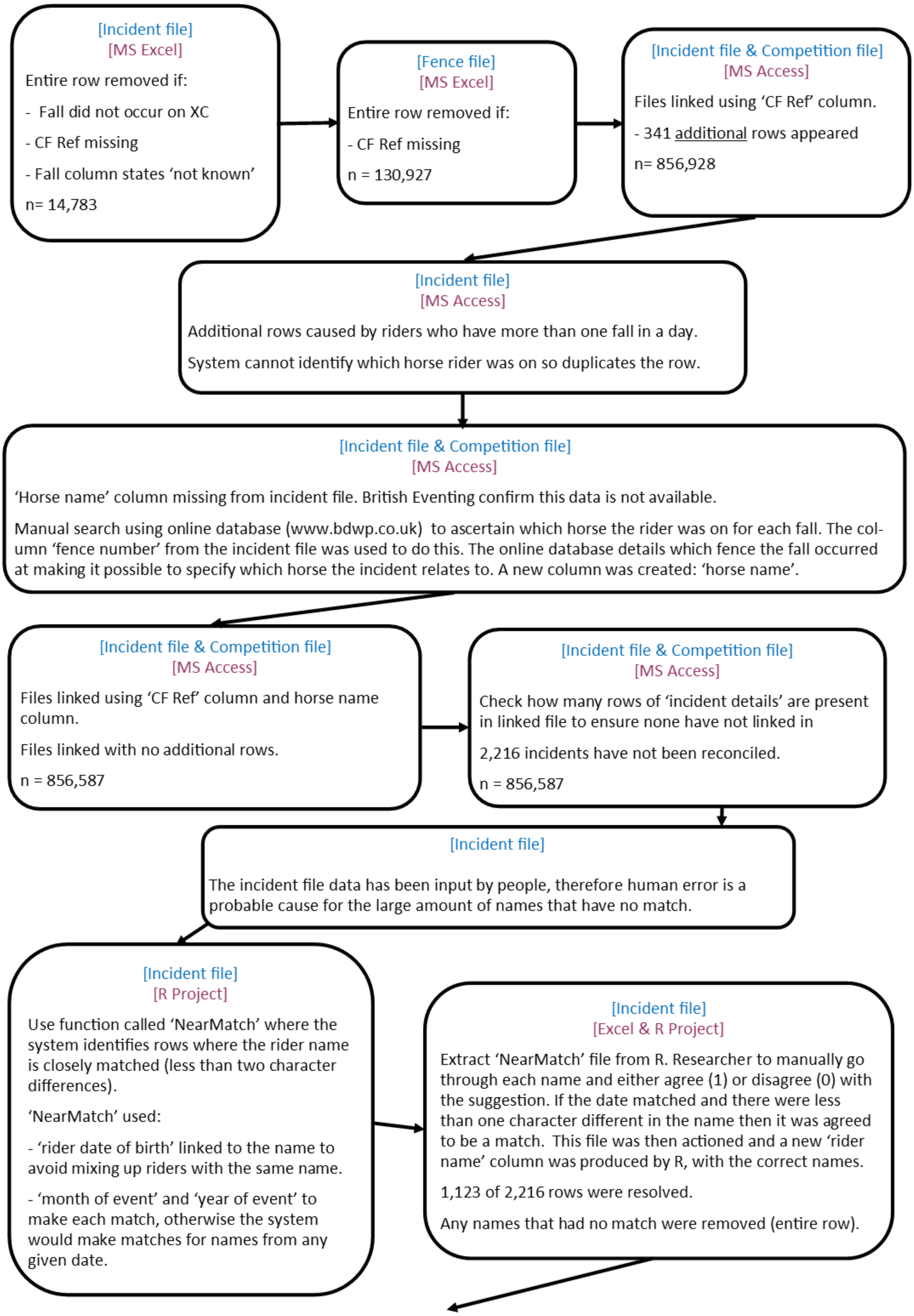


Figure 4-1: Flow diagram of the data processing methods used.

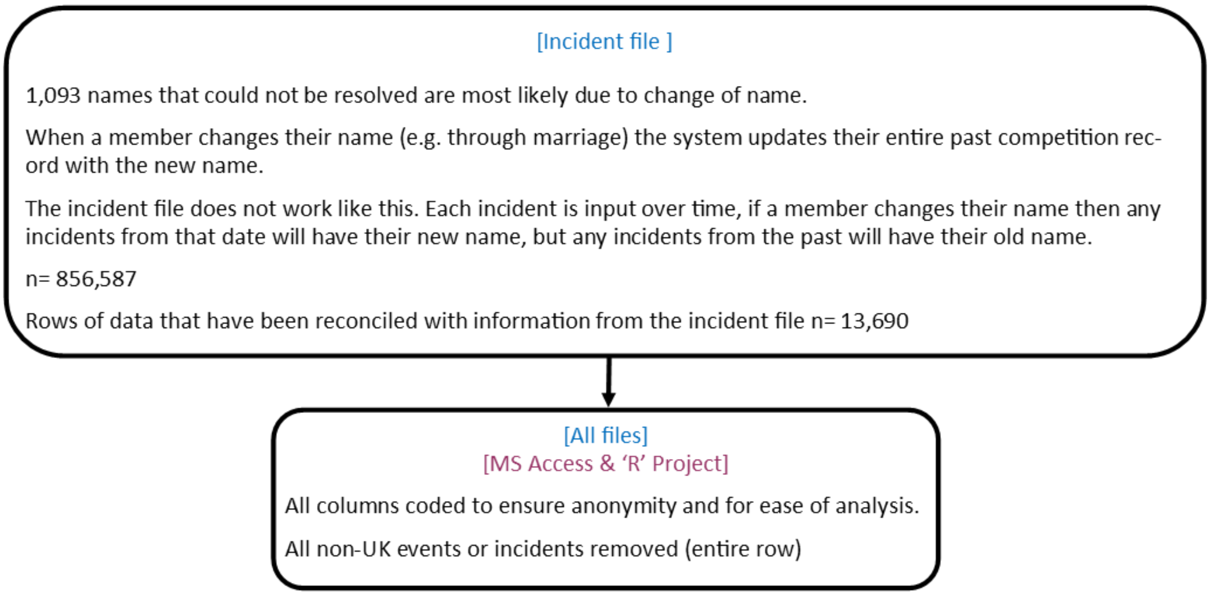


Figure 4-1: continued.

4.2.1.3.1 Initial data selection and cleaning

The process outlined in Figure 4-2 describes the initial data handling up to the point of having reconciled 'unseated rider' and 'horse fall' report forms with the competition data set. At this stage, the data had 856,587 rows with 13,690 rows of reconciled data.

The next step of the process was to remove any reconciled rows of data pertaining to 'unseated rider' falls. This reduced the reconciled data down to 1,123 reconciled horse falls, which is less than expected (a reduction of 1,510 falls from what was present in the competition data file following data cleaning). Further reconciliation of the data was attempted using class, event name and date, however no further data could be resolved. The data was checked manually at this stage and it became apparent that there were several inconsistencies between the two data sets, which included:

- There were fall report forms for 'horse falls', which when the corresponding row was checked in the competition data there was no elimination code recorded for that horse and rider partnership on that day of competition.
- There were horse falls recorded in the competition data set which did not have a corresponding fall report form.
- There were discrepancies in how the class of competition was recorded between the data sets.
- There were discrepancies in how the event name was recorded between the two data sets.

At this stage, the course details file was also reconciled into this data. Out of 4,662 events, only 1,150 could be reconciled. This contained 831 horse falls that occurred across 522 competitions. Following attempts at additional reconciliation as described above, no further reconciliations were possible.

Similar limitations were found while attempting to reconcile the fence detail data. When all files had been reconciled the final data contained 408 controls and 270 cases. Thus, this it was decided that this data would not represent a true sample and was not taken forward for analysis.

4.2.2 Competition data

4.2.2.1 Study design

Retrospective data of competition results were collected from the BE Database for risk factor analysis. All cross-country starts which resulted in a horse fall (case starts) were compared to starts that did not result in a horse fall (control starts). A 'start' is any time a horse and rider combination started the cross-country phase in an eventing competition.

4.2.2.2 Background – competition information

Details pertaining to the competition data file can be viewed in section 4.2.1.1.

4.2.2.3 Statistical methods

The relationship between continuous potential risk factors and the outcome horse fall was reviewed by assessment of graphical plots of the log of odds (Boden et al, 2007a). If a non-linear relationship was observed, appropriate categorical terms for risk factors were created and were considered. Categorisation was based on quintiles or plausible biological explanations (where possible) on the basis of 'best fit' in a multivariable model using Akaike Information Criterion (AIC) and log-likelihood, in an attempt to find the most parsimonious model (Dohoo et al, 2010; Royston & Sauerbrei, 2008). Based on univariable analysis, any category labelled as 'unknown' was folded into the reference category providing that this category was not statistically significantly different from the reference category and that the AIC of the model did not lower (rider age and rider sex). Explanations for categorisation of individual variables are provided in the descriptive analysis Section 4.3.1.

4.2.2.4.1 Univariable analysis

Univariable logistic regression was performed on all risk factors considered biologically plausible or supported within the literature, to assess the association between potential risk factor and horse fall. Wald P-values were calculated; any risk factors with values of $P<0.20$ in univariable analysis were deemed eligible for inclusion in a multivariable logistic regression model. A threshold of $p<0.20$ was chosen to avoid exclusion of a potentially significant risk factor which only becomes evident when a confounding variable has been controlled for in a multivariable analysis (Dohoo et al, 2010).

4.2.2.4.2 Multivariable model

A stepwise bi-directional (forwards-adding and backwards-removing) process was used to construct the multivariable model, with each step assessed using the AIC. The AICs for competing models were compared, with the lowest AIC indicating the preferred model (Bozdogan, 1987). The AIC was relied upon for including risk factors in the final model and no other exclusion criteria based on potential biological interaction was used. A Wald P value of less than 0.05 was required for a risk factor to be retained in the final model.

Risk factors included in the final model were checked for possible collinearity (Bagley et al, 2001), correlation coefficients were produced for all pairs with a threshold for inclusion set at 0.7. Risk factors rejected at the univariable and multivariable stages were subsequently tested for confounding in the final model (Boden et al, 2007a). If the odds ratios for variables in the final model were altered by >20% by the potentially confounding variable then the confounder was retained in the final model (Dohoo et al, 2010).

The potential impact of horse and rider clustering was assessed by creating a mixed-effects model that included horse and rider as random effects together and separately (Boden et al, 2007a; Lyle et al, 2011) with the final model. Random effects were checked for after all other model fitting procedures had been completed which enabled confirmation that the final model was not altered by random effects.

Biologically-plausible interaction terms were created to assess whether two or more factors that were associated with the outcome horse fall resulted in an increased or decreased frequency of a horse fall when presented in combination, in the final model (Thrusfield, 2007). Interaction terms with P values of <0.05 were retained in the final model.

The final model was tested for goodness-of-fit using the Hosmer-Lemeshow test (Hosmer & Lemeshow, 2000; Dohoo et al, 2003). The predictive ability of the model was assessed by calculating the area under the receiver operating characteristic curve (Bozdogan, 1987). Statistical analyses and calculations in this chapter were conducted using RStudio, developed by RStudio Team (2017), and the R programming language by the R Development Core Team (2017).

Figures for the results of the multivariable model display the probability of a horse fall per start. Probability was obtained using the log-odds with the following formula, where x represents the log-odds value:

$$\frac{exp(x)}{1 + exp(x)}$$

4.3 Results

4.3.1 Descriptive statistics

4.3.1.1 Data selection

Data were also filtered to only include one-day-event competitions where the format of competition phases were run in the order of dressage, show-jumping, then cross-country (to enable identification of potential risk predictors within the phases prior to cross-country). The competition level BE80 was not included in the data as this level of competition was only introduced in 2008 so would not have spanned the entire study period. CIC (international) competitions which were run over one day and in the format (order of phases) stated above were included.

4.3.1.2 Initial data cleaning

Prior to descriptive data being produced, the data was sorted and cleaned. One issue with this data set that affected several variables was the inconsistent use of either 'NA' (Not Applicable), blank cells, and zero's; making it difficult to identify 'no penalties awarded' (which should be a zero), missing data (which should be blank) and genuine NA's. Initial data cleaning is described within this section for relevant variables.

4.3.1.3 Study Population prior to data cleaning

Following removal of BE80 class competitions, the data contained a total of 833,062 starts in eventing competition in the UK from 1st January 2005 to 31st December 2015 These starts were made by 53,850 unique horses and 26,772 unique riders. There were 84,943 unique horse/rider combinations (Table 4-4).

Table 4-4: Average number of starts for unique horses, riders and horse/rider combinations prior to data cleaning.

	Total Data	Starts	Average number of starts
Horse	833,062	53,850	15.5
Rider	833,062	26,772	31.1
Unique horse/rider combination	833,062	84,943	9.8

4.3.1.4 Case definition

Cases were defined as starts in the cross-country phase that resulted in a horse fall. All other cross-country starts within the data set were classified as controls.

4.3.1.5 Description and incidence of horse falls

There were 3,388 horse falls recorded, with four falls per 1000 starts for the 833,062 starts in the 11-year study period.

4.3.1.6 Data cleaning

Data were cleaned to remove rows where there was any ambiguity as to:

- Whether the combination had started the competition
- Whether the combination had started the cross-country phase
- Whether the competition included all three phases (e.g. mis-labelled 'arena eventing' that includes only show-jumping and cross-country)

Examples of data that would indicate the above points:

- All penalty columns missing values within the same row (indicates non-starter)
- No values given in the dressage penalty column. Empty cells within the dressage penalty column indicate that the combination did not start the competition, or that the competition was not a one-day event (which encompasses all three phases).
- No values given in the show-jumping penalty column (empty cell). If a combination achieved zero penalties within this phase, then the value input should be a zero.

Manual searches were performed for a number of these rows to find the corresponding results published on the BE website, this revealed that some of these blank cells should have been zero (no penalties), some of them were non-starters, and some of them had elimination codes; therefore there was no way to fix the entirety of these errors without manually checking several thousand event records. However, a variety of techniques were performed to correct as much of this data as possible. For example, for rows where the sum of dressage penalties and cross-country penalties corresponded with total penalties, empty show-jumping penalty cells were assigned a score of zero, as in this instance it was reasonable to assume that the combination must have completed the show-jumping phase without incurring any penalties.

Data that had missing values but did not call in to question whether the combination had started the competition (or the cross-country phase) were deemed acceptable. Details of how these data were managed can be seen in the following sections of this chapter.

Missing data within the show-jumping penalty columns largely contributed to necessary removal of data, with 79,657 rows containing empty cells within these columns. Following data correction techniques outlined above, only 3,127 of these errors could be corrected. Cleaning and correction of the entire data set resulted in a total of 83,528 rows of data being removed from the raw data file, leaving a total of 749,534 rows to go forward for descriptive and statistical analysis. As a result of this removal of spurious data, the total number of horse falls (cases) within the data set was reduced by

755 (reduction of 22%). This is unfortunate due to these falls being the dependent variable, and already having such limited numbers. It is therefore strongly recommended that BE investigate these errors in the data and attempt to prevent the continuation of such errors, to improve any future data analysis.

4.3.2 Descriptive statistics of final data set

4.3.2.1 Study population

The study population contained a total of 749,534 starts in the cross-country phase of eventing competition in the UK from 1st January 2005 to 31st December 2015. These starts were made by 52,083 unique horses and 23,664 unique riders. There were 81,407 unique horse/rider combinations. A breakdown of the average number of rides per horse, rider and unique horse/rider combinations is given in Table 4-5.

Table 4-5: Average number of starts for unique horses, riders and horse/rider combinations.

	Total Data	Starts	Average number of starts
Unique horse	749,534	52,083	14.1
Unique rider	749,534	23,664	31.7
Unique horse/rider combination	749,534	81,407	9.2

4.3.2.2 Description and incidence of horse falls

There were 2,633 horse falls recorded, with 3.5 falls per 1000 starts for the 749,534 cross-country starts in the 11-year study period. A breakdown of falls for each variable within the data set are provided in the subsequent sections.

4.3.2.3 Event year

The data selected contained the date (dd/mm/yyyy) of each event. The year was isolated and a new variable was created titled event year. The number of horse falls, along with their 95% confidence intervals, for each year are shown at Table 4-6.

Table 4-6: Descriptive statistics of event year and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Year	Starts	Falls	Falls per 1000 starts	LCI	UCI
2005	60,805	262	4.31	3.82	4.86
2006	62,671	246	3.93	3.47	4.45
2007	62,836	232	3.69	3.25	4.20
2008	69,060	268	3.88	3.44	4.37
2009	71,968	233	3.24	2.85	3.68
2010	70,485	263	3.73	3.31	4.21
2011	71,736	222	3.09	2.71	3.53
2012	58,797	207	3.52	3.07	4.03
2013	72,728	242	3.33	2.93	3.77
2014	71,750	239	3.33	2.94	3.78
2015	76,698	219	2.86	2.50	3.26

4.3.2.4 Horse grade

The data selected included the grade of each horse. The unknown category includes any empty cells within this variable in the data set. It is not clear why empty cells were present within this column of the data set as horses should be graded as soon as they start in their first BE competition (with Grade IV encompassing starts at the lowest levels of competition, regardless of competition result – i.e. 'nil' points). It would therefore be reasonable to assume that the blanks are missing data/errors which is why they have been classified as unknown. The number of horse falls, along with their 95% confidence intervals, for each horse grade are shown at Table 4-7.

Table 4-7: Descriptive statistics of horse grade and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse Grade	Starts	Falls	Falls per 1000 starts	LCI	UCI
Grade I	121,076	640	5.29	4.89	5.71
Grade II	130,401	609	4.67	4.31	5.06
Grade III	180,770	660	3.65	3.38	3.94
Grade IV	301,297	701	2.33	2.16	2.51
Unknown	15,990	23	1.44	0.96	2.16

4.3.2.5 Horse sex

The data selected contained the sex of each horse. The proportion of geldings was 73%, mares 26% and stallions 1%. The number of horse falls, along with their 95% confidence intervals, for each horse sex are shown at Table 4-8.

Table 4-8: Descriptive statistics of horse sex and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse Sex	Starts	Falls	Falls per 1000 starts	LCI	UCI
Gelding	546,424	1893	3.46	3.31	3.62
Mare	198,258	715	3.61	3.35	3.88
Stallion	4,852	25	5.15	3.49	7.60

4.3.2.6 Dressage penalties

The data selected contained the dressage penalties for each start. The number of horse falls, along with their 95% confidence intervals, for quantiles of dressage penalties are shown at Table 4-9.

Table 4-9: Descriptive statistics of dressage penalties and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Dressage Penalties	Starts	Falls	Falls per 1000 starts	LCI	UCI
10.0 - 32.5	200,066	553	2.76	2.54	3.00
32.6 - 35.9	174,873	580	3.32	3.06	3.60
36.0 - 39.8	187,248	671	3.58	3.32	3.86
40.0 - 100	187,347	829	4.42	4.13	4.74

4.3.2.7 Show-jumping penalties

The data selected included show-jumping penalties for each start. The number of horse falls, along with their 95% confidence intervals, for show-jumping penalties are shown at Table 4-10.

Table 4-10: Descriptive statistics of show-jumping penalties and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Show-jumping penalties	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	313,777	949	3.02	2.84	3.22
4	227,717	785	3.45	3.21	3.70
8	114,219	444	3.89	3.54	4.27
12	53,735	258	4.80	4.25	5.42
16	24,645	125	5.07	4.26	6.04
20	10,542	51	4.84	3.68	6.35
80	4,899	21	4.29	2.81	6.54

4.3.2.8 Show-jumping time penalties

The data selected contained show-jumping time penalties. One show-jumping time penalty is given for every commenced second in excess of the time allowed. The number of horse falls, along with their 95% confidence intervals, for show-jumping time penalties are shown in quantiles at Table 4-11.

Table 4-11: Descriptive statistics of show-jumping time penalties and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

	Starts	Falls	Falls per 1000 starts	LCI	UCI
0-2	692,844	2,420	3.49	3.36	3.63
3-5	20,773	96	4.62	3.79	5.64
6-10	16,010	48	3.00	2.26	3.97
11-98	19,907	69	3.47	2.74	4.38

4.3.2.9 Rider sex

The data selected contained information on rider sex. Empty cells within this variable were categorised as 'unknown'. The number of horse falls, along with their 95% confidence intervals, for rider sex are shown at Table 4-12.

Table 4-12: Descriptive statistics of rider sex and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider sex	Starts	Falls	Falls per 1000 starts	LCI	UCI
Female	571,243	1,820	3.19	3.04	3.34
Male	153,203	727	4.75	4.41	5.10
Unknown	25,088	86	3.43	2.78	4.23

4.3.2.10 Rider age

The data selected contained the date of birth for each rider; this was used to calculate biological age of riders at each start. Rider age in eventing is categorised into junior rider (age 12-17), young rider (age 18-21) and senior riders (>21). Within the raw data there were 54 riders recorded as being under the age of 10 (with the lowest age recorded as 0.22), riders can enter BE competition in their 12th year as per BE rules. It was therefore reasonable to assume that any values lower than 11 were errors and that these riders would be in their 12th year as a minimum, so all of these values were folded into the age '11' (to include those in their 12th year but are not yet the age of 12). The number of horse falls, along with their 95% confidence intervals, for rider age are shown in quantiles at Table 4-13.

Table 4-13: Descriptive statistics of rider age and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider age (years)	Starts	Falls	Falls per 1000 starts	LCI	UCI
12-21 years*	214,229	744	3.47	3.23	3.73
22-31 years	240,337	911	3.79	3.55	4.04
32-41 years	170,468	634	3.72	3.44	4.02
42-51 years	95,849	285	2.97	2.65	3.34
51 or more years of age	28,651	59	2.06	1.60	2.66

4.3.2.11 Horse height

The data selected contained information on horse height. Where horse height is mentioned within this study it pertains to horse height at the withers. The lowest category (132cm-148cm) is representative of ponies; animals over this height are classified as horses and therefore cannot compete in pony classes of competition. There were no horses within the study with a height of 148-151cm recorded. The number of horse falls, along with their 95% confidence intervals, for horse height are shown at Table 4-14.

Table 4-14: Descriptive statistics of horse height and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse height	Starts	Falls	Falls per 1000 starts	LCI	UCI
143-148cm	40,795	121	2.97	2.48	3.54
151-155cm	29,617	85	2.87	2.32	3.55
156-160cm	91,377	249	2.72	2.41	3.08
161-165cm	267,334	945	3.53	3.32	3.77
166-170cm	252,860	971	3.84	3.61	4.09
More than 170cm	67,551	262	3.88	3.44	4.38

4.3.2.12 Horse age

The data selected contained the date of birth for each horse; this was used to calculate biological age of horses at each start. The number of horse falls, along with their 95% confidence intervals, for quartiles of horse age are shown at Table 4-15.

Table 4-15: Descriptive statistics of horse age and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse age (years)	Starts	Falls	Falls per 1000 starts	LCI	UCI
4-7	270,457	785	2.90	2.71	3.11
8-9	192,989	714	3.70	3.44	3.98
10-11	131,209	518	3.95	3.62	4.30
11-29	154,879	616	3.98	3.68	4.30

4.3.2.13 Class

The data selected contained information on the class (level) of each competition. Classes were grouped depending on the level of the cross-country competition. For example, within the class 'Advanced-Intermediate' the dressage and show-jumping phases are run at Advanced level, however the cross-country phase is run at Intermediate level; this class was therefore grouped with Intermediate classes. Pony trials are run at Novice level for all three phases; therefore, this class was grouped with Novice classes. This approach was followed for all relevant classes within the data set to ensure that each class category contains competitions that run the cross-country phase at the same standards (e.g. height of fences, speed, number of fences & length of course). As with other variables, any blank cells were categorised as 'unknown' as it is reasonable to assume that these blank cells are there due to error. The number of horse falls, along with their 95% confidence intervals, for class are shown at Table 4-16.

Table 4-16: Descriptive statistics of class and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Class	Starts	Falls	Falls per 1000 starts	LCI	UCI
BE90	168,452	204	1.21	1.06	1.39
BE100	183,463	365	1.99	1.80	2.20
Novice	268,575	1,153	4.29	4.05	4.55
Intermediate	67,165	548	8.16	7.51	8.87
Advanced	8,554	103	12.04	9.94	14.58
International	33,663	237	7.04	6.20	7.99
Unknown	19,662	23	1.17	0.78	1.75

4.3.2.14 Horse – days since last start

A variable to calculate the days since each horse's last start was created. The calculation also accounted for the horses first start in career. The number of horse falls, along with their 95% confidence intervals, for each horse's days since last start are shown at Table 4-17.

Table 4-17: Descriptive statistics of days since horses last start and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse – days since last start	Starts	Falls	Falls per 1000 starts	LCI	UCI
First Start (in career)	48,719	101	2.07	1.71	2.52
Start in previous 14 days	289,210	1,189	4.11	3.88	4.35
Start in previous 15-21 days	122,681	445	3.63	3.31	3.98
Start in previous 22-28 days	69,934	251	3.59	3.17	4.06
Last start more than 28 days ago	218,990	647	2.95	2.74	3.19

4.3.2.15 Rider – days since last start

A variable to calculate the days since each rider's last start was created. The calculation also accounted for riders' first start in career. The number of horse falls, along with their 95% confidence intervals, for rider's days since last start are shown at Table 4-18.

Table 4-18: Descriptive statistics of days since riders' last start and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider – days since last start	Starts	Falls	Falls per 1000 starts	LCI	UCI
First Start (in career)	23,664	37	1.56	1.13	2.15
Start in previous 14 days	45,3668	1,853	4.08	3.90	4.27
Start in previous 15-21 days	79,786	254	3.18	2.82	3.60
Start in previous 22-28 days	44,277	118	2.67	2.23	3.19
Last start more than 28 days ago	148,139	371	2.50	2.26	2.77

4.3.2.16 Horse – starts in previous 0-30 days

A variable to calculate the number of times each horse had started in the previous 30 days was created. The number of horse falls, along with their 95% confidence intervals, for horse starts in the previous 0-30 days are shown at Table 4-19.

Table 4-19: Descriptive statistics of horse starts in previous 0-30 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse starts in previous 0-30 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	25,1914	669	2.66	2.46	2.86
1	295,388	1,070	3.62	3.41	3.85
2	164,779	728	4.42	4.11	4.75
3	33,964	150	4.42	3.77	5.18
4	3,249	16	4.92	3.03	7.98
5	225	0	0.00	0.00	16.79
6	14	0	0.00	0.00	215.32
7	1	0	0.00	0.00	793.46

4.3.2.17 Horse – starts in previous 30-60 days

A variable to calculate the number of times each horse had started in the previous 30-60 days was created. The number of horse falls, along with their 95% confidence intervals, for horse starts in the previous 30-60 days are shown at Table 4-20.

Table 4-20: Descriptive statistics of horse starts in previous 30-60 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse starts in previous 31-60 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	34,8179	967	2.78	2.61	2.96
1	214,263	847	3.95	3.70	4.23
2	143,154	616	4.30	3.98	4.66
3	39,238	184	4.69	4.06	5.42
4	4,357	19	4.36	2.79	6.80
5	322	0	0.00	0.00	11.79
6	19	0	0.00	0.00	168.18
7	2	0	0.00	0.00	657.63

4.3.2.18 Horse – starts in previous 60-90 days

A variable to calculate the number of times each horse had started in the previous 60-90 days was created. The number of horse falls, along with their 95% confidence intervals, for horse starts in the previous 60-90 days are shown at Table 4-21.

Table 4-21: Descriptive statistics of horse starts in previous 60-90 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015

Horse starts in previous 60-90 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	44,3924	1,275	2.87	2.72	3.03
1	163,509	674	4.12	3.82	4.44
2	108,734	515	4.74	4.35	5.16
3	29,722	149	5.01	4.27	5.88
4	3,400	17	5.00	3.12	7.99
5	238	2	8.40	2.31	30.12
6	7	1	142.68	25.68	513.13

4.3.2.19 Horse – career falls

A variable to calculate the number of horse falls each horse had incurred in its career was created. The number of horse falls, along with their 95% confidence intervals, for horse career falls are shown at Table 4-22.

Table 4-22: Descriptive statistics of career horse falls (horse) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse career falls	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	705,075	2,373	3.37	3.23	3.50
1	40,223	233	5.79	5.10	6.58
2	3,806	24	6.31	4.24	9.37
3	396	3	7.58	2.58	22.03
4	34	0	0.00	0.00	101.52

4.3.2.20 Horse – falls in previous 180 days

A variable to calculate the number of horse falls each horse had incurred in the previous 180 days was created. The number of horse falls, along with their 95% confidence intervals, for horse falls in the previous 180 days are shown at Table 4-23.

Table 4-23: Descriptive statistics of horse falls in previous 180 days (horse) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse falls in previous 180 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	740,626	2,581	3.48	3.35	3.62
1	8,798	51	5.80	4.41	7.61
2	110	1	9.09	1.61	49.71

4.3.2.21 Horse – falls in previous 365 days

A variable to calculate the number of horse falls each horse had incurred in the previous 365 days was created. The number of horse falls, along with their 95% confidence intervals, for horse falls in previous 365 days are shown at Table 4-24.

Table 4-24: Descriptive statistics of horse falls in previous 365 days (horse) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse falls in previous 365 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	731,632	2,531	3.46	3.33	3.60
1	17,496	99	5.66	4.65	6.88
2	395	3	7.59	2.59	22.09
3	11	0	0.00	0.00	258.84

4.3.2.22 Rider career falls

A variable to calculate the number of times each rider had a horse fall in their career was created. The number of horse falls, along with their 95% confidence intervals, for rider career falls are shown at Table 4-25.

Table 4-25: Descriptive statistics of career horse falls (rider) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Career falls (Rider)	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	538,458	1,703	3.16	3.02	3.32
1	101,236	438	4.33	3.94	4.75
2	47,891	194	4.05	3.52	4.66
3	23,022	108	4.69	3.89	5.66
4	13,918	67	4.81	3.79	6.11
5	7,778	44	5.66	4.22	7.59
6	4,561	25	5.48	3.72	8.08
7	3,810	15	3.94	2.39	6.49
8	2,942	18	6.12	3.87	9.65
9	2,991	9	3.01	1.58	5.71
10	941	6	6.38	2.93	13.84
11	619	2	3.23	0.89	11.70
12	302	1	3.31	0.58	18.52
13	47	1	21.28	3.77	111.13
14	37	1	27.03	4.79	138.24
15	27	0	0.00	0.00	124.56
16	570	1	1.75	0.31	9.87
17	264	0	0.00	0.00	14.34
18	120	0	0.00	0.00	31.02

4.3.2.23 Rider – horse falls in previous 180 days

A variable to calculate the number of times each rider had incurred a horse fall in the previous 180 days was created. The number of horse falls, along with their 95% confidence intervals, for rider horse falls in the previous 180 days are shown at Table 4-26.

Table 4-26: Descriptive statistics of horse falls in previous 180 days (rider) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse falls in previous 180 days (Rider)	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	706,982	2,409	3.41	3.27	3.55
1	38,089	196	5.15	4.48	5.92
2	3,763	24	6.38	4.29	9.47
3	609	3	4.93	1.68	14.38
4	75	1	13.33	2.36	71.74
5	16	0	0.00	0.00	193.61

4.3.2.24 Rider – horse falls in previous 365 days

A variable to calculate the number of times each rider had incurred a horse fall in the previous 365 days was created. The number of horse falls, along with their 95% confidence intervals, for rider horse falls in the previous 365 days are shown at Table 4-27.

Table 4-27: Descriptive statistics of horse falls in previous 365 days (rider) and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Horse falls in previous 365 days (rider)	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	667,813	2,238	3.35	3.22	3.49
1	67,241	318	4.73	4.24	5.28
2	11,896	67	5.63	4.44	7.15
3	2,218	8	3.61	1.83	7.10
4	344	2	5.81	1.60	20.95
5	22	0	0.00	0.00	148.66

4.3.2.25 Rider – starts in the previous 0-30 days

A variable to calculate the number of times each rider had started in the previous 0-30 days was created. The number of horse falls, along with their 95% confidence intervals, for rider starts in the previous 0-30 days are shown at Table 4-28.

Table 4-28: Descriptive statistics of rider starts in the previous 0-30 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider starts in previous 0-30 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	355,584	1,159	3.26	3.08	3.45
1	257,782	922	3.58	3.35	3.81
2	104,691	422	4.03	3.66	4.43
3	25,969	109	4.20	3.48	5.06
4	4,685	17	3.63	2.27	5.80
5	694	2	2.88	0.79	10.45
6	112	2	17.86	4.91	62.78
7	16	0	0.00	0.00	193.61
8	1	0	0.00	0.00	793.46

4.3.2.26 Rider – starts in the previous 30-60 days

A variable to calculate the number of times each rider had started in the previous 30-60 days was created. The number of horse falls, along with their 95% confidence intervals, for rider starts in the previous 30-60 days are shown at Table 4-29.

Table 4-29: Descriptive statistics of rider starts in the previous 30-60 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider starts in previous 30-60 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	530,779	1,902	3.58	3.43	3.75
1	128,603	411	3.20	2.90	3.52
2	68,420	225	3.29	2.89	3.75
3	18,481	83	4.49	3.62	5.56
4	2,820	10	3.55	1.93	6.52
5	381	1	2.62	0.46	14.72
6	41	0	0.00	0.00	85.67
7	7	1	142.86	25.68	513.13
8	2	0	0.00	0.00	657.63

4.3.2.27 Rider – starts in the previous 60-90 days

A variable to calculate the number of times each rider had started in the previous 60-90 days was created. The number of horse falls, along with their 95% confidence intervals, for rider starts in the previous 60-90 days are shown at Table 4-30.

Table 4-30: Descriptive statistics of rider starts in previous 60-90 days and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Rider – starts in previous 60-90 days	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	600,231	2,136	3.56	3.41	3.71
1	88,575	300	3.39	3.03	3.79
2	47,042	154	3.27	2.80	3.83
3	11,797	33	2.80	1.99	3.93
4	1,684	8	4.75	2.41	9.35
5	178	2	11.24	3.09	40.04
6	22	0	0.00	0.00	148.66
7	4	0	0.00	0.00	489.90
8	1	0	0.00	0.00	793.46

4.3.2.28 Combination first start

A variable to calculate the competition start was the 'first start' within the dataset for this horse and rider combination was created. The number of horse falls, along with their 95% confidence intervals, for horse and rider combination first start are shown at Table 4-31.

Table 4-31: Descriptive statistics of combination first start and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Combination – first start	Starts	Falls	Falls per 1000 starts	LCI	UCI
No	673,075	2,490	3.73	3.56	3.85
Yes	76,459	143	1.76	1.59	2.20

4.3.2.29 Combination number of starts

A variable to calculate the number of times each horse and rider combination had previously started together was created. Number of previous starts for each combination is displayed in intervals of ten up to 60 starts and anything above is categorised as >60 for ease of presentation at this stage. The number of horse falls, along with their 95% confidence intervals, for combination number of starts are shown at Table 4-32.

Table 4-32: Descriptive statistics of combination number of starts and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Combination – number of starts	Starts	Falls	Falls per 1000 starts	LCI	UCI
0-10	455787	1,297	3.04	2.87	3.22
11-20	151419	605	4.00	3.69	4.33
21-30	72500	343	4.73	4.26	5.26
31-40	35561	190	5.34	4.64	6.16
41-50	17669	99	5.60	4.60	6.82
51-60	8821	60	6.80	5.29	8.74
>60	7777	39	5.01	3.67	6.85

4.3.2.30 Has combination fallen before

A variable to calculate whether each horse and rider combination had previously experienced a horse fall was created. The number of horse falls, along with their 95% confidence intervals, for whether each combination of horse and rider had fallen before are shown at Table 4-33.

Table 4-33: Descriptive statistics of has combination fallen before and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Combination – fallen before?	Starts	Falls	Falls per 1000 starts	LCI	UCI
No	719,552	2,458	3.42	3.28	3.55
Yes	29,982	175	5.84	5.04	6.76

4.3.2.31 Combination – number of horse falls

A variable to calculate the number of times each combination of horse and rider had previously experienced a horse fall was created. The number of horse falls, along with their 95% confidence intervals, for the number of times each combination of horse and rider had previously experienced a horse fall are shown at Table 4-34.

Table 4-34: Descriptive statistics of combination number of horse falls and horse falls for cross-country starts in BE competition during the 11-year period from 2005 to 2015.

Combination – number of horse falls	Starts	Falls	Falls per 1000 starts	LCI	UCI
0	719,552	2,458	3.42	3.28	3.55
1	27,592	162	5.87	5.04	6.84
2	2,171	12	5.53	3.16	9.64
3	219	1	4.57	0.81	25.41

4.3.3 Univariable analysis

In total 29 possible risk factors were screened using univariable analysis; of the possible risk factors, 27 were found to have a P-value of less than 0.20 and were included in the subsequent stepwise bidirectional elimination to be potentially included in the final multivariable model (Table 4-35).

*Table 4-35: Results of univariable logistic regression for assessment of risk factors associated with horse falls in the cross-country phase of BE competition during the 11-year period from 2005-2015. Cases were starts that recorded a horse fall during the cross-country phase. Among categorical variable levels, a * denotes the reference category.*

Risk Factor	Controls (%)	Cases (%)	Odds Ratio	95% confidence interval	p-value
Event year					
2005*	60,543 (99.6%)	262 (0.4%)	1.00	-	-
2006	62,425 (99.6%)	246 (0.4%)	0.91	0.76 - 1.08	0.293
2007	62,604 (99.6%)	232 (0.4%)	0.86	0.72 - 1.02	0.086
2008	68,792 (99.6%)	268 (0.4%)	0.90	0.76 - 1.07	0.227
2009	71,735 (99.7%)	233 (0.3%)	0.75	0.63 - 0.90	0.001
2010	70,222 (99.6%)	263 (0.4%)	0.87	0.73 - 1.03	0.099
2011	71,514 (99.7%)	222 (0.3%)	0.72	0.60 - 0.86	<0.001
2012	58,590 (99.6%)	207 (0.4%)	0.82	0.68 - 0.98	0.775
2013	72,486 (99.7%)	242 (0.3%)	0.77	0.65 - 0.92	0.004
2014	71,511 (99.7%)	239 (0.3%)	0.77	0.65 - 0.92	0.004
2015	76,479 (99.7%)	219 (0.3%)	0.66	0.55 - 0.79	<0.001
Horse grade					
Grade IV*	300,596 (99.8%)	701 (0.2%)	1.00	-	-
Grade I	120,436 (99.5%)	640 (0.5%)	0.64	0.59-0.69	<0.001
Grade II	129,792 (99.5%)	609 (0.5%)	0.82	0.77-0.87	0.002
Grade III	180,110 (99.6%)	660 (0.4%)	0.91	0.86-0.97	0.112
Unknown	15,967 (99.9%)	23 (0.1%)	1.03	0.82-1.29	0.887
Horse sex					
Gelding*	544,531 (99.7%)	1,893 (0.3%)	1.00	-	-
Mare	197,543 (99.6%)	715 (0.4%)	1.04	0.96 - 1.13	0.359
Stallion	4,827(99.5%)	25 (0.5%)	1.49	1.00 - 2.21	0.048
Dressage penalties					
Per additional point	-	-	1.03	1.03 - 1.04	<0.001
Show-jumping penalties					
0*	312,828 (99.7%)	949 (0.3%)	1.00	-	-
4	226,932 (99.7%)	785 (0.3%)	1.14	1.04 - 1.25	0.007
8	113,775 (99.6%)	444 (0.4%)	1.29	1.15 - 1.44	<0.001
12	53,477 (99.5%)	258 (0.5%)	1.59	1.39 - 1.83	<0.001
16	24,520 (99.5%)	125 (0.5%)	1.68	1.39 - 2.03	<0.001
20	10,491 (99.5%)	51 (0.5%)	1.60	1.21 - 2.13	0.001
80	4,878 (99.6%)	21 (0.4%)	1.42	0.92 - 2.19	0.113
Show-jumping time penalties					
Per additional point	-	-	1.13	1.00 - 1.27	0.045
Rider Sex					
Female*	594,425 (99.7%)	1,906 (0.3%)	1.00	-	-
Male	152,476 (99.5%)	727 (0.5%)	1.49	1.36 - 1.62	<0.001

Table 4-35: Continued.

Risk Factor	Controls (%)	Cases (%)	Odds Ratio	95% confidence interval	p-value
Rider age					
12-21 years*	213,485 (99.7%)	744 (0.3%)	1.00	-	-
22-31 years	239,426 (99.6%)	911 (0.4%)	1.09	0.99 - 1.20	0.076
32-41 years	169,834 (99.6%)	634 (0.4%)	1.07	0.96 - 1.19	0.204
42-51 years	95,564 (99.7%)	285 (0.3%)	0.86	0.75 - 0.98	0.026
51 or more years of age	28,592 (99.8%)	59 (0.2%)	0.59	0.45 - 0.77	<0.001
Horse height					
161-165cm*	266,389 (99.6%)	945 (0.4%)	1.00	-	-
143-148cm	40,674 (99.7%)	121 (0.3%)	0.84	0.69 - 1.01	0.069
151-155cm	29,532 (99.7%)	85 (0.3%)	0.81	0.65 - 1.01	0.065
156-160cm	91,128 (99.7%)	249 (0.3%)	0.77	0.67 - 0.89	<0.001
166-170cm	25,1889 (99.6%)	971 (0.4%)	1.09	0.99 - 1.19	0.069
More than 170cm	67,289 (99.6%)	262 (0.4%)	1.10	0.96 - 1.26	0.183
Horse Age					
Per additional year	-	-	1.04	1.02 - 1.05	<0.001
Class					
BE90*	168,248 (99.9%)	204 (0.1%)	1.00	-	-
BE100	183,098 (99.8%)	365 (0.2%)	1.64	1.39 - 1.95	<0.001
Novice	267,422 (99.6%)	1,153 (0.4%)	3.56	3.06 - 4.13	<0.001
Intermediate	66,617 (99.2%)	548 (0.8%)	6.78	5.78 - 7.97	<0.001
Advanced	8,451 (98.8%)	103 (1.2%)	10.05	7.92 - 12.75	<0.001
International	33,426 (99.3%)	237 (0.7%)	5.85	4.85 - 7.05	<0.001
Unknown	19,639 (99.9%)	23 (0.1%)	0.97	0.63 - 1.49	0.875
Horse days since last start					
Start in previous 14 days*	288,021 (99.6%)	1,189 (0.4%)	1.00	-	-
First Start (in career)	48,618 (99.8%)	101 (0.2%)	0.50	0.41 - 0.62	<0.001
Start in previous 15-21 days	122,236 (99.6%)	445 (0.4%)	0.88	0.79 - 0.98	0.024
Start in previous 22-28 days	69,683 (99.6%)	251 (0.4%)	0.87	0.76 - 1.00	0.050
Last start more than 28 days ago	218,343 (99.7%)	647 (0.3%)	0.72	0.65 - 0.79	<0.001
Rider days since last start					
Start in previous 14 days*	451,815 (99.6%)	1,853 (0.4%)	1.00	-	-
Start in previous 15-21 days	79,532 (99.7%)	254 (0.3%)	0.78	0.68 - 0.89	<0.001
Start in previous 22-28 days	44,159 (99.7%)	118 (0.3%)	0.65	0.54 - 0.79	<0.001
Last start more than 28 days ago	147,768 (99.7%)	371 (0.3%)	0.61	0.55 - 0.68	<0.001
First Start (in career)	23,627 (99.8%)	37 (0.2%)	0.38	0.28 - 0.53	<0.001
Horse starts in previous 0-30 days					
Zero starts*	251,245 (99.7%)	669 (0.3%)	1.00	-	-
One start	294,318 (99.6%)	1,070 (0.4%)	1.37	1.24 - 1.50	<0.001
Two starts	164,051 (99.6%)	728 (0.4%)	1.67	1.50 - 1.85	<0.001
Three starts	33,814 (99.6%)	150 (0.4%)	1.67	1.40 - 1.99	<0.001
Four or more starts	3,473 (99.5%)	16 (0.5%)	1.73	1.05 - 2.84	0.031

Table 4-35: Continued.

Risk Factor	Controls (%)	Cases (%)	Odds Ratio	95% confidence interval	p-value
Horse starts in previous 30-60 days					
Zero starts*	347,212 (99.7%)	967 (0.3%)	1.00	-	-
One start	213,416 (99.6%)	847 (0.4%)	1.43	1.30 - 1.56	<0.001
Two starts	142,538 (99.6%)	616 (0.4%)	1.55	1.40 - 1.72	<0.001
Three starts	39,054 (99.5%)	184 (0.5%)	1.69	1.44 - 1.98	<0.001
Four or more starts	4,681 (99.6%)	19 (0.4%)	1.46	0.92 - 2.30	0.105
Horse starts in previous 60-90 days					
Zero starts*	442,649 (99.7%)	1,275 (0.3%)	1.00	-	-
One start	162,835 (99.6%)	674 (0.4%)	1.44	1.31 - 1.58	<0.001
Two starts	108,219 (99.5%)	515 (0.5%)	1.65	1.49 - 1.83	<0.001
Three starts	29,573 (99.5%)	149 (0.5%)	1.75	1.48 - 2.07	<0.001
Four or more starts	3,625 (99.5%)	20 (0.5%)	1.92	1.23 - 2.98	<0.004
Career falls - horse					
Per additional fall	-	-	1.55	1.40 - 1.72	<0.001
Horse: horse falls in previous 180 days					
Per additional fall	-	-	1.66	1.27 - 2.17	<0.001
Horse: horse falls in previous 365 days					
Per additional fall	-	-	1.61	1.34 - 1.95	<0.001
Rider previous horse falls in career					
Per additional fall	-	-	1.06	1.04 - 1.08	<0.001
Rider: horse falls in previous 180 days					
Per additional fall	-	-	1.41	1.27 - 1.57	<0.001
Rider: horse falls in previous 365 days					
Per additional fall	-	-	1.28	1.19 - 1.38	<0.001
Rider starts in previous 0-30 days					
Per additional start	-	-	1.09	1.05 - 1.14	<0.001
Rider starts in previous 30-60 days					
Per additional start	-	-	0.99	0.95 - 1.04	0.757
Rider starts in previous 60-90 days					
Per additional start	-	-	0.96	0.91 - 1.02	0.203
Combination first start					
No*	670,585 (99.6%)	2,490 (0.4%)	-	-	-
Yes	76,316 (99.8%)	143 (0.2%)	0.50	0.43 - 0.60	<0.001
Combination: number of starts					
Per additional start	-	-	1.02	1.01 - 1.02	<0.001
Combination: have they fallen before?					
No*	717,094 (99.7%)	2,458 (0.3%)	-	-	-
Yes	29,807 (99.4%)	175 (0.6%)	1.71	1.47 - 2.00	<0.001
Combination: previous horse falls					
Per additional fall	-	-	1.54	1.35 - 1.76	<0.001

4.3.4 Multivariable model

The final model included 749,534 starts, with 2,633 falls. Variables that were not significant in the model were removed. Eleven variables were retained in the final model and are thus deemed to have a significant effect on the risk of horse fall. Multivariable model results are presented in Table 4-36.

*Table 4-36: Multivariable model results for the outcome horse fall. Cases were cross-country starts that recorded a horse fall during the cross-country phase. Risk factors with a p-value of less than 0.05 were retained in the final model, unless model fit was improved by inclusion of non-significant variables. Among categorical variable levels, a * denotes the reference category. For continuous variables, the median and interquartile range are shown in place of the numbers of cases and controls.*

Risk Factor	Controls (%)	Cases (%)	Odds Ratio	95% confidence interval	p-value
Class					
BE90*	168,248 (99.9%)	204 (0.1%)	1.00	-	-
BE100	183,098 (99.8%)	365 (0.2%)	1.65	1.38 - 1.97	<0.001
Novice	267,422 (99.6%)	1,153 (0.4%)	3.62	3.07 - 4.27	<0.001
Intermediate	66,617 (99.2%)	548 (0.8%)	8.19	6.72 - 9.97	<0.001
Advanced	8,451 (98.8%)	103 (1.2%)	13.01	9.86 - 17.17	<0.001
International	33,426 (99.3%)	237 (0.7%)	4.74	3.60 - 6.24	<0.001
Unknown	19,639 (99.9%)	23 (0.1%)	1.00	0.64 - 1.57	0.997
Dressage penalties					
Per additional point	Median = 35.9	IQR = 7.3	1.02	1.01 - 1.03	<0.001
Horse starts in previous 60-90 days					
Zero starts*	442,649 (99.7%)	1,275 (0.3%)	1.00	-	-
One start	162,835 (99.6%)	674 (0.4%)	1.23	1.11 - 1.35	<0.001
Two starts	108,219 (99.5%)	515 (0.5%)	1.27	1.14 - 1.41	<0.001
Three starts	29,573 (99.5%)	149 (0.5%)	1.30	1.09 - 1.54	0.003
Four or more starts	3,625 (99.5%)	20 (0.5%)	1.45	0.93 - 2.26	0.103
Horse grade					
Grade IV*	300,596 (99.8%)	701 (0.2%)	1.00	-	-
Grade I	120,436 (99.5%)	640 (0.5%)	0.64	0.59 - 0.69	<0.001
Grade II	129,792 (99.5%)	609 (0.5%)	0.82	0.77 - 0.87	0.002
Grade III	180,110 (99.6%)	660 (0.4%)	0.91	0.86 - 0.97	0.112
Unknown	15,967 (99.9%)	23 (0.1%)	1.03	0.82 - 1.29	0.887
Rider Sex					
Female*	594,425 (99.7%)	1,906 (0.3%)	1.00	-	-
Male	152,476 (99.5%)	727 (0.5%)	1.23	1.13 - 1.35	<0.001
Horse sex					
Gelding*	544,531 (99.7%)	1,893 (0.3%)	1.00	-	-
Mare	197,543 (99.6%)	715 (0.4%)	1.17	1.07 - 1.28	<0.001
Stallion	4,827 (99.5%)	25 (0.5%)	1.34	0.90 - 1.99	0.150

Table 4-36: Continued.

Risk Factor	Controls (%)	Cases (%)	Odds Ratio	95% confidence interval	p-value
Horse height					
161-165cm*	266,389 (99.6%)	945 (0.4%)	1.00	-	-
143-148cm	40,674 (99.7%)	121 (0.3%)	1.29	1.06 - 1.58	0.012
151-155cm	29,532 (99.7%)	85 (0.3%)	1.09	0.87 - 1.36	0.458
156-160cm	91,128 (99.7%)	249 (0.3%)	0.91	0.79 - 1.04	0.172
166-170cm	251,889 (99.6%)	971 (0.4%)	1.03	0.94 - 1.13	0.566
More than 170cm	67,289 (99.6%)	262 (0.4%)	1.08	0.94 - 1.25	0.265
Rider: days since last start					
Start in previous 14 days*	451,815 (99.6%)	1,853 (0.4%)	1.00	-	-
Start in previous 15-21 days	79,532 (99.7%)	254 (0.3%)	0.86	0.76 - 0.99	0.032
Start in previous 22-28 days	44,159 (99.7%)	118 (0.3%)	0.77	0.64 - 0.93	0.007
Last start more than 28 days ago	147,768 (99.7%)	371 (0.3%)	0.90	0.80 - 1.01	0.086
First Start (in career)	23,627 (99.8%)	37 (0.2%)	0.74	0.53 - 1.04	0.082
Rider age					
12-21 years*	213,485 (99.7%)	744 (0.3%)	1.00	-	-
22-31 years	239,426 (99.6%)	911 (0.4%)	0.94	0.85 - 1.04	0.221
32-41 years	169,834 (99.6%)	634 (0.4%)	0.93	0.83 - 1.05	0.233
42-51 years	95,564 (99.7%)	285 (0.3%)	0.83	0.72 - 0.95	0.009
51 or more years of age	28,592 (99.8%)	59 (0.2%)	0.68	0.52 - 0.89	0.006
Rider: horse falls in career					
Per additional fall	Median = 0	IQR = 1	0.98	0.95 - 1.00	0.070
Horse: horse falls in career					
Per additional fall	Median = 0	IQR = 0	1.17	1.05 - 1.31	0.005

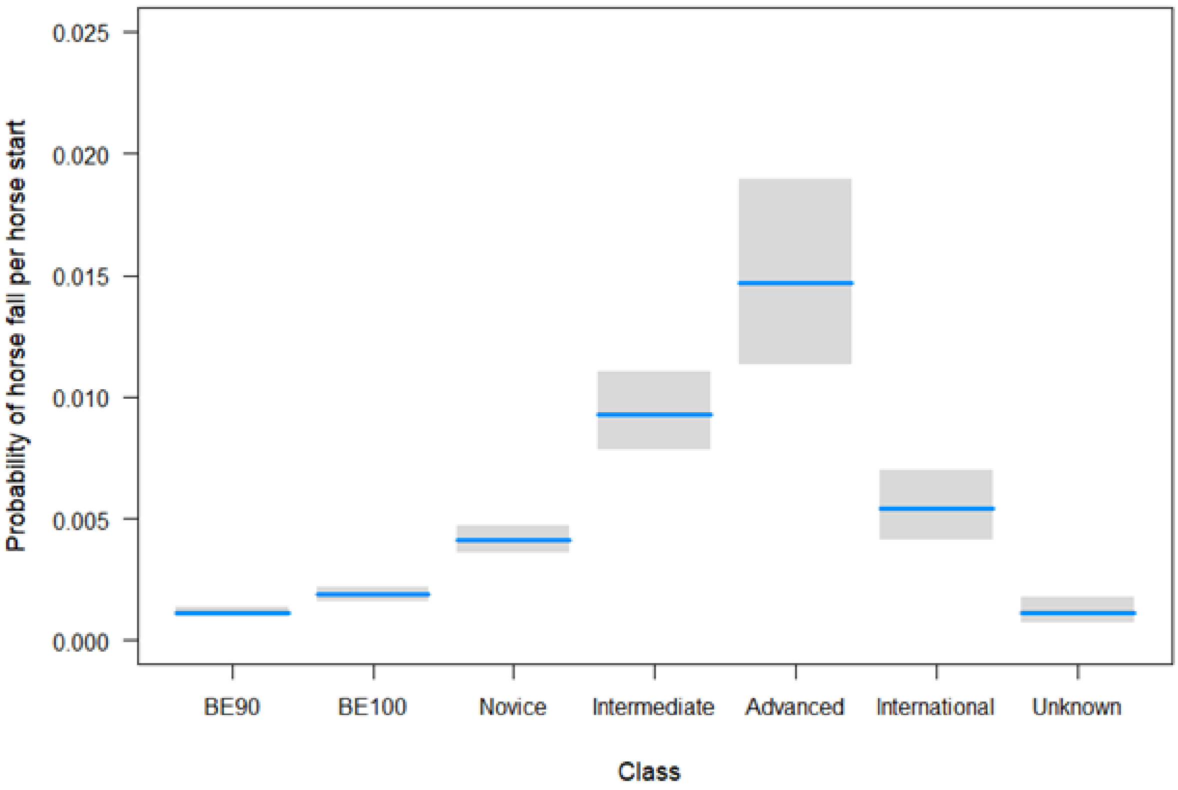


Figure 4-2: Relationship between class of competition and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

There is a gradually increasing likelihood of a horse fall as the levels increase from BE90 (reference category) up to Advanced level competition throughout which the difference between groups remained statistically significant ($p<0.001$). The only class not to have a statistically significant higher likelihood of a horse fall than BE90 level competition was the 'unknown' category. The probability of a horse fall per start for class can be seen in Figure 4-2.

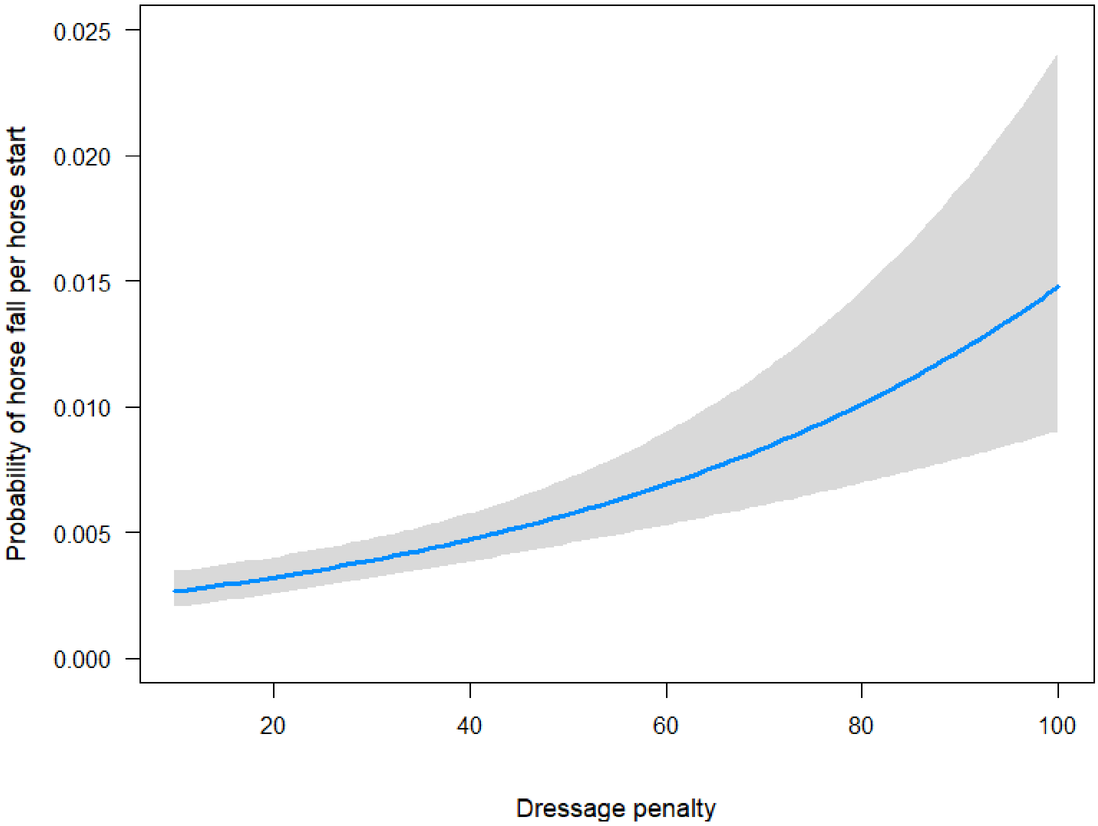


Figure 4-3: Relationship between dressage penalties and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

There is a gradually increasing likelihood of a horse fall as dressage penalties increase. For a one-unit change in dressage penalties there is a 1.02 increase in the likelihood of a horse fall during cross-country ($p<0.001$). The effect may be small if the difference in penalty points is low, but as the gap between penalty points widens, the risk increases greatly. Horses and Riders who incur a large amount of penalty points during the dressage are at an increased risk of a horse fall during cross-country in comparison to horse and rider combinations who incur a low amount of penalties. For example, combinations at or above the 75th percentile of dressage penalty points (39.8) were at odds ratio of 1.16 compared to combinations at or below the 25th percentile (32.5). The probability of a horse fall per start for dressage penalties can be seen in Figure 4-3.

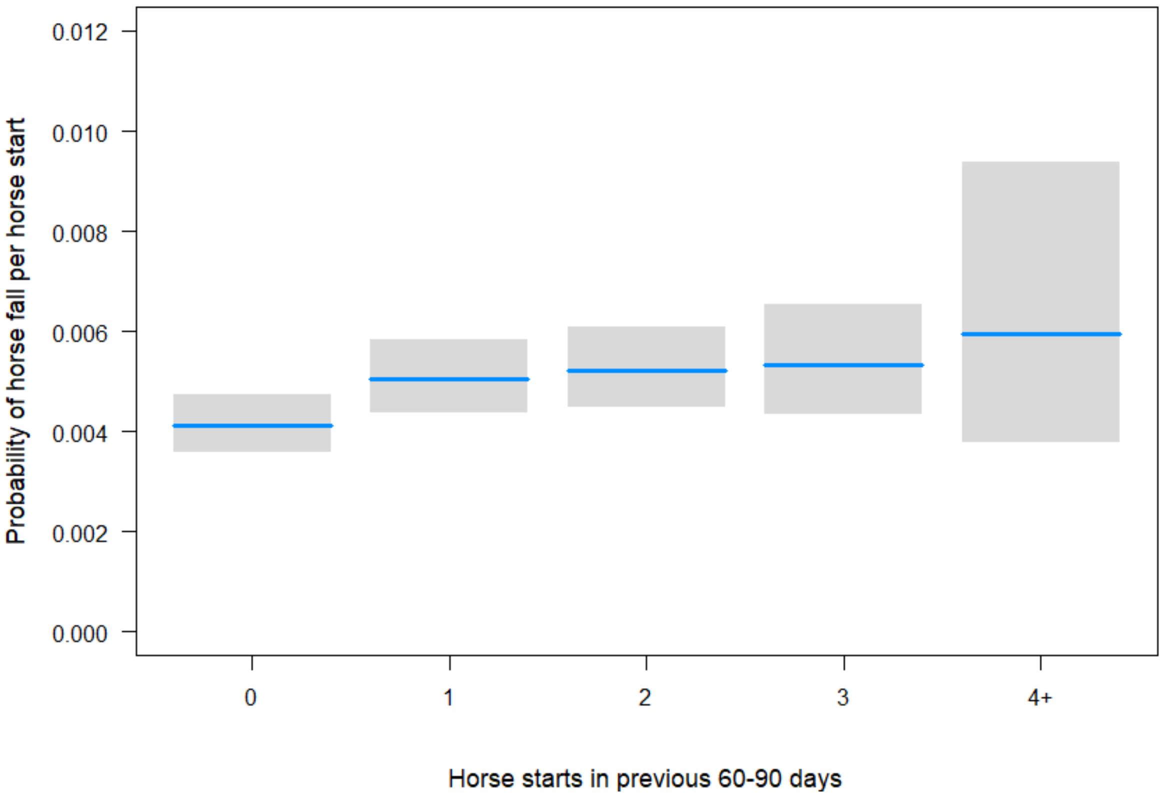


Figure 4-4: Relationship between horse starts in previous 60-90 days and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

There is a gradually increasing likelihood of a horse fall if the horse has started one, two or three times in the previous 60-90 days in comparison to zero times (reference category), with the difference between groups remaining statistically significant ($p<0.05$). Horses who have started four or more times were the only category not to have a significantly increased risk of a horse fall when compared to horses who have had zero starts in this time-period. The probability of a horse fall per start for horse starts in previous 60-90 days can be seen in Figure 4-4.

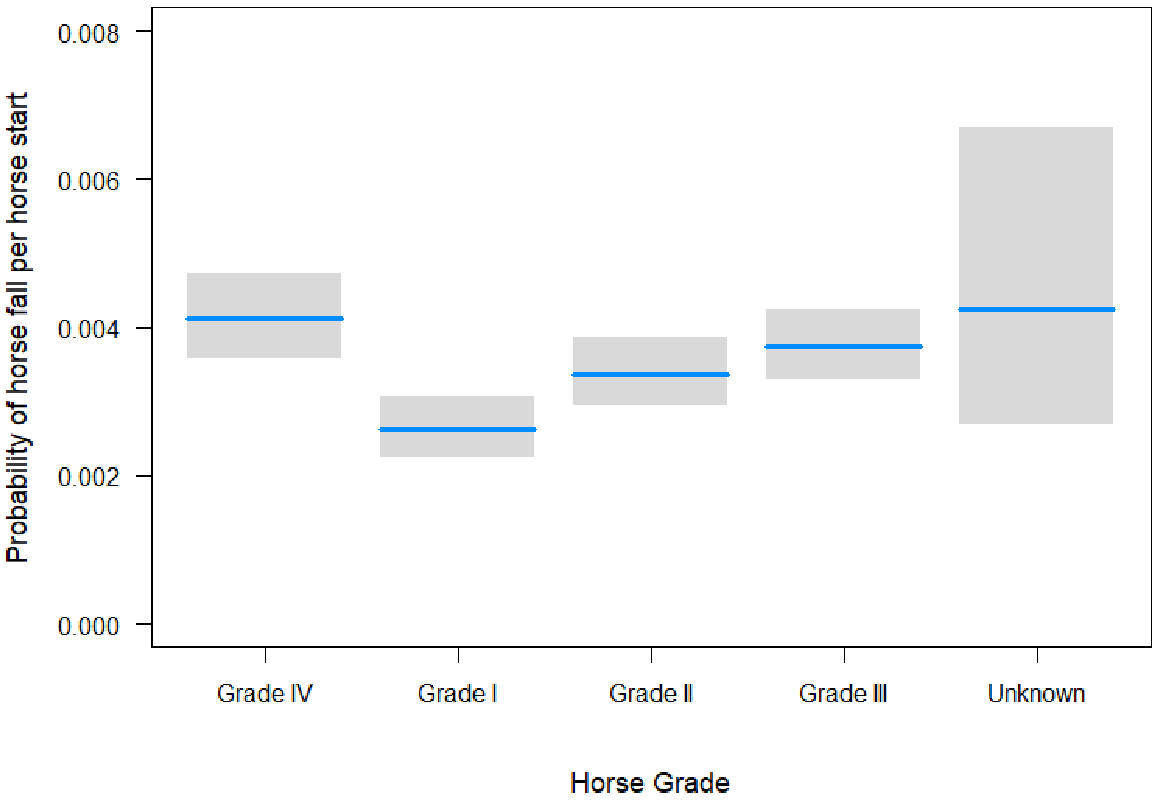


Figure 4-5: Relationship between horse grade and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Grade one and two horses have a significantly lower likelihood ($p<0.001$ and $p<0.002$, respectively) of a horse fall than grade four (reference category) horses. There was no significant difference between the risk of a horse fall for grade three and 'unknown' category horses in comparison with grade four horses. The probability of a horse fall per start for horse grade can be seen in Figure 4-5.

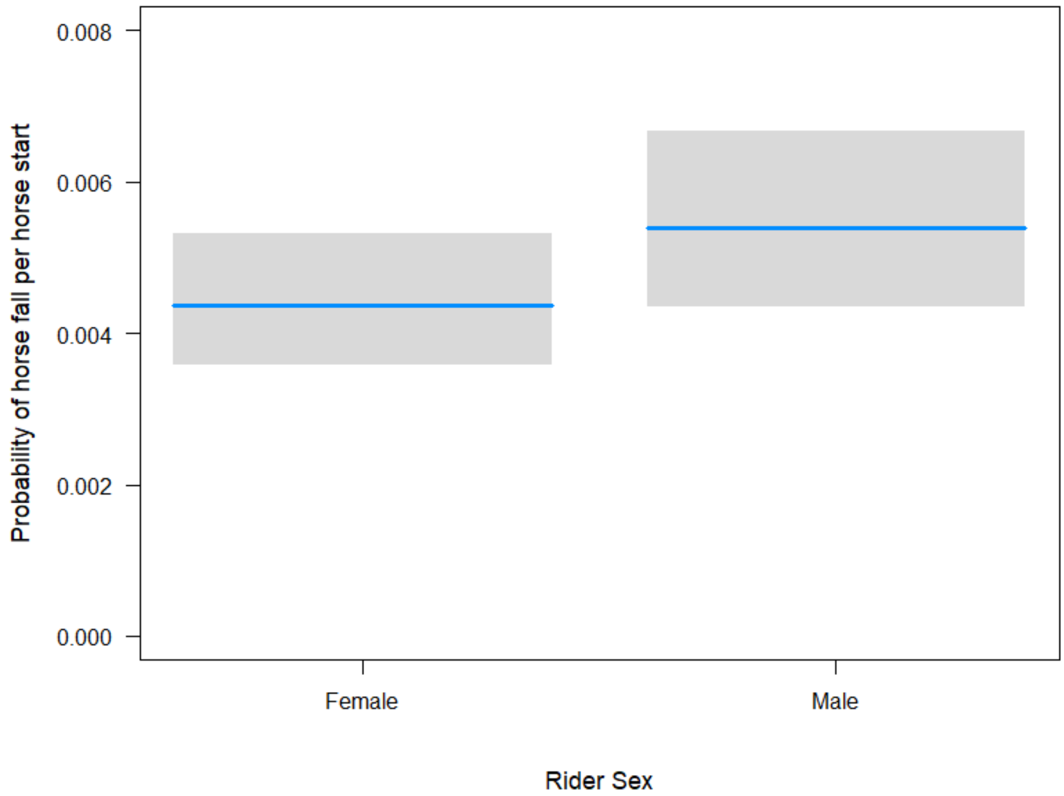


Figure 4-6: Relationship between rider sex and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Male riders are 1.23 times more likely to have a horse fall than female riders, with this difference being statistically significant ($p<0.001$). Male riders are at an increased risk of a horse fall in comparison to female riders. The probability of a horse fall per start for rider sex can be seen in Figure 4-6.

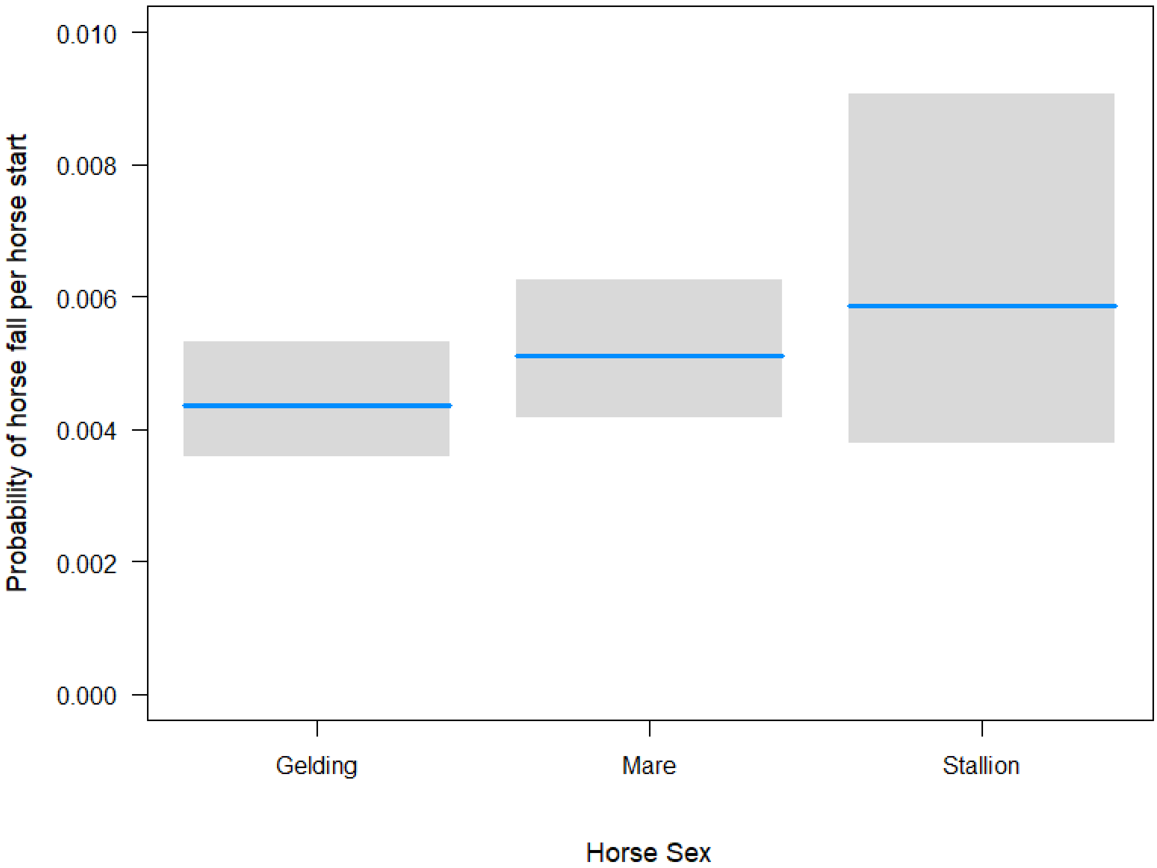


Figure 4-7: Relationship between horse sex and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Mares are 1.17 times more likely to have a horse fall than geldings (reference category), with this difference being statistically significant ($p<0.001$). There was no significant difference in the likelihood of a horse fall between geldings and stallions. The probability of a horse fall per start for horse sex can be seen in Figure 4-7.

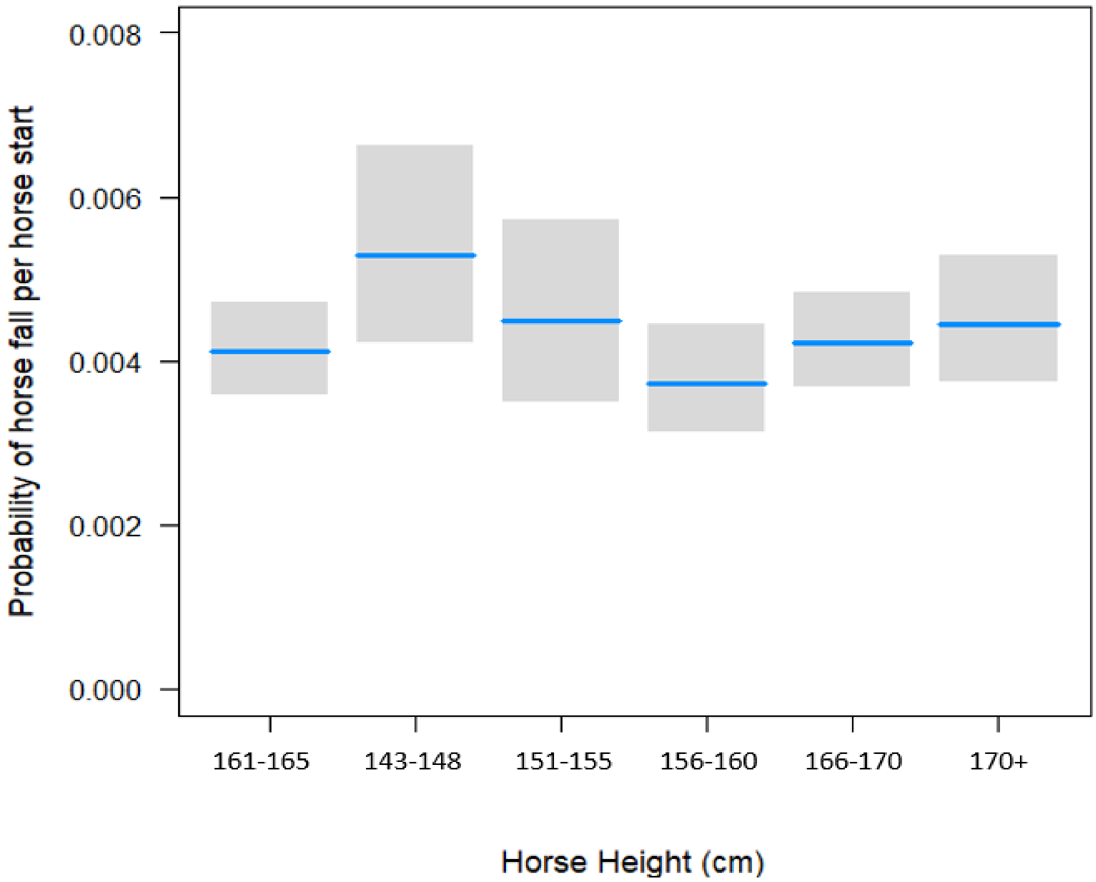


Figure 4-8: Relationship between horse height and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Horses that are 143-148cm in height (categorised as 'ponies' as per BE rules) are 1.29 times more likely to have a horse fall than horses that are 161-165cm in height (reference category), with this difference being statistically significant ($p<0.05$). There was no other statistically significant difference between any of the other horse height categories and the reference category. The probability of a horse fall per start for horse height can be seen in Figure 4-8.

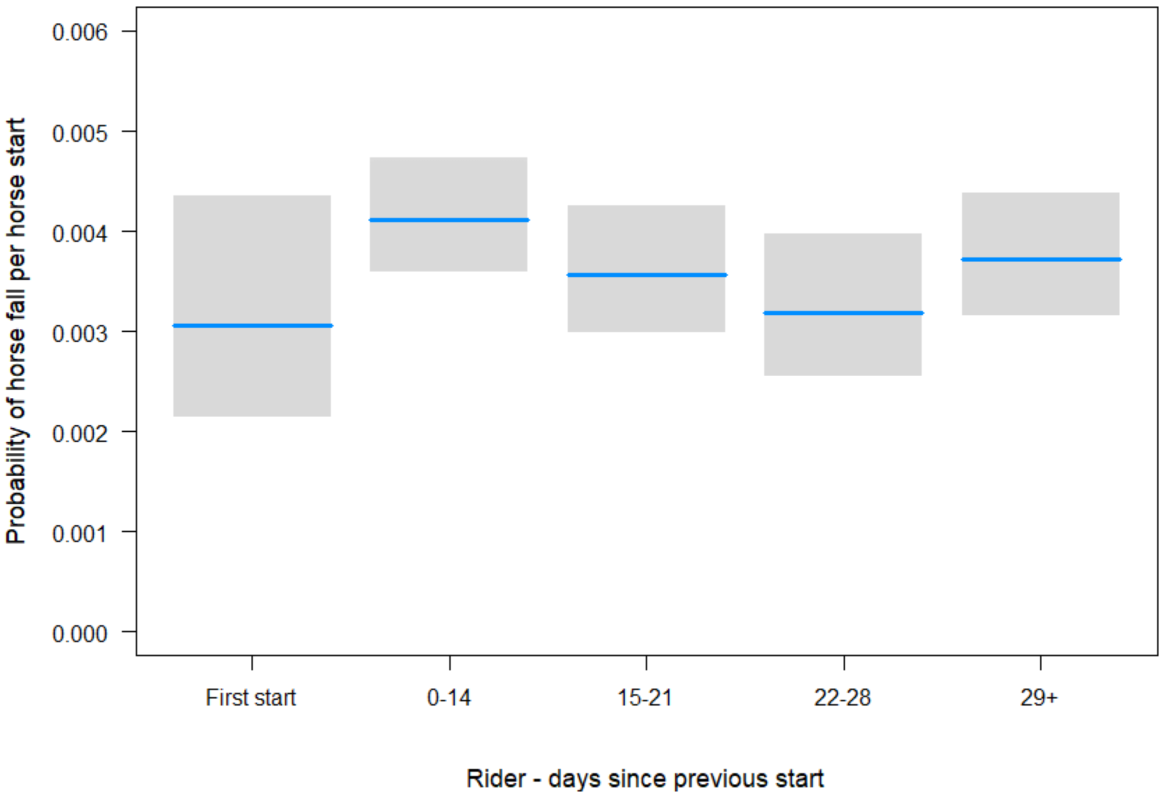


Figure 4-9: Relationship between the number of days since riders' last start and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Riders who have started in the previous 15-21 or 22-28 days are 0.86 and 0.77 times less likely to have a horse fall than riders who have had a start in the 14 days prior to the competition (reference category), with both of these differences being statistically significant ($p<0.05$). There was no statistically significant difference for the likelihood of a horse fall between the reference category and riders whose previous start was more than 28 days ago, or for riders' first start in their career. The probability of a horse fall per start for number of days since riders' last start can be seen in Figure 4-9.

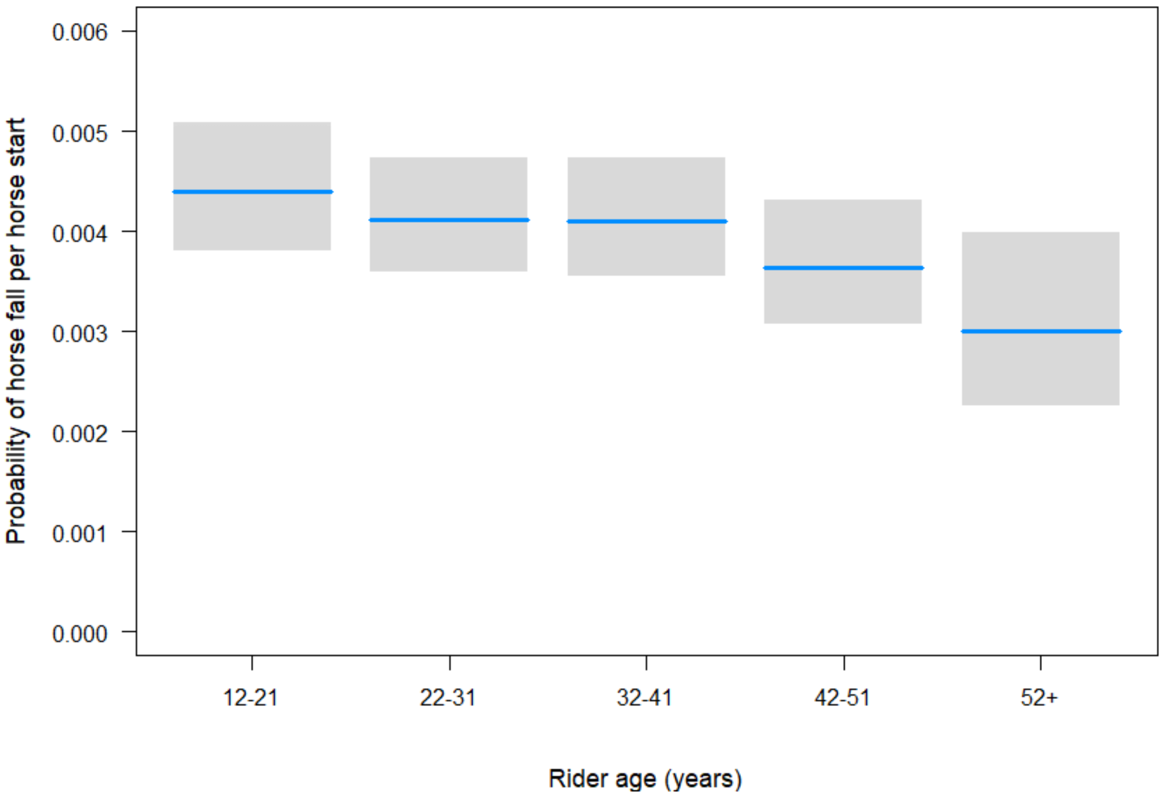


Figure 4-10: Relationship between rider age and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

Riders who are 42-51 or more than 51 years of age are 0.83 and 0.68 times less likely to have a horse fall than riders who are 12-21 years of age (reference category), with both of these differences being statistically significant ($p<0.05$). There was no statistically significant difference for the likelihood of a horse fall between the reference category and riders who are 22-31 or 32-41 years of age. The probability of a horse fall per start for rider age can be seen in Figure 4-10.

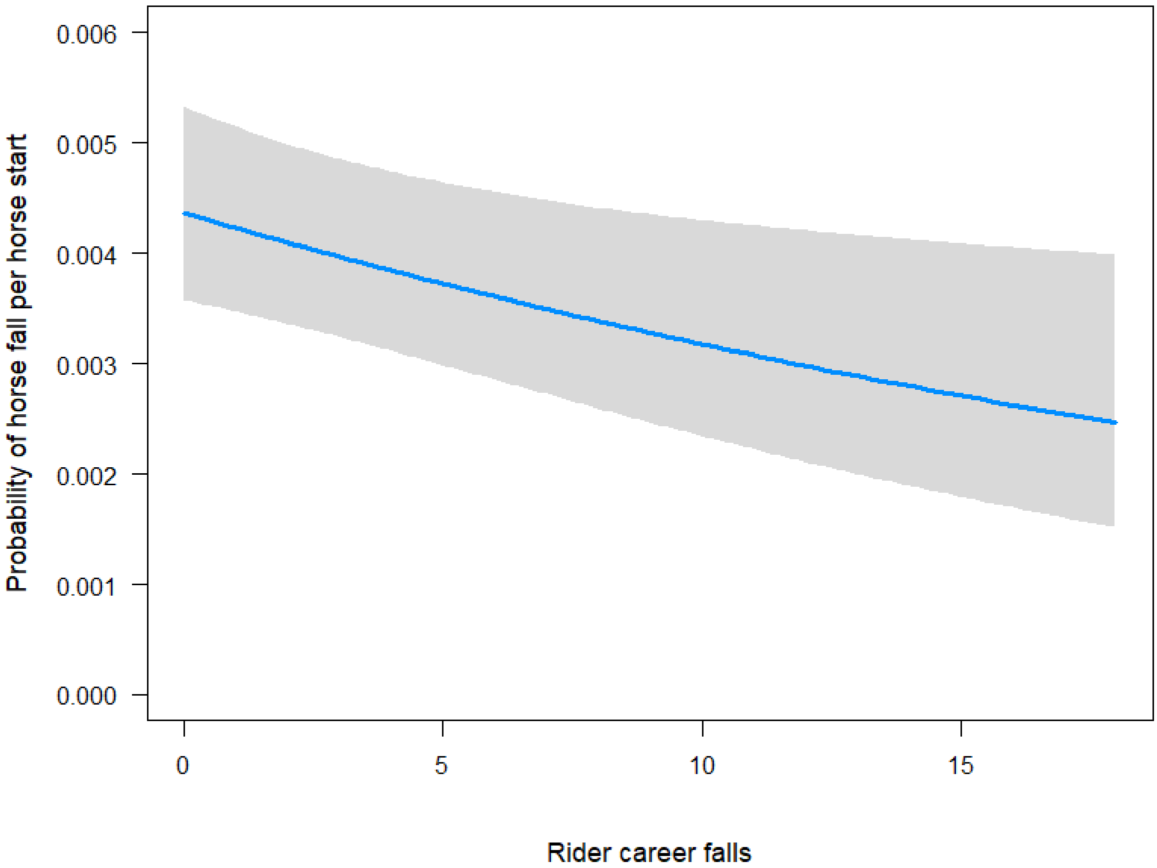


Figure 4-11: Relationship between the number horse falls the rider has had in their career and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

There is a gradually decreasing likelihood of a horse fall as the number of horse falls a rider has had in their career increases. For a one-unit change in the number of horse falls a rider has had in their career there is a 0.98 decrease in the likelihood of a horse fall during cross-country. This finding was not statistically significant, but its inclusion improved the overall fit of the model according to the AIC therefore it was retained in the final model. The probability of a horse fall per start for rider career falls can be seen in Figure 4-11.

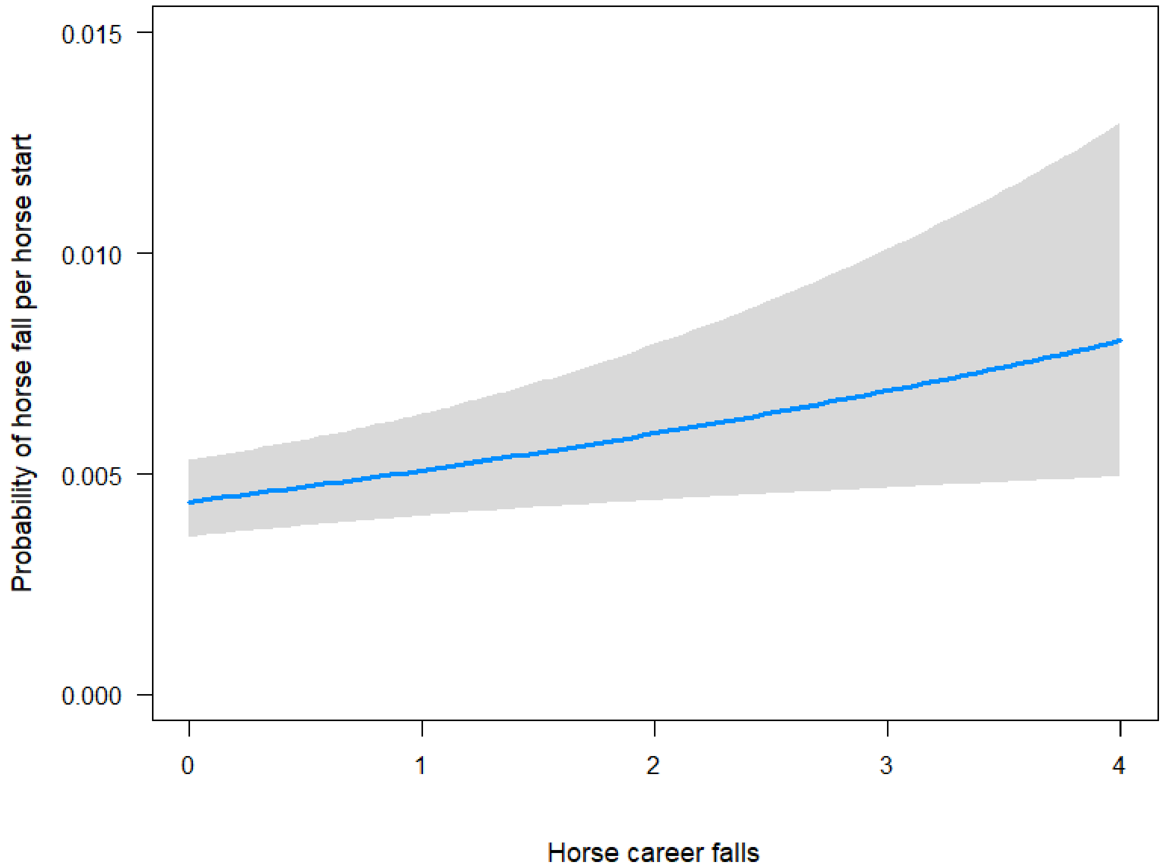


Figure 4-12: Relationship between the number of horse falls the horse has had in their career and the probability of a horse fall during cross-country. The blue line shows the predicted mean (probability of a horse fall, controlling for all other variables in the model) from the multivariable model. The upper and lower grey bands represent 95% upper and lower confidence intervals, respectively.

There is a gradually increasing likelihood of a horse fall as the number of horse falls a horse has had in their career increases. For each additional horse fall a horse has had in its prior career, they are 1.17 times more likely to fall again ($p<0.05$). The probability of a horse fall per start for number of horse falls the horse has had in their career can be seen in Figure 4-2.

4.3.4.1 Collinearity, confounding and random effects

No evidence of collinearity was found. No second-order interactions terms were found to be significant in the final model. None of the risk factors which were rejected at any stage of model-building were found to be confounded with any of the retained risk factors. There were no meaningful changes in P values and less than 10% change in odds ratios (ORs) compared to results obtained with models that did not include random effects, so the single level models were retained. With the horse included as a random effect, less than 1% of the variance as measured by the R^2 was due to the horse ID (ρ=0.01). With the rider included as a random effect, less than 15% of the variance as measured by the R^2 was due to the rider ID (ρ=0.14).

4.3.4.2 Model fit

The multivariable model had a deviance of 33,753 with 749,500 degrees of freedom. The X^2 statistic of the Hosmer-Lemeshow goodness of fit test was 7.3483 with 8 degrees of freedom and a p-value of 0.49 indicating no evidence of a lack of fit.

The final multivariable model was not affected by influential covariate patterns. The area under the receiving operating characteristic curve was 70% (95% confidence interval 67%-73%) indicating moderate predictive ability (Figure 4-13).

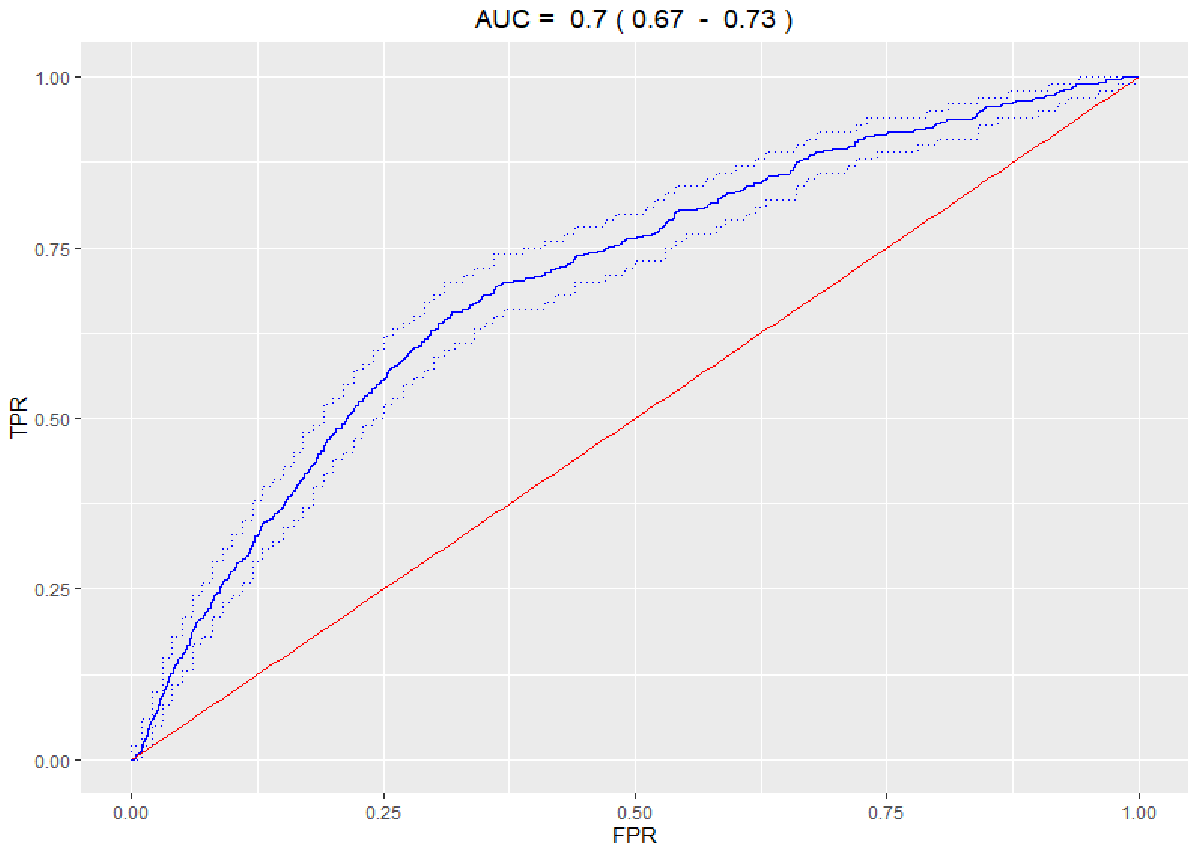


Figure 4-13: ROC curve of the multivariable logistic regression model trained on starts from 2005-2015 for horse fall prediction for the same period. TPR: True Positive Rate, FPR: False Positive Rate, AUC: Area Under Curve. Red line represents random classifier. Blue line represents model classifier.

4.4 Discussion

The purpose of the data analysis was to determine possible risk factors that are associated with a horse fall on the cross-country course of a one-day eventing competition in the UK. Eleven variables were retained in the final model, which demonstrates that they have a significant effect on the risk of a horse fall.

This is the first study to investigate horse falls during the cross-country phase of one-day eventing competitions in the UK since the change in format of eventing (removal of roads and tracks phase) and the addition of frangible devices. Additionally, this is the first study to analyse risk factors for horse falls during the cross-country phase of one-day eventing competitions in the UK with the inclusion of calculated variables such as horse and rider combination history (number of previous starts, number of previous falls etc.) and the start history of individual horses and riders prior to each current start (as used in horse racing risk factor analysis). The hypothesis is supported, with eleven risk factors having been identified to be significantly associated with the risk of a horse fall. Only two competition level variables were retained in the final model; class and dressage penalties. Five horse-level variables were retained in the final model including, grade, sex, height, starts in previous 61-90 days and horse falls in career. Finally, four rider-level variables were retained in the final model including, sex, age, days since last start and horse falls in career. Identification of these risk factors could potentially be used by governing bodies in guidance for reduction of horse falls in the cross-country phase of one-day eventing competitions.

A comparison with previous studies into horse falls in the cross-country phase of eventing indicates that the current study has a lower fall rate than previous studies. Previous studies have reported falls per jumping efforts whereas the current study reports falls per starts. The data provided by BE for the current study does not currently record fence-level information which can be easily reconciled with competition-level data. However, if we assume that there are 25 jumping efforts per start (on average) then we can offer some comparison. The current study reported a fall rate of 3.5 falls per thousand starts, thus if it can be assumed that there are 25 jumping efforts per start then this translates to 0.14 falls per 1000 jumping efforts. Singer et al (2003) reported a fall rate of 0.86 per 1000 jumping efforts during the 1999 eventing season (however this included two- and three-day events). Murray et al (2005, 2006b) reported 0.27 falls per 1000 jumping efforts for one-day events during the 2001 and 2002 eventing seasons. Barnett (2016) reported a horse fall rate of 0.54 per 1000 jumping efforts for FEI competitions in the six-year period from 2009-2014; it is important to note that this is from FEI competitions which typically have a higher fall rate than one-day competitions (as FEI competitions consist one-, two- and three- day competitions and do not encompass lower levels of eventing) (16.8

falls per 1000 starts at FEI events 2005-2015 and 4 falls per 1000 starts at BE events during the same period) (BE, 2015; FEI, 2016, February 26).

International (FEI) competitions comprised the smallest portion of the class of competition in the current data set, and thus BE competitions were the most prominent within the current study. The speed at which the cross-country should be completed is comparable between BE and FEI competitions however the maximum distance of the top class at BE (advanced) is 4,000m with a maximum of 40 jumping efforts, whereas at the top classes of FEI (four and five star, which are run over three-days) the maximum distance is 6,270m with 40 jumping efforts and 6,840m with 45 jumping efforts, respectively. Singer et al (2003) reported that increased jumping efforts decreased the likelihood of a horse fall, however the data included was from the year 1999, and has not since been supported with findings of other, more recent studies (Murray et al, 2005, 2006b). It could be assumed that having to maintain speed over longer courses with additional jumping efforts may contribute to fatigue in horses and could explain in some part, why there is a higher likelihood of experiencing a horse fall reported from studies that only encompass FEI events of one-, two- and three-day competitions, as opposed to studies that only include data from one-day events in the UK. Furthermore, the maximum base spread of fences at FEI events is 3.00m whereas the maximum base spread at a BE one-day event is 2.70m. Murray et al (2006b) reported that increased spread at the base of the fence was associated with increased likelihood of horse falls, which could also contribute to explaining why higher fall rates are typically seen when FEI competition data is analysed in isolation.

Before data cleaning the fall rate for this study was 4 falls per 1000 starts which would equate to 0.16 falls per 1000 jumping efforts (if one start equals 25 jumping efforts). Indeed, even after reduction of data due to cleaning within this study the fall rate does not hugely differ from 0.16 (0.14 after data cleaning), although it is important to note. Nevertheless, these values indicate that the fall rate within the sport could have reduced which could be a reflection of attempts to improve safety within the sport, or the changes that have occurred in the format of the sport during the last 20 years.

4.4.1 Class

As the class (level) of competition increases from BE90 up to advanced level, the risk of a horse fall increases, respectively. International level competitions also had an increased risk of a horse fall in comparison to BE90 level. Previous studies into the risk of a horse fall during the cross-country phase of national level (BE) competitions have not reported the class of competition to have a significant effect on the risk of a horse fall. However, Paix (1999) said that for every 14 hours of cross-country within competitions there is one injury to the rider, but that riders at the highest level of competition had an injury rate of one per 5.5 hours, which is over 180 times more than for all forms of horse riding combined. The findings of Paix (1999) may support the current study findings as it would be plausible to assume that if rider injury is greater at the higher levels then this could be a product of increased difficulty/risk of incident at the higher levels in regards to horse and rider falls.

Singer et al (2003) recorded data from ten BE100 (formerly known as pre-novice), ten novice, seven intermediate, one CCI one-star and one CCI three-star events however class was not retained in the final model. It is possible that class was not retained in the final model for Singer et al (2003) study due to the low sample size of classes, with less than 80 starts within each class in the study. The class with the lowest sample in the current study by comparison was 8,554 (advanced). Murray et al (2005, 2006b) included class of the competition in their analysis and the variable was also not retained in their final models. The authors did not state which levels were included in the data set and the sample size of each, they also did not state how many events in total the data were extracted from, so it is difficult to evaluate why the class of competition was not retained in their final model however, due to these studies being a case/control match design (1/3; 180 cases and 540 matched controls) it could be assumed that the sample for each individual class of competition would be low and thus could be the reason that this variable was not retained in the final models (Murray et al, 2005, 2006b). The studies by Murray et al (2005, 2006b) were based on appropriate sample size calculations, so the points made here regarding the sample for the class of competition variable are not a criticism of the quality of these studies, but rather an observation which may explain why this variable in particular was not identified in previous studies as a risk factor for horse falls but is identified as a risk factor in the current study.

Barnett (2016) conducted an audit on risk of horse falls in FEI competitions and reported that two-, three-, and four-star competitions all had increased risk of a horse fall in comparison to one-star competitions. The findings of the Barnett (2016) audit are comparable to the findings of the current study; that as the class of competition increases, the risk of a horse fall increases. Regardless of whether the competition is a BE competition or an FEI competition the difficulty of the event increases as the class increases. For the cross-country phase, this includes but is not limited to; the length of the course, the height and spread of the fences, the number of jumping efforts and the speed at which the horse and rider combination must complete the course to achieve the optimum time.

Research has stated several fence and course level risk factors that can be directly related to the level of competition. Fences with a take-off and/or landing in water have been associated with increased risk of a horse fall (Murray et al, 2005, 2006b). Fences in water are not permitted in BE90 level competition; as the levels increase, they are permitted and can be placed in increasingly deep water (BE, 2018). As there has been an increased risk associated with fences that jump in/out of water it could be assumed that the horse/rider combinations who are competing at higher level classes are more at risk of a horse fall because of the potential increased presence of this type of fence in the cross-country courses. Wider fences and fences on increased angles have also been associated with an increased risk of a horse fall during eventing cross-country in previous literature (Murray et al, 2005, 2006b). The maximum width of cross-country fences increases as the levels of eventing increase, so it could be assumed that this is a contributing factor as to why higher-level classes are at an increased risk of a horse fall. This notion is supported by Barnett (2016) who stated that certain fence types were associated with increased risk of a horse fall at FEI competitions and identified that the fences with the highest risk were most often seen in the higher competition classes (the finding was significant even after a smaller subset of data was made to account for the imbalance in fence type distribution). Indeed, it may be that the increased difficultly presented by certain styles of fence affects the ability of the horse to jump the fence without fault, which may explain why the higher levels of competition carry an increased risk of a horse fall. Furthermore, approaching a fence 'too fast' has been previously associated with the risk of a horse fall (Murray et al, 2006b). As the levels of competition increase the optimum speed for cross-country also increases, with the lower levels of cross-country competition (e.g. BE90) requiring a speed of 450 meters per minute to meet the optimum time, whereas the highest level of national competition (Advanced) requires a speed of 570 meters per minute (BE, 2018). It is possible that riders competing at a higher-level ride more competitively than those at the lower levels, in order to meet the optimum time and therefore may encourage their horses to approach fences at speeds that would be deemed too fast, increasing the risk of a horse fall. Pinchbeck et al (2003) reported that horse falls were more likely to occur in longer steeplechase races (>17.5 furlongs/3.5 kilometres), a distance equal only to the higher classes of eventing (BE advanced and FEI three- to five-star) although the speed of eventing at these distances is considerably slower than speeds reported for steeplechase races of this distance (570 and 785 metres per minute respectively) (BE, 2018; Pinchbeck et al, 2003).

Contrary to the links between higher class level and increased risk, Singer et al (2003) reported that the risk of a horse fall decreased per additional jumping effort however later studies by Murray et al (2005, 2006b) also included the variable and it was not retained in the final models. The finding by Singer et al (2003) may have therefore been down to chance or may be specific to the time-period in which they analysed which was earlier than subsequent studies.

It is probable that the increased risk seen in horses of a higher levels is directly associated with the course and fence level factors that have previously been attributed to an increased risk of a horse fall. It may have been assumed that fatigue could be affecting horses at the higher levels as the courses are longer and require faster speeds, but research by White et al (1995) disputes this as they found there to be no difference in work intensity across different levels of cross-country competition. The fence and course level factors that have been associated with increased risk of a horse fall may therefore be due to the physiological capability in the horse, specifically kinematics. Fences that are wider, on increasing angles and situated in water may be difficult for the horse to jump safely, additionally the water on landing and take-off could affect the horses balance and therefore put the horse at an increased risk of a horse fall (Murray et al, 2005, 2006b). It is noted that the research on work intensity of the horse during cross-country at different levels is dated, for this reason it is accepted that the work intensity of the different levels may affect risk of horse falls however more research is needed in this area to confirm.

Class had the largest effect sizes within the final multivariable model; Novice, Intermediate and International classes had medium effect sizes, and Intermediate and advanced classes had large effect sizes. This finding is therefore one of the strongest predictors of horse fall risk in our final multivariable model and should therefore be considered appropriately when assessing how to reduce the risk of horse falls in eventing. It is clear from the current findings that the highest levels of BE competition (intermediate and advanced) carry a notably increased risk in comparison with the lower classes and thus should be the focus of any attempts to reduce the risk of horse falls for horses and riders competing in the sport.

4.4.2 Dressage penalties

As dressage penalties increase, the risk of a horse fall increases. Horse and rider combinations who score a high number of penalties (perform poorly) in dressage are therefore more likely to have a horse fall during the cross-country than those who score a low number of penalties (perform well). The effect size of this factor is small, but it is important to consider that the effect size is for every one-unit in change. If there is a 20-penalty difference between one horse and rider combination and another then the effect size becomes much larger. To our knowledge, this is the first study that has identified dressage penalties as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK. This finding indicates that horse and rider combinations who perform poorly in the dressage are more likely to perform poorly in the cross-country phase (resulting in a horse fall). Poor performance in the cross-country phase could include approaching fences too fast or too slow, both of which have an increased risk of a horse fall (Murray et al, 2005, 2006b). Furthermore, horse and rider combinations who are awarded poor scores in the dressage phase may not be competing at the most suitable level of the sport for their respective level of ability. These combinations may benefit from moving down a level until they are at an ability where they will achieve better scores. Additionally, it should be considered that there may be occasions where horses achieve a poor score within the dressage due to sub-clinical injury or poor health, which could possibly affect their gait/performance and therefore their respective score. Greve and Dyson (2014) conducted a study of 506 sports horses and found that 47% of the horses that were believed to be sound (by riders) were lame or had pain-related gait abnormalities. In a later study, Dyson and Greve (2016) found that of 57 sport horses (dressage and show-jumping), 47% exhibited lameness whilst ridden. The findings of Greve and Dyson (2014) and Dyson and Greve (2016) indicate that some riders appear unable to recognise pain-related gait abnormalities in their horses and support the theory that some horses may be performing with undiagnosed pain/lameness which could affect their dressage score and subsequently their risk of a horse fall. Further research is needed to identify whether horses who perform poorly in the dressage have sub-clinical injury or pain.

Murray et al (2006b) reported that riders who were aware they were in first place were more likely to fall than riders who were aware they were in second place or lower and those who did not know their position in the competition at all. Murray et al (2006b) discussed that this finding may be due to competitive riding where the rider takes risks such as riding faster or pushing the horse to jump even after it has attempted to refuse, in order to maintain their position in the competition. Furthermore, Murray et al (2006b) suggested that the finding could be because horse and rider partnerships who achieved good dressage and show-jumping scores (and therefore have achieved first place) are possibly not as capable in the cross-country phase. Over 70% of Murray et al (2006b) sample were riders who were unaware of their position so it is expected that the reason behind their finding is due to competitive riding rather than the capability of the horse and rider, as the finding is unique to riders who were aware of their position and not those that were in a high position, but unaware of it.

There is currently no cap on the amount of dressage penalties that a horse and rider can receive before attempting the show-jumping and the cross-country. As this study has found that a poor dressage score increases the risk of a horse fall during cross-country regardless of show-jumping score it is suggested that the governing bodies consider placing a cap on the dressage penalties that can be given before the combination is permitted to begin the subsequent phases of competition (similar to current procedures for show-jumping penalties). A cap on maximum dressage penalties may be particularly effective where the format of the event is run in the order of dressage, cross-country and show-jumping. At competitions where the show-jumping penalty restriction is not in place before the cross-country phase a dressage penalty restriction may assist in restricting high risk horse and rider combinations from attempting the cross-country. Furthermore, it is suggested that further research is carried out to investigate this risk factor which will aid in understanding of this finding. Finally, an alternative step that governing bodies could take is to monitor the dressage penalty scores of horses and riders over a selected period of time. If a horse and rider combination repeatedly achieve high penalty scores in the dressage, governing bodies could suggest to the rider that they drop down a level until performance is improved, as a safety measure.

4.4.3 Horse starts in previous 60-90 days

This is the first time (to knowledge) that previous starts have been analysed for their effect on the risk of a horse fall during the cross-country phase of one-day eventing competition in the UK. Due to the absence of literature on the effect of previous starts in the risk of horse falls in eventing the findings of this study are not directly comparable, but some comparisons can be drawn from the literature on the subject in racing.

Horse starts in previous 60-90 days were associated with an increased risk of a horse fall. The risk of a horse fall increased with every one-unit increase (start) in this time-period prior to the competition start. Reardon et al (2012) reported a reduced risk of tendinopathy for horses who had started between one and seven times in the previous 3 months (0-92 days) compared to horses who had not started or had more than seven starts in that time-period. Reardon et al (2013) also reported that horses who had started 2-4 or more than four times in the previous three months were less likely to experience tendinopathy than horses who had only started 0-1 times in that period. Additionally, Georgopoulos and Parkin (2017) reported that there was a decreased risk of equine fracture for a higher number of starts in the periods of up to one month prior to the race (0-31 days) and between 30 and 60 days prior to the race however for every additional start between 60 and 90 days, the horses were at a higher risk of fracture. Boden et al (2007a) investigated comparable start history periods to the current study, with periods of 14, 30, 60 and 90 days prior to the current race start used for analysis. Only one of these time-periods were retained in the final model; the authors found that horses who had started one or more times in the 31-60 day period had an increased risk of fatality than those who had zero starts in this period (Boden et al, 2007a). In consideration of the literature it appears that an increased number of starts around the 60-90 day period can be both protective and detrimental to the risk of horse injury in racing.

Other studies that have looked into prior start history (in different periods of time) as a risk factor have been conducted. Rosanowski et al (2018) reported that increasing number of previous starts (during the study period of 2000 to 2013) was associated with a decreased risk of fatality in flat racing thoroughbreds further highlighting the complexity of such analysis. Reed et al (2013) investigated exercise-related risk factors for joint injury in young thoroughbred racehorses in flat race training and found that an increase in high-speed exercise was significantly associated with joint injury whereas an increase in daily canter exercise reduced the risk of joint injury. Boden et al (2007b) analysed periods of 1-14 and 1-60 days prior to the current race start (jump racing) and found that horses who had one or more starts in the 1-14 day period were at increased risk of fatality in comparison to those who had zero starts in this period, however additional starts for horses in the 1-60 day period prior to the current race were associated with a decreased the risk of fatality (flat, hurdle and steeplechase racing).

The findings of previous literature in combination with the current study findings indicate that an increased number of starts around the 60-90 day period can be both protective and detrimental to the risk of horse injury in racing. The findings of the current study are in agreement with some findings of previous studies (Georgopoulos & Parkin, 2017), however it is clear that this risk factor is complex and cannot be evaluated simply. There are also several studies which included this time-period in analysis, but it was not subsequently retained in the final models. Although racing typically requires the horse to travel at faster speeds and thus requires high intensity work from the horse, it is most often shorter in duration when compared to eventing, due to eventing encompassing three different phases. The reason that more starts around these time-periods are protective for risk of injury in racehorses could be that the exercise is optimal in intensity, duration and loading to strengthen the horses musculoskeletal system therefore creating a ‘healthier’ and fitter horse, which is better protected from injury. Eventing on the other hand encompasses three different phases, so the duration and loading of one eventing competition will be much higher than that of a singular race. Eventing horses may need increased periods of rest to enable them to recover fully so that they can complete each event safely.

There are different theories as to why racehorses are at an increased or decreased risk of injury/fatality dependent on their start history. Where horses have increased risk of injury/fatality due to a higher number of prior starts it could be due to the link between the accumulation of high-speed exercise and increased risk of injury, which has been reported on by several studies (e.g. Boden et al, 2007a; Cogger et al, 2006). Previous studies have reported evidence that both supports and opposes this theory. Verheyen et al (2005) reported that the risk of Dorsal Metacarpal Disease (DMD) in racing thoroughbreds decreases with accumulation of distances exercised at canter and high speed (since entering training). However, the authors stated that increased exercise distances in short periods (up to one month) increased the risk of DMD. In agreement with this finding of accumulation of exercise in short periods having more risk, Verheyen et al (2006) found that horses that exceeded certain distances at canter and gallop (44km and 6km, respectively) at speeds of more than 14 meters per second (840 meters per minute) in a 30-day period were at an increased risk of fracture. The study also reported that accumulation of gallop exercise in ‘previously untrained bones’ decreased the risk of fracture, whereas an accumulation of canter exercise increased the risk (Verheyen et al, 2006). In contrast, the authors reported that for horses who had been trained since they were skeletally immature, accumulation of gallop exercise decreased the risk of fracture (Verheyen et al, 2006). Reardon et al (2012) discussed that having more than seven starts in a three-month period could result in excessive cumulative strain on the superficial digital flexor tendon which could predispose the structure to injury. In consideration of the findings of these studies it appears that accumulation of high speed exercise in short periods of time increases the risk of injury in racehorses, this could explain why the current study found that horses who had increased number of starts in 61-90 days were at an increased risk of a horse fall. It may be that horses who have accumulated starts in this period are predisposed to injury (possibly sub-clinical) and therefore their performance is compromised, leaving them at an increased risk of making an error whilst attempting to jump a fence and falling. It is however important to note that this period was the only one retained in the final model of the three periods included, which further highlights the complexity of this risk factor. There are also other studies which have found opposing findings regarding risk and accumulation of starts/exercise. For example, Bennet and Parkin (2018a) investigated risk factors for 'failure to qualify' in FEI endurance competition, finding increased risk of failure to qualify due to lameness for increases in previous ride distance, number of rides in the last 120 days, and number of rides in the last 365 days. These findings should however be compared with eventing/racing studies with caution as endurance rides are typically between 80-160km in distance which is far greater than that of the distance and duration of eventing competitions, nonetheless the notion that repetitive loading on the horses limbs can carry risk for incidents in equestrian sport is supported.

At International eventing competitions which are governed by the FEI, horses have to pass a veterinary inspection before they are permitted to begin the competition, the horse then has to pass another veterinary inspection immediately after the cross-country, and then another prior to the show-jumping (FEI, 2021b, January 1). The first inspection is in place to ensure the horse is healthy for competition and is showing no signs of lameness, the second inspection is to check that horses have not picked up an injury during the cross-country and the third is to check that the horse has recovered from cross-country, is not displaying any delayed signs of injury and is fit to compete in the show-jumping phase. The veterinary inspections are led by the veterinary delegate, who is responsible for deciding if the horse is fit to compete or not. These inspections are only carried out at FEI governed competitions (CCI/CIC one-, two-, three-, four- and five-star). BE do not currently carry out official veterinary checks of horses before or during one-day events. It could be assumed that the finding of increased risk of a horse fall for starts in 60-90 days could be linked to sub-clinical injury or lack of recovery from previous competitions in the horse. Sub-clinical injury may be a contributing factor to increased risk of horse falls as these injuries could have the potential to effect the horses mobility and performance. Considering the findings of Verheyen et al (2005, 2006) it would be beneficial to investigate the exercise regimes of eventing horses during training, as the starts at competition only reveal part of the story in regards to the accumulation of loading.

Future research is warranted to help understand why accumulation of starts in certain time-periods have an increased risk of a horse fall. Future research could include training exercise distance/duration/speed which may enable more definitive findings. It is suggested that BE monitor this factor going forward and perhaps trial a new safety protocol whereby horses must pass a veterinary check prior to starting the cross-country phase at all levels of competition.

4.4.4 Horse grade

Grade one and two horses were significantly less likely to have a horse fall than grade four horses. An explanation of the grading system for horses in BE can be found in Table 4-2, Section 4.2.1.2.5. The results of this finding indicate that horses with the highest number of points in eventing (grade one and two) are at a decreased risk of a horse fall in comparison to horses at the lowest level (grade four). To our knowledge, this is the first study that has identified horse grade as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK.

It is possible that grade one and two horses are less likely to have a horse fall than grade four horses as the horses that have achieved grade one and two status have done so through good performance and obtaining clear rounds, whereby they have not incurred any show-jumping or cross-country jumping penalties. This finding indicates that horses with the most experience in eventing are at a decreased risk of a horse fall, as the horses within this grade have achieved numerous double clear jumping rounds. Murray et al (2006b) reported that approaching a fence 'too fast' or 'too slow' was attributed to increased risk of a horse fall. Horses with a history of obtaining double clear rounds in the competition may approach fences at an appropriate speed (due to experience) which may be why they had a decreased risk of a horse fall. Additionally, points are awarded for being placed in the competition thus it would be reasonable to assume that some horses that have achieved grade one or two status have done so by not only completing clear rounds, but also by being placed in previous competitions. Horses that are regularly placed in competition may be ridden by more experienced riders or alternatively may be of a superior athletic stature which enables them to complete the cross-country safely.

The effect size of the significant findings is small so these findings should be interpreted in consideration of this. Future studies into risk factors for horse falls in eventing should include horse grade in their analyses with the aim of confirming whether this variable is a risk factor for horse falls.

4.4.5 Rider sex

Male riders were associated with a higher risk of a horse fall than female riders. Barnett (2016) reported that male riders were at an increased risk of a horse fall at FEI events (one-, two- and three-day, worldwide) than female riders, thus the current study supports these findings for one-day events in the UK. Males have been reported to score higher in self-efficacy than females in sports such as Parkour (free running) (Merritt & Tharp, 2013) and rock climbing (Llewellyn & Sanchez, 2008).

Additionally, it has been reported that men take greater risks than women in sports such as rock climbing (Llewellyn & Sanchez, 2008), skiing and snowboarding (Ruedl et al, 2012) and Parkour (Merritt & Tharp, 2013). Furthermore, males are reported to score higher in sensation seeking (Cross et al, 2013; Zuckerman & Kuhlman, 2001). These findings indicate that males are more inclined to take risks and that this could be attributed to their higher scores in self-efficacy, risk taking and sensation seeking. Males who score high in self-efficacy may have a greater belief that they can cope with any risky situation that might arise, indicating that they would be more inclined to take risks such as approaching fences faster in order to meet the optimum time. Approaching fences 'too fast' has previously been reported to increase the risk of a horse fall during cross-country (Murray et al, 2006b). Additionally, unlike other sports such as rock climbing, Parkour or skiing/snowboarding, eventing is inter-species with a partnership between each horse and rider. If a male rider is more willing to take risks due to their belief in themselves and their own tendency to take risk/sensation seek, they may be at increased risk of having horse falls because they cannot wholly control the horse and how it will deal with such situations despite their belief in themselves.

Meyers et al (1999) said that male riders displayed less tension, fatigue, depression, confusion and total mood disturbance than females during Olympic trials for dressage and show-jumping competition. Additionally, male riders reported higher anxiety management and confidence than female riders. The findings of this study indicate that male riders cope better than female riders in a competitive environment and may experience less pre-competitive stress. It is possible that male riders compete with less caution than female riders, as they score higher in confidence and anxiety management at competition. Perhaps the higher measures of tension, lack of confidence and anxiety experienced by females equips a female rider with a suitable mind-set to ride a cross-country course safely and make cautious decisions on how to approach fences. Future research into psychological sex differences in riders who compete in eventing is warranted to assist in building a clearer picture of the psychology of event riders. It may be beneficial for BE to provide workshops for riders with trained sports psychologists who can educate riders on how to manage their own sensation seeking, risk taking and competition stress.

In the past, BE enforced a rule whereby all horses competing in the endurance phase of three-day events had to carry a minimum of 11 stone 11 pounds (rider and tack weighed together) (Clayton, 1997). Riders who were under the minimum weight limit were required to carry lead weights in specially designed weight cloths (worn under the saddle) to make up the weight. A study into the effect of weight on landing kinematics of the horse stated that when the rider carried an additional weight in a weight cloth, the leading forelimb of the horse landed closer to the fence, as well as an increase in the extension of the fetlock and carpal joints during the landing phase of the horse clearing the fence (Clayton, 1997). These findings indicate that the horse struggled to increase impulse sufficiently at take-off and that loading on the leading forelimb increased due to the added weight, which puts the horse at an increased risk of ligament and tendon injury (Clayton, 1997). The minimum weight rule was subsequently eradicated by BE in 1998. Although the rule was abolished the findings by Clayton (1997) still highlight a potentially important factor in horse fall risk. There is currently no minimum or maximum weight limit for riders to compete in the sport of eventing. Males typically weigh more than females with increased bone mass (Dennis et al, 2001) and muscle density (Miller et al, 1993). On average, men are taller and heavier in comparison to women (Schorr et al, 2018). It is possible that the increased risk of a horse fall for male riders could be due to male riders weighing more than female riders. Horses that are carrying more weight have been reported to be predisposed to lower limb injury (Clayton, 1997), so it is possible that horses carrying heavier riders are at risk of compromised jumping ability, in relation to the mechanics in which the horse jumps over a fence. A horse that is carrying a heavier load may have to alter its technique which could increase the risk of a horse fall. Additionally, horses that are carrying heavy riders may be at risk of sustaining a sub clinical injury (Clayton, 1997) which could then affect their ability to complete the cross-country safely. There is a lack of recent published research on the effects of rider weight to the welfare and performance of the horse although a recent pilot study stated that horses showed significantly higher pain scores when ridden by heavy and very heavy riders (Dyson, 2018). The weight distribution of riders in regard to sex within the sport of eventing is currently unknown and regardless of the sex of the rider future research on the weight of the rider and how this affects the horses jumping ability is warranted and it is suggested that BE consider a maximum weight rule for riders pending further investigation into the topic.

4.4.6 Horse sex

Mares were associated with a higher risk of a horse fall than geldings. Stallions were also associated with a higher risk of falling however this finding was not statistically significant. Of the available literature on horse falls in eventing, only Singer et al (2003) included horse sex as a potential predictor however the variable was not retained in the final model. Thus, this study is the first to identify horse sex as a risk factor for horse falls in eventing. Pinchbeck et al (2002) included horse sex in their analysis of risk factors for horse falls in steeplechase racing; the variable was retained in the final model however was not statistically significant. The authors (Pinchbeck et al, 2002) displayed the descriptive data for horse sex as mare/gelding/stallion but the subsequent final model retains a variable titled 'sex' with binary male/female levels. There is no explanation as to whether horse sex was altered from its original format to a binary variable however there is no mention of jockey sex anywhere in the paper so it seems reasonable to assume that the sex variable in the final model pertains to the sex of horses. Further studies into point-to-point and hurdle racing have included horse sex in their analysis but it was not retained in any final models (Pinchbeck et al, 2003; Smith et al, 2020). Thus, in consideration of the available literature in racing it appears that horse sex is not associated with increased risk of horse falls.

Previous studies have found horse sex to have an effect on the risk of horse injury. Georgopoulos and Parkin (2017) found that stallions had a higher chance of sustaining a fracture than geldings and mares in flat racing. Bennet and Parkin (2018b) found that stallions had increased odds of 'failure to qualify' due to lameness in FEI endurance events compared to mares and geldings. Furthermore, Anthenill et al (2007) found that stallions were at an increased risk of fracture when compared with geldings and mares (although the difference between gelding and stallion was not statistically significant). These findings indicate that stallions have increased risk of injury than mares and geldings. It is not clear however, why these previous studies grouped geldings and mares together as from a biological perspective, geldings and stallions are notably different than mares. For example, Thompson et al (1994) reported that stallions and geldings had comparable concentrations of growth hormone (8.6 and 8.5 ng/ml, respectively) whereas mares had significantly lower concentrations (2.4 ng/ml). Growth hormone is reportedly used as an ergogenic aid in racing in a bid to improve physical performance and aid faster wound healing (Bailly-Chouriberry et al, 2008), thus it could be assumed that male horses will have the benefit of enhanced performance regardless of whether they have been castrated or not and therefore biologically it would make more sense to group geldings and stallions together rather than mares and geldings. It would be beneficial for studies to separate geldings and mares within analysis in future to allow for a true comparison in the differences between different horse sex. Due to previous studies grouping this factor in this way it is difficult to conclude whether their findings are comparable to the current study. The current study did not find any significant differences between stallions and other horse sex'; this may be because stallions were underrepresented in this data set in comparison to geldings/mares. It is also important to note that the conflicting findings on the effect of horse sex in racing/eventing could be due to the key differences within these two sports. Eventing involves three phases which are much more complex in nature than a horse race. Even the cross-country which is the most comparable phase to a hurdle race is notably different due to the technicality of combination fences and the difference in fence style and location (such as in and out of shaded areas, water, narrow fences and corners). It may be that horse sex is less important in relation to risk within racing due to the simplistic nature of racing.

Previous research has investigated sex differences in eventing horse performance. Hanousek et al (2020) reported that stallions had more polarised patterns in their performance in comparison to mares and geldings, however stallions and gelding's peak performance was better than mares at all levels of BE. An earlier study lead by the same author (Hanousek et al, 2018) also reported that both stallions and geldings performed significantly better than mares, although for cross-country jumping specifically there was no consistent pattern of performance for penalties based on horse sex. O'Brien et al (2005) found that mares were less likely to achieve Grade I status in eventing sport than geldings, indicating that mares have inferior performance in the sport. A number of studies in other equestrian sports have also been in agreement of the findings in eventing; Marsalek et al (2005) analysed show-jumping competition results and reported that mares and geldings obtained a lower percentage of clear rounds (zero penalties) than stallions. Furthermore, they reported that mares refused at fences more often than geldings and stallions (Marsalek et al, 2005).

The effect size of this finding in the current study is low, which does support the contradictory nature of sex-based performance findings in the literature. For example, Whitaker et al (2008) found no significant difference between cross-country jumping penalties at any level of competition between mares, geldings and stallions. The authors did find that geldings had significantly lower cross-country time penalties at Novice level competition, but this difference was not seen at any other level so may not be entirely representative (Whitaker et al, 2008). Hanousek et al (2020) also noted that in their analysis, horse sex was the weakest variable in predicting performance. The studies considered here indicate that female horses have inferior performance in equestrian sport in general, compared to males, which supports the finding of the current study whereby mares are more likely to have horse falls (and thus are worse performers). It is important to note however that the findings considered here mostly involve general performance rather than performance of the cross-country phase in particular. The studies that have investigated cross-country jumping performance (relevant to horse falls during cross-country) have found inconsistent evidence for poor performance in mares during this particular phase of the competition (Hanousek et al, 2018; Whitaker et al, 2008).

The reasons why mares are more likely to fall than male horses is unknown; although some studies have considered that horse trainers and riders have pre-conceived ideas about the temperament of horses based on their sex. Aune et al (2020) conducted a survey of 1,233 horse enthusiasts and found that riders prefer geldings over mares and stallions. Dashper et al (2018) also conducted a survey and investigated whether respondents had preferences for the sex of horses used in show-jumping, dressage and trail riding. The authors found that mares were the least popular choice with respondents using anthropomorphic descriptions of gender stereotypes that depict mares as being moody, flighty and unpredictable to justify their preferences (Dashper et al, 2018). The presence of these pre-conceived ideas in reference to mares may alter the way that they are handled and trained. These perceptions may contribute to an unconscious bias within horse trainers, handlers and riders who may attribute unwanted behaviours of mares to anthropomorphic characteristics, rather than to a lack of training or poor handling/riding technique (Aune et al, 2020). In consideration of the literature it appears that these perceptions are supported at times (although the reported differences in mare performance may be attributable to the handlers'/riders' unconscious bias rather than their inherent performance ability), however the literature is inconsistent on this topic and further research is needed.

4.4.7 Horse height

Horses that are 143-148cm in height (classified as 'pony' as per BE rules) were more likely to have a horse fall than horses that are 161-165cm in height. This variable was investigated in a binary manor as horse Vs pony however model fit (AIC) was improved with the variable in a non-binary format. Furthermore, in binary format the variable did not produce a significant result, so it was evident that there was a specific margin of interest (161-165cm) within horses that were not categorised as ponies. No other significant differences in height were found. To our knowledge, this is the first study that has identified horse height as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK. Additionally, Holmström and Philipsson (1993) found a positive correlation between height and dressage scores in horses during canter movements. Ducro et al (2009a) also stated that horses of a higher height were ranked higher in dressage competition. Although a number of these studies are now dated, the findings suggest that taller horses may perform better in sport which supports the finding of the current study whereby the lowest height category included was the only one to demonstrate a significantly increased risk for horse falls (and thus is inferior in performance). In contrast, Ducro et al (2009b) found that horses of higher heights were associated with a higher risk of early retirement from dressage and show-jumping competition, suggesting that smaller horses have better longevity in competition.

Ponies (143-148cm) may be at an increased risk of a horse fall during cross-country due to the increased difference between their height and the height of the fences. Ponies can compete at all levels of BE competition. It would be logical to assume that as the height and width of the jumps increases that taller horses may find it easier to clear the obstacles, which may be why ponies are at an increased risk of a horse fall. To knowledge, there is currently no literature to support this, thus it would be beneficial for studies into jumping kinematics to explore the effect of horse height on the horse's ability to clear an obstacle safely at different heights. It would also be reasonable to assume that ponies will be more commonly ridden by young riders or children, thus the riders lack of experience may also contribute to this finding. This is partially supported by the finding in the current study that older riders were less likely to have a horse fall than riders who were between 12-21 years of age (although this finding was only significant for riders aged 42-51 and 52 or more years of age). Finally, Barrey et al (2002) observed that taller horses had a lower stride frequency (cadence) and a longer stride length, which enabled them to travel at fast speeds. The observation of Barrey et al (2002) suggest that horses of a lower height (e.g. ponies) may struggle to meet the optimum time during cross-country, and therefore must travel faster relevant to their height, with a higher cadence. If ponies are required to travel at faster speeds (relevant to height) with an increased cadence, then this may implicate the intensity in which they are working which could predispose them to earlier onset of fatigue than taller horses. Additionally, the shorter stride length of a pony may alter the way in which they need to approach combination fences (which are set at a specific distance). It is plausible that the distances between fences within a jump combination are not appropriate for all heights (and thus all stride-lengths) of horses and therefore may affect the horses' ability to jump the fences safely. Further research is needed in this area to confirm.

Overall, there is limited research available on horse height and its effect on performance or risk during jumping competitions. The findings of the current study only found one significant finding and the results do not demonstrate a linear relationship as has been reported previously (Holmström & Philipsson, 1993). The effect size of this finding is also small thus it is recommended that future studies into risk factors for horse falls include horse height in their analysis to aid in finding a more definitive result for this variable.

4.4.8 Rider days since last start

The number of days since the riders' last start (competition intensity) was associated with the risk of a horse fall. The risk of a horse fall decreased for riders who had started 15-21 or 22-28 days prior to the competition, in comparison with riders who had started in the 0-14 days prior to competition. This finding indicates that riders who have started in the two weeks prior to the competition have the highest risk of a horse fall. To our knowledge, this is the first study that has identified the number of days since the riders' last start as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK

Previous studies have investigated the physiological demands of eventing and have concluded that eventing is physically demanding and requires high cardiovascular effort (Douglas, 2017; Roberts et al, 2010). Indeed, the cross-country phase is comparable to a sprint distance triathlon in relation to mean heart rate. García-Pinillos et al (2016) reported mean HRs of 169±22bpm (swim), 164±12bpm (bike) and 176±13bpm (run) for athletes completing a simulated sprint distance triathlon. In comparison, Roberts et al (2010) reported mean HRs of 157±15bpm (dressage), 180±11bpm (show-jumping) and 184±11bpm (cross-country) for athletes riding in a simulated one-day event. Notably, mean HR is lower for the sprint triathlon athletes however it is expected that this is due to the discrepancies in the duration of each phase between the two sports. Although the triathlon is labelled a 'sprint', the phases are certainly longer in duration than each eventing phase with mean times for each phase of triathlon being 13:35 (swim), 31:40 (cycle) and 21:48 (run) (García-Pinillos et al, 2016). The eventing phases demonstrated mean times of 04:43 (dressage), 01:88 (show-jumping) and 04:79 (cross-country) in comparison (Roberts et al, 2010). Eventing is therefore higher in intensity but shorter in duration. Nevertheless, the findings of the studies (García-Pinillos et al, 2016; Roberts et al, 2010) highlight the physiological cost of eventing on riders and therefore the risk of possible fatigue or over-training if suitable time is not taken between competitions to rest, which may explain the current study findings. This is the first study to demonstrate that the competition intensity for the rider has an effect on the risk of a horse fall in eventing. The effect size of this finding within the current study is small therefore further research which includes this variable would be beneficial. Furthermore, studies that quantify fitness levels and possible presence of overreaching/overtraining syndrome in riders would be advantageous in understanding the reason for this finding.

4.4.9 Rider age

Riders who were 42-51 years and more than 52 years of age at the date of competition were significantly less likely to have a horse fall than riders who were 12-21 years at the date of competition. To our knowledge, this is the first study that has identified rider age as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK. Previous studies have found that risk taking generally declines with age in people (Martin & Leary, 2001; Nicholson et al, 2005). Additionally, it has been reported that risk taking scores decrease with age specifically in sports such as Skiing and Snowboarding (Ruedl et al, 2012), Parkour (Merritt & Tharp, 2013), Skateboarding (Kern et al, 2014) and Eventing (Wolframm et al, 2015). The findings of these studies indicate that eventing riders could be at a decreased risk of horse falls at older ages because they have a lower willingness to take risks, it could be assumed that people who are less willing to take risk (older riders) are therefore less likely to have a horse fall because of their lower inclination to take risks. The reason that people take less risks as they get older is not entirely understood, but it has been theorised that this is due to their heightened awareness of the consequences of injury (Dumas & Laforest, 2009; Kern et al, 2014). As people age, they may prioritise good health in order to earn a living, keep up with financial obligations, support a family or care for a loved one. This could also be reflected in a rider in the sense that they do not want their horse to become injured (which is possible if they experience a horse fall). Thompson et al (2015) said that riders attributed a good relationship between themselves and their horse with increased performance and reduced risk. If a rider has a strong bond with their horse it could be assumed that they will be more concerned with protecting the horse from any serious injury. As previous studies have found that humans prioritise their own health more as they age in order to protect things such as their financial independence and their family (Dumas & Laforest, 2009;

Kern et al, 2014), it is possible that older riders have a stronger bond with their horse and therefore are more concerned about protecting it than a younger rider may be. Older riders may feel a stronger inclination to protect their own and their horse's health so therefore perhaps ride more cautiously and are consequently less likely to experience horse falls.

Unlike other sports, equestrian sport does not experience a decrease in sport participation as participants get older (Owen & Bauman, 1992; Wolframm et al, 2015). Riders can and do continue to participate in equestrian sport in to advanced age, even at a professional level, which is evident by riders present on the Great Britain Show Jumping team at the Olympic Games in Rio 2016 including Nick Skelton OBE, age 58; John Whitaker MBE, age 60 and Michael Whitaker, age 56 (British Show Jumping 2016, July 5). Eventing riders also display longevity at a professional level in the sport with two of the eventing team riders named for the same Olympics at the age of 47; William Fox-Pitt & Pippa Funnell MBE (British Show Jumping, 2016, July 5). Due to the prospect of a long career in the sport it is possible that older eventing riders harness extensive experience that equips them with well-developed coping mechanisms which allow them to manage any sports related anxiety, and to focus their performance and skill in to completing the cross-country accurately and safely. It is suggested that the governing bodies for eventing utilise experienced riders to educate young and new riders on how to cope with competition stress and how to ride competitively, but with safety and welfare of the horse in mind.

4.4.10 Rider previous falls in career

The number of horse falls that the rider has had in their career (within the data time-period) was significantly associated with risk for horse falls. The risk of a horse fall decreased with every one-unit change in the number of horse falls the rider had in their career. Although this variable was not statistically significant in the final model, AIC was used to distinguish model fit and the fit was improved with inclusion of this variable therefore the variable was retained in the final model. Additionally, no evidence of interactions or confounding were found for this variable.

Riders who have had a higher number of horse falls during their career may be at a decreased risk of a horse fall as accumulation of previous falls may indicate that those riders are more experienced. Furthermore, in consideration of the descriptive data on this variable it is evident that 72% of riders have never experienced a horse fall, with a further 13.5% only experiencing one fall in their career. The negligible effect size and lack of statistical significance is likely due to this distribution within the data. We could have changed the variable to 'has the rider fallen before?' with two levels of yes/no however categorising the variable in this way would have made any biologically plausible recommendations to the governing body a challenge. It is important to note that where 'career' is stated within this study that this is limited to the period of interest utilised within analysis; it is plausible therefore that riders may have had other falls prior to this time-period which may alter the presentation of this finding in future studies. Further research is needed to reveal whether this variable will remain a risk factor for horse falls in subsequent data sets.

4.4.11 Horse previous falls in career

The number of horse falls that the horse has had in its career (within the data time-period) was significantly associated with risk for horse falls. The risk of a horse fall increased with every one-unit change in the number of horse falls the horse had in their career. To our knowledge, this is the first study that has identified horses' previous falls in career as a risk factor for horse falls during the cross-country phase of one-day eventing competitions in the UK. Barnett (2016) included this variable in their analysis however it was not retained in the final model. This increase in risk could be attributed to the all-round ability of the horse. A horse that has had several falls during the cross-country may not have the athletic or psychological capabilities that is required to complete the cross-country safely. As previously discussed in Chapter Two, an all-round performance horse is needed for eventing. A horse that has the skill and accuracy to achieve an excellent dressage score and jump clear around a show jumping course may not have the bravery, stamina and ground covering stride to be effective in the cross-country phase (Marlin & Nankervis, 2002). Horses that have had several falls may simply not be suitable for the sport. Future research is necessary to distinguish any patterns or similarities in the horses that experience several falls during their career as assessment of this finding is purely speculative without this information.

BE currently have a 'Horse Fall Protocol' in place for tracking and responding to horse falls. If a horse has two falls in a 12-month period then the governing body will conduct an investigation in to why the horse falls have occurred and will discuss steps that need to be taken to prevent future falls, with the owner and rider of the horse (BE, 2018). Additionally, if a horse falls three times in a 24-month period then the horse will be automatically suspended pending investigation (BE, 2018). It is suggested that the governing bodies for eventing sport consider creating a cap on how many horse falls a horse can experience during its eventing career before it is deemed unsuitable for the sport, possibly invoking a life time ban. The current protocol for horse falls in Britain developed by BE is valuable but may benefit from being altered to be more rigid concerning horses that have fallen several times. Additionally, the current protocol used by BE does not consider horses that have had several falls in longer time-periods than 12- or 24-months. As this is now the second study to highlight this risk factor (along with Barnett, 2016), it is suggested that the governing bodies should consider lengthening the time-periods for the horse fall protocol to 'career' falls in response to the findings of this research, and that other countries follow this example. Alternatively, if governing bodies do not want to make any procedural/rule changes with regards to this finding then it is advised that they monitor this data with greater care going forward, as a minimum. It is important to note that where 'career' is stated within this study that this is limited to the period of interest utilised within analysis; it is plausible therefore that horses may have had other falls prior to this time-period and that their respective risk for horse falls may be in fact higher than what is presented here.

4.4.12 Model evaluation

Performance of the predictive model was completed as recommended by Bradley (1997), by calculating the Area Under the Receiver Operating Characteristic Curve. This method of evaluation considers both possible outcomes (case and control) which is vital due to the imbalance of these factors in the data set. The True Positive Rate (TPR) within this calculation considers how often the model classifier predicts a horse fall, when there was an actual horse fall. The False Positive Rate (FPR) considers how often the model classifier predicts a horse fall, when there was no actual horse fall. The AUC ranges from 0.5 to 1. An AUC of 0.5 is equivalent to 'chance' (e.g. the toss of a coin), whereas an AUC of 1 would represent a model that can predict two outcomes perfectly (100% of the time). The predictive performance of the model in this study is 70%. This should be interpreted with caution; this finding does not indicate that the model could correctly identify 70% of all starts that will result in a horse fall. Instead, it indicates that if we were to choose between two starts, we would be correct 70% of the time in identifying which one would result in a horse fall. This model could be used to aid in decision making by the governing bodies over future monitoring of horse falls however there is still further work that needs to be done to enable reliable predictions to be made.

4.4.13 Limitations to the study and future improvements

4.4.13.1 Study limitations

All affiliated (BE/FEI) one-day eventing competition results in the UK with complete data are recorded so the data set is large, however there are several limitations to the study:

1. Due to the cross-country fences being judged by volunteers without any qualifications it is possible that their judgement may not always be correct as per BE rules, particularly in inexperienced or first-time fence judges.
2. All scores during competition are collated on paperwork and handwritten, before being transferred by an appointed person on to the online database. There is a possibility for human error through these various streams of data gathering.
3. A number of issues were noted with the quality and consistency of the data as outlined in section 4.3.1.6. Loss of data was mostly as a result of discrepancies found within the show-

jumping penalty data. The study is limited by this loss of data with the reduction in cases likely having the largest effect on the final results. Additionally, due to the errors found within the show-jumping penalty data the study may have failed to identify a significant risk factor for horse falls relevant to this variable.

4. The sample size is large however the study is limited due to fence- and course-level variables not being included in analysis. It would have been beneficial to consider the findings of previous research which has identified fence- and course-level risk factors for horse falls.
5. The study only considers one-day events thus does not represent risk factors for horse falls at two- or three-day events.
6. The study is not geographically comprehensive (only includes eventing competition in the UK) and thus aspects of horse/rider competition history may be absent from the data set (e.g. for horses/riders that compete outside of the UK).
7. The data does not include any information on training activity of horses or riders which may be beneficial to investigate in future in the context of horse falls.

4.4.13.2 Future improvements

It would be beneficial to be able to reconcile the several different data sets that BE have in their possession. Future studies should aim to reconcile competition, fence, course and incident data as one large file which would enable a thorough analysis of risk factors for horse falls. Unfortunately, this will not be possible unless the data management protocols at the governing body are improve d.

4.4.14 Recommendations

Based on the results of this study, in order to minimise the risk of horse falls in the cross-country phase of one-day eventing competitions in the UK, we recommend that:

1. Further research is conducted to investigate the effect of different fence types on the risk of a horse fall at eventing competitions in the UK. Considering the findings of increased risk as the class (difficulty) of the competition increases (which is related to fence type, height and width). Current studies on this topic for BE competition are now dated and recent research into FEI events has revealed that fence-level variables do have a significant effect on the risk of a horse fall.
2. The higher levels of competition carry a significant increased risk of horse-falls (which large effect sizes apparent). Aspects related to the differences between the levels of competition such as the speed, distance and design of cross-country courses at the higher classes of

competition warrant further investigation. In the interim, it may be appropriate to increase the MERs required for the higher levels of competition.

3. Consider inclusion of a penalty cap on dressage score in line with the current penalty cap on show-jumping penalty score. This may be particularly important at events where the competition format is run in the order of dressage, cross-country then show-jumping.
4. Further research is needed on rider sex differences in the sport of eventing to understand why male riders have an increased risk of a horse-fall. We are the second study to report this finding which has now been reported for both FEI and national (BE) events. We propose that this difference in risk could be due to discrepancies in body composition (weight), personality traits (such as self-efficacy) and/or risk-taking behaviour of male and female riders. If the reason for this finding can be identified then it may be simple to mitigate.
5. Consider inclusion of a cap on (or begin monitoring) number of horse falls horses are permitted to have in their career before being deemed unsuitable for the sport. This could be a welfare issue as much as a risk mitigation issue as if a horse is continually falling then it may not be physiologically capable of completing the cross-country safely.

4.4.15 Contribution to knowledge

This study has revealed nine risk factors that significantly affect the risk of a horse fall during the cross-country phase of eventing competitions in the UK that have not been previously reported in the literature (class, dressage penalties, horse starts in the previous 60-90 days, horse grade, rider sex, horse sex, horse height, the number of days since the riders' last start, horse previous falls in career and rider age), demonstrating a significant and original contribution to knowledge. Previous studies have tended to focus on fall outcomes at fences, with fence-level factors consistently being identified as a risk factor for horse falls. Although some of this research is now dated and would benefit from being repeated, the current study was designed to build upon the available research in an original way, rather than repeat what has been done. This study has utilised existing knowledge and techniques from other fields of research such as horse racing and has utilised them in an original manner by applying them to a different, but comparable sport. The risk factors that have been identified in the current study could be mitigated by procedural (rule) change at the discretion of the governing body. Alternatively, the governing body may use the findings to inform monitoring of horse/rider combinations who are most at risk of a horse fall. Additional to the identification of new risk factors, the findings of the current study also support and expand upon the findings of previous research which will add weight to recommendations that can be made to the governing bodies of the sport. Ultimately, any knowledge that contributes to the aggregation of marginal gains in terms of the reduction of horse falls in eventing is valuable, as horse falls during cross-country can and do transpire to the loss of life of an animal or person.

4.4.16 Conclusion

This study has identified a number of modifiable risk factors for horse falls during the cross-country phase of eventing competitions in the UK, related to the horse, rider and competition performance prior to the cross-country phase. The mechanisms of how/why these risk factors affect the likelihood of a horse fall is unknown and can only be speculated upon. Discrepancies were found within the data set which call into question the quality of the data; however, the findings support the results of prior studies and are biologically plausible therefore the study findings should not be disregarded. The findings of the current study can be used to modify regulations, rules or restrictions stipulated by the governing body in the UK (BE) to reduce the risk of a horse fall for competitors. We propose that consideration is given to these findings as soon as possible to permit the implementation of modifications. Furthermore, we recommend that future studies attempt to confirm the current study findings.

5. Using heart rate monitors to measure short-term heart rate and heart rate variability for the assessment of stress in horses: a scoping review.

5.1 Introduction

5.1.1 Methods of measuring HR/HRV in horses

Clinical electrocardiogram (ECG) devices are the traditional choice to assess cardiac activity and are considered the 'gold standard' device for this purpose (Task Force, 1996). ECG devices record and display a graphical representation of the electrical activity of the heart (Ashley & Niebauer, 2004). An ECG comprises of five 'waves' known as 'P', 'Q', 'R', 'S' and 'T' (Figure 5-1): P represents cardiac atrial depolarisation (and thus the onset of atrial contraction), Q represents depolarisation of the interventricular septum, R represents depolarisation of the main mass of the ventricles, S represents the final depolarisation of the ventricles (at the base of the heart) and T represents ventricular repolarisation (Ashley & Niebauer, 2004; Dupre et al, 2005). Waves Q, R and S are collectively known as the QRS complex and together represent ventricular depolarisation (marking the beginning of ventricular contraction); the atria also simultaneously repolarise during this phase but this is masked by the overriding electrical activity of the ventricles and thus cannot be seen on the ECG (Dupre et al, 2005; Task Force, 1996). ECG is the recommended method for detecting and analysing HR/HRV data (Stucke et al, 2015; Task Force, 1996), however ECG equipment is expensive, requires specialist knowledge to use and due to the necessity of multiple cables and adhesive electrodes can present some challenges in terms of the practicalities of their use for in-field research (Dobbs et al, 2019; von Borell et al, 2007).

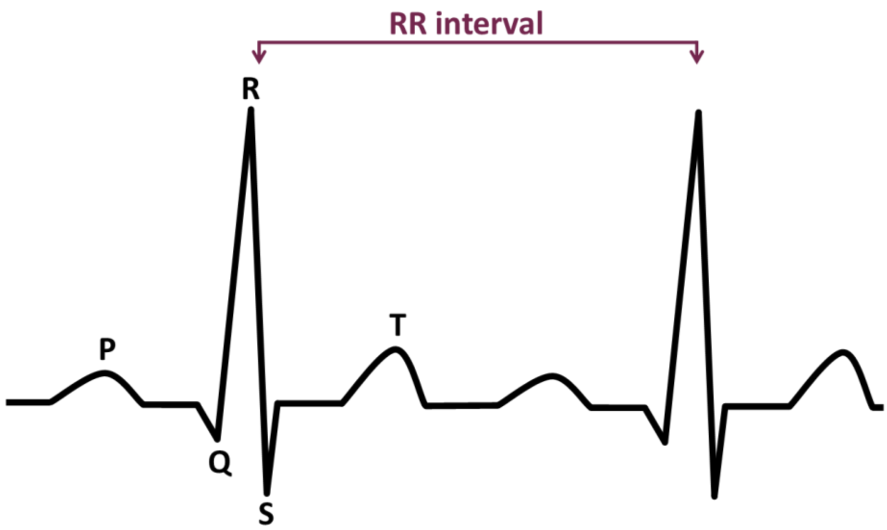


Figure 55-1: Illustration of QRS complexes and RR-interval of ECG signals.

Advances in technology have enabled the development of portable, commercially available, and affordable monitoring devices that can be used as an alternative to an ECG, known as Heart Rate Monitors (HRMs). HRM's do not record the whole ECG trace, instead, they detect the R-wave peak of the ECG in isolation and use this to record the 'inter-beat interval' (IBI). The IBI represents the time between each contraction of the cardiac ventricles, this is also known as the RR-Interval, as ventricular contraction is demonstrated by the R-wave peak in an ECG (Dupre et al, 2005; Task Force, 1996). HRMs automatically record IBI data and store it in digital form, which can later be used to analyse HR/HRV (Dobbs et al, 2019), with the devices offering an affordable and time efficient alternative to HR/HRV analysis using ECG (von Borell et al, 2007). There are however limitations with HRMs since they only detect successive R-wave peaks, and do not record the entire ECG trace. This can result in the HRMs incorrectly identifying R-peaks that cannot be subsequently checked and corrected by researchers. For example, horses can have a more pronounced T-wave (due to their high parasympathetic tone); HRMs may incorrectly identify pronounced T-waves in horses as an R-wave (von Borell et al, 2007). When using an ECG, visual assessment can be performed and if the system has identified two R-waves within a few milliseconds of each other then the researcher can identify and correct the misidentified T-wave, however this process is a challenge when using HRMs as they do not record the entire ECG trace (von Borell et al, 2007). Additionally, previous research has reported that movement of sensors (during ECG or HRM recording) on the horse's skin and muscle contraction can result in errors (also known as 'artefacts'). As with the T-wave identification, this can be corrected manually via visual assessment of an ECG which is not possible when using HRMs.

Previous studies have assessed the validity of HRMs against the gold-standard ECG, with mixed results. Ille et al (2014b) reported that HRM devices are a reliable tool for the assessment of HR/HRV data in stationary horses. The strong agreement demonstrated by Ille et al (2014b) between HRM and ECG data for all indices echoes the findings of Parker et al (2010) who also stated that there were no significant main effects of measurement type (between HRM and ECG) for horses in a stationary setting. Notably, the settings that included movement of subjects in Parker et al (2010) study demonstrated poor agreement between ECG and HRM data, which was supported by Lenoir et al (2017) findings that agreement between HRM and ECG in ridden (exercising) horses was poor. The studies available that have assessed agreement between HRM and ECG thus indicate that these devices are valid whilst horses are stationary, but that validity of the HRM data declines with increasing movement of subjects. Although there are validation studies available, these are limited in number and represent variation in methods such as devices used, activity of subjects and data handling and analysis. A thorough review is therefore necessary to aid in summarising the validity of HRM devices in consideration of the many factors that can affect the validity of HR/HRV data.

5.1.2 The use of HR/HRV to assess stress/arousal

Analysis of Heart Rate Variability (HRV) is a useful, non-invasive tool for quantitative analysis of autonomic activity, with the method being widely applied to assess Autonomic Nervous System (ANS) regulation in humans (Marques et al, 2010), dogs (Katayama et al, 2016), farm animals and horses (Stucke et al, 2015; von Borell et al, 2007). Heart rate variability is a measure of the irregular time intervals between consecutive heart beats (RR-intervals) (Bogucki & Noszczyk-Nowak, 2015). This is deemed as healthy cardiac function, whereby beat-to-beat intervals of cardiac sinus rhythm demonstrate complex and continuous fluctuations (Iwase & Hayano, 2016). This irregularity is a demonstration of the body's homeostatic function in maintaining and regulating bodily functions as well as its response to stimuli (von Borell et al, 2007).

The ANS has a key role in regulating physiological fluctuations in the cardiac cycle, with the sympathetic (SNS) and parasympathetic (PNS) divisions of the nervous system often being described as an antagonistic pair (Iwase & Hayano, 2016). There are situations however, where these subdivisions of the ANS appear to work in a symbiotic manner. During exercise for example, the SNS increases heart rate and thus contractility and the PNS is simultaneously inhibited which contributes to the mediation of heart rate and contractility in unity with its physiological counterpart (Pan & Li, 2007). Alongside the ANS, cardiovascular function is regulated by neuroendocrine control mechanisms which tend to have a longer term regulatory effect than the short-term effects caused by neural controls, due to their continuous role in regulating physiological and behavioural states (Pan & Li, 2007). Furthermore, the sinus node in the heart responds to PNS activity within one to two heartbeats, thus rapid alterations in HR are exclusively caused by changes in PNS activation (von Borell et al, 2007). Analysis of HRV to assess ANS activity is therefore particularly beneficial as an indicator of short-term psychophysiological stress/arousal (von Borell et al, 2007).

Analysis of HRV has been evidenced to produce reliable measures of PNS activity during both homeostasis and stress/arousal (Porges, 1995). Although the majority of research that utilises HRV analysis for assessment of emotional states focuses on humans as their subjects, the work is comparable to other mammals due to the presence of the limbic system (Reep et al, 2007). Furthermore, vagal control works similarly across mammals (Porges, 1995). HRV is especially useful when assessing stress/arousal in animals, due to the communicative challenges faced between animals and humans (Stucke et al, 2015). This review will focus on analysis of short-term HR/HRV in horses for the assessment of acute stress.

5.1.3 HR/HRV measures

There are a variety of different measures that can be utilised to analyse HRV; these are chosen dependent on the conditions at which the data has been recorded (e.g. short-term or long-term), and the research question that is being asked, as different parameters represent different biological activity. The three main categories of HRV indices are Time Domain, Frequency Domain, and Non-Linear measures.

5.1.3.1 Time domain indices

HRV time-domain indices calculate the variance in measurements of the IBI (Shaffer & Ginsberg, 2017). To achieve a more normal distribution, time domain indices may be presented as the natural logarithm (Ln) as opposed to the original units (Shaffer & Ginsberg, 2017). In layman's terms, time domain indices consider how many 'beats' are in a given time-period. Table 5-1 displays Time Domain indices previously reported in the literature for the assessment of HRV in horses, and their respective descriptions.

Table 55-1: Time domain measures for HRV as described by Shaffer & Ginsburg (2017).

Parameter	**Unit**	**Description**
RR-interval	ms	*time between each contraction of the cardiac ventricles*
SDNN	ms	*SD of NN intervals (RR-intervals that have had artifacts removed)*
SDRR	ms	*SD of RR-intervals*
pNN50	%	*Percentage of successive RR-intervals that differ by more than 50 ms*
RMSSD	ms	*Root mean square of successive RR-interval differences*

SD - standard deviation, ms – milliseconds, bpm – beats per minute

5.1.3.2 Frequency Domain Indices

HRV frequency domain indices calculate the distribution of absolute or relative power in to four frequency bands (Shaffer & Ginsberg, 2017). The four frequency bands are; ultra-low-frequency (ULF), very-low-frequency (VLF), low-frequency (LF) and high-frequency (HF) (Task Force, 1996). In layman's terms, frequency domain indices consider how the RR-intervals are modulated. Table 5-2 displays Frequency Domain indices previously reported in the literature for the assessment of HRV in horses, and their respective descriptions.

Table 5-2: Frequency domain measures for HRV as described by Shaffer & Ginsburg (2017).

Parameter	**Unit**	**Description**
VLF power	ms^2	*Absolute power of the very-low-frequency band*
LF peak	Hz	*Peak frequency of the low-frequency band*
LF power	ms^2	*Absolute power of the low-frequency band*
LF power	nu	*Relative power of the low-frequency band in normal units*
LF power	%	*Relative power of the low-frequency band*
HF peak	Hz	*Peak frequency of the high-frequency band*
HF power	ms^2	*Absolute power of the high-frequency band*
HF power	nu	*Relative power of the high-frequency band in normal units*
HF power	%	*Relative power of the high-frequency band*
LF/HF	%	*Ratio of LF-to-HF power*

5.1.3.2 Non-Linear measures

Non-linear measurements index the unpredictability of a time series (Shaffer & Ginsburg, 2017). Poincaré plots (also known as return maps) are typically utilised to obtain non-linear measurements and are graphed by plotting each RR-interval against the prior interval which creates a scatter plot (Ciccone et al, 2017; Shaffer & Ginsburg, 2017). Table 5-3 displays Non-Linear measures previously reported in the literature for the assessment of HRV in horses, and their respective descriptio ns.

Table 55-3: Non-linear measures for HRV as described by Shaffer & Ginsburg (2017).

Parameter	**Unit**	**Description**
SD1	ms	*Standard deviation of the perpendicular distance of points from the line of identity (Poincaré plot)*
SD2	ms	*Standard deviation of distance of points along the line of identity (Poincaré Plot)*

5.1.4 Aims and objectives

Although HR/HRV data has been used successfully to assess welfare/stress in horses and this has been reviewed in the literature (Stucke et al, 2015; von Borell et al, 2007), there are no studies to date which have reviewed the literature in the context of the validity of HRM devices for assessment of HR/HRV. The aim of this study is to review the literature on the validity of HRMs to collect HR/HRV data for the assessment of stress/arousal in horses. The objectives are therefore (1) To collate information on the validity of HRM devices to collect HR/HRV data in horses, (2) To assess the methods used for short-term HR/HRV analysis in horses using HRMs, including equipment, data handling and analysis, (3) To make methodological recommendations for the use of HRMs to assess short-term HR/HRV in horses and (4) To suggest future considerations for research that aims to assess the validity of HRMs for the obtainment of HR/HRV data in horses.

5.2 Methods

Guidelines for systematic reviews were followed from reliable academic sources (Board et al, 2016; Higgins & Thomas, 2019). Due to the limited numbers of studies, any studies that measured HR/HRV in combination with other validated techniques for assessing equine stress/arousal were included. The other validated measures of stress/arousal included ocular (eye) surface temperature (IRT) (Yarnell et al, 2013), salivary (Peeters et al, 2011) and blood cortisol (Mormède et al, 2007). Only studies that used devices capable of extracting HR from HRV data were deemed suitable for inclusion, therefore studies that measured HR alone were not included. Any study that assessed contemporary equipment in combination with the gold standard for HR/HRV data collection (ECG) was also included.

5.2.1 Search strategy

A review framework was set *a priori* to standardise the data collection by defining study population, outcomes and setting (Appendix VI). The systematic review was performed between July and August 2020. During this time the electronic databases Scopus and VetMed were used to source relevant research published between 2010 and the time of review. The following search terms were used: (“Heart Rate” OR “HR”) AND ("Heart Rate Variability" OR "HRV") AND ("Equine" OR "Horse") AND ("Welfare" OR "Stress").

5.2.2 Study selection

Study inclusion criteria can be seen in Appendix VII. Studies that investigated short-term HR and HRV (where short term is defined as <1 hour) were deemed eligible for inclusion within this review. Inter-beat interval data derived from commercially available devices that detect the R wave peaks of the ECG during recording and then store IBI data in digital form (von Borell et al, 2007) was essential for studies to be accepted as suitable for inclusion. Studies that included HR/HRV measures at rest (loose), during handling, during exercise, during travel or immediately post-exercise were included. Only studies that used HR/HRV data from contemporary devices in combination with another method of assessing welfare/stress in horses (as described in section 5.2.1) were deemed eligible for inclusion. Articles were restricted to the English language due to limited access to reliable translation services. Furthermore, inclusion was restricted to studies that included healthy, adult horses, aged three to 25 years. Only full-text, peer reviewed scientific literature was included. Theses, undergraduate dissertations and conference proceedings/abstracts were excluded.

Initially, titles and abstracts of citations were screened for relevance. Further studies were then found by manually searching through reference lists of the relevant studies found in initial screening. This enabled identification of any sources that did not appear in the initial search of the electronic data base.

Articles that were deemed eligible by this process were then read in full and filtered as per the inclusion criteria.

Due to limited numbers of eligible studies, all outcome measures of HR and HRV were included. Studies that utilised controlled measures within methodology were regarded as reliable sources. This strengthened the value of the research outcomes. For example, the use of chronological event markers to clearly define the exact start and finish times within methods was viewed as evidence of good control. Furthermore, strenuous or vigorous exercise were regarded as controlled if strict protocols were followed as outlined by comparable review studies (Board et al, 2016). The study selection process is presented as a PRISMA flow diagram (Figure 5-2).

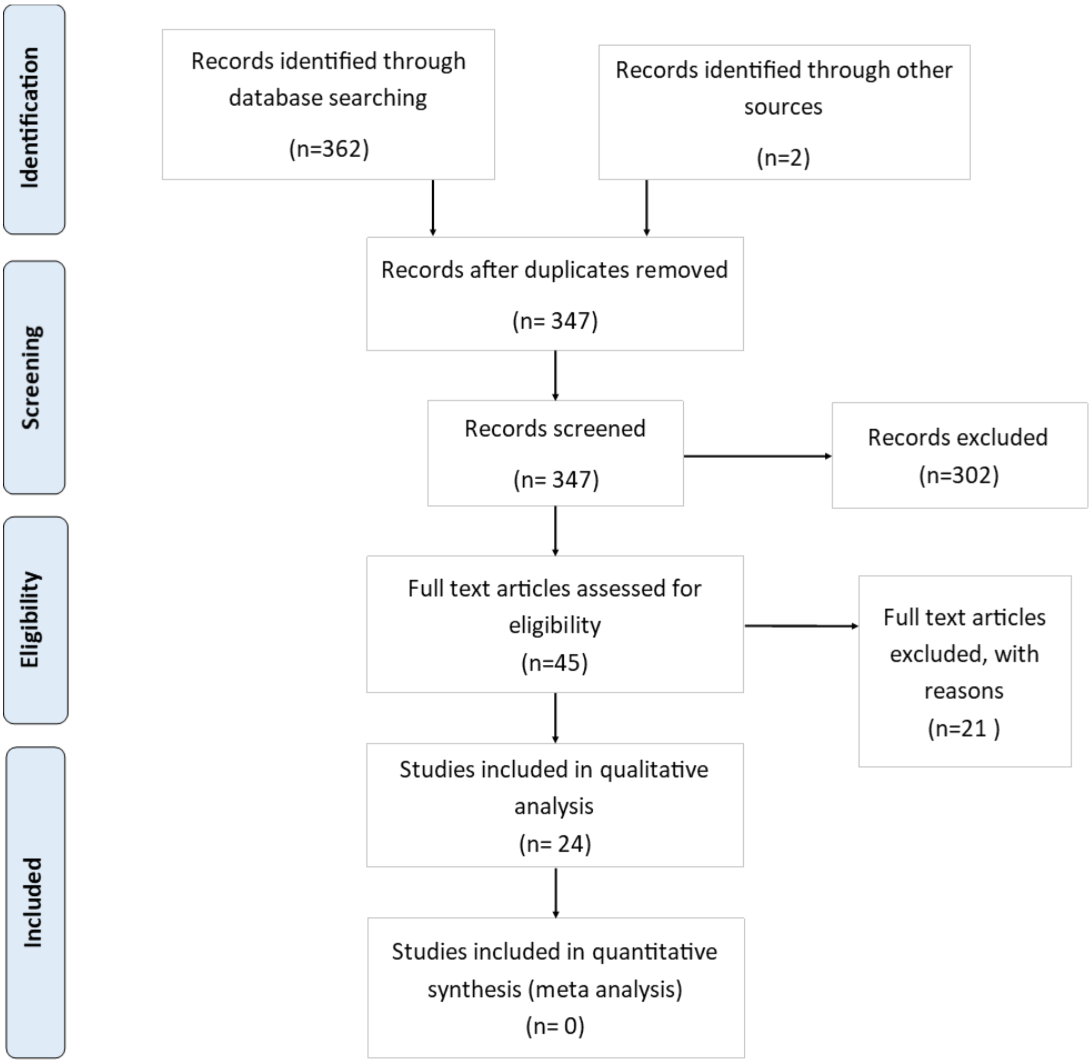


Figure 55-2: PRISMA diagram illustrating the study selection process.

5.2.3 Data extraction and synthesis

Data for each publication were extracted and entered into a reference manager system (Mendeley, Elsevier Inc, New York, NY 10169) and tabulated in Microsoft Excel (v.2002). Data were tabulated in order to prevent duplication of included studies. Quality assessment of included articles was conducted using the ''Critical Review Form for Quantitative Studies'' (Law et al, 1998). The quality of each publication was evaluated using 16 dichotomous items that were assigned a score of either 1 (fulfils criterion) or 0 (does not fill criterion) in accordance with published systematic reviews (Hobbs et al, 2020; Zadnikar & Kastrin, 2011). Explanation of each criterion can be viewed in Table 5-4. The scores were then totalled for each study and then calculated as a percentage. A score of >80% was considered as indicating excellent methodological quality. Due to a lack of homogeneity of the included articles, meta-analysis was not possible. Descriptive summary tables were thus used to synthesize results. The descriptive summary tables included the extracted data and quality score for each individual study (Appendix VIII).

Table 5-4: Quality scoring criterion in accordance with Hobbs et al (2020) and Zadnikarr & Kastrin (2011).

Quality Assessment Scoring Criteria	
Criterion 1	Purpose clearly stated
Criterion 2	relevant background literature reviewed
Criterion 3	design appropriate for study question
Criterion 4	absence of any bias (sampling, intervention or measurement) influencing results
Criterion 5	sample described in detail
Criterion 6	sample size justified[1]
Criterion 7	informed consent obtained
Criterion 8	outcome measures reliable[2]
Criterion 9	outcome measures valid
Criterion 10	intervention described in detail[3]
Criterion 11	results reported with statistical significance
Criterion 12	analysis methods appropriate
Criterion 13	significant differences between groups ~~clinically~~ meaningful
Criterion 14	conclusions appropriate from results
Criterion 15	implications of results influencing ~~clinical~~ practice reported[4]
Criterion 16	main limitations or biases of the study discussed

[1]A point was awarded for 'sample described in detail' if the authors described the horse's breed, sex and age. [2]Reliability and validity points were awarded if the authors clearly stated what time intervals and indices were used for HRV analysis. [3]None of the included articles were intervention studies. [4]A point was awarded here when the authors described how findings might be applied in equestrian practice.

5.3 Results

Due to noticeable variety between study designs, sample populations and methods of analysis, no meta-analysis was performed. Instead, studies are described with their findings, applicability and limitations.

Using the search strategy outlined in the methods section, 145 articles were retrieved from SCOPUS and 93 from VetMed. Two further articles were identified from the reference lists of relevant articles. Exclusion of duplicates and addition of articles identified from reference lists of relevant article s yielded 347 articles. Of these articles, 302 were excluded following title and abstract screening according to the predefined criteria outlined in the methods. Forty-five articles were selected for full text review, resulting in exclusion of a further 21 articles due to not meeting the inclusion criteria previously listed. A summary of the methodology used (including setting, HR/HRV indices analysed, HR/HRV time intervals analysed & other measures of stress/arousal used) as well as the main findings for included studies can be seen in Table 5-5. Key findings are formatted to highlight whether agreement was found between HRM devices and other data collection methods used, to enable appraisal of the validity of HRM devices for assessment of stress/arousal. For ease of scrutiny, agreement between HRM derived HRV and other measures of stress/arousal were categorised as: Unclear (not clear from results data presented), Poor (no agreement), Moderate (some agreement), Good (majority agreement) and Excellent (agreement across all indices).

A total of 421 subjects were involved in the included studies, with the largest study comprising of 60 subjects. Polar HRM devices were used in all articles, with a variety of models, including the S810i (n=14), RS800 CX (n=4), V800 (n=3), RS800 G3 (n=2) and the F810i (n=1). Many of the studies failed to give details of the model and type (electrode set or elasticated belt) of the sensor that was used to collect IBI data. Only two studies stated the brand and model of sensor used, these sensors were the Polar H2 Sensor (elasticated belt, n=1) and Polar Equine WearLink (elasticated belt, n=1). For some studies, it was possible to identify within the methods that Polar Elasticated Belts (model not stated, n= 4) and Polar Electrode Sets (model not stated, n=13) were used. For the remaining studies, it was not stated what type, model or brand of sensor was used (n=5).

5.3.1 Quality assessment

Quality scores applied to each criterion for all 24 publications can be seen in Appendix IX. A summary of the quality scores given, sample sizes, HRM device and sensor used by each study is displayed in Table 5-6. Mean ± SD (%) quality score was 78.1 ± 11.4. The overall quality of publications was good with 80% of studies achieving a score of >70%. The remaining 20% of studies all achieved a quality score of >50%.

Table 5-5: Details for each study.

#	Articles	Experiment (setting)	HR/HRV indices	HRV Time Interval (Analysis)	Other Measure(s)	Agreement	Details
1	*Lenoir et al. (2013)*	Validation during exercise test (ridden)	RR , HR, LF, HF, SDNN, RMSSD	5 Min	ECG	Poor	Only HR and RR showed agreement. For all other measures, agreement was inadequate
2	*Bohák et al. (2018)*	Pre-training and Pre-competition (ridden & at liberty in stable)	RMSSD, LF/HF	5 Min	Blood Cortisol	Moderate	Cortisol was significantly higher pre-competition ($p<0.001$). LF/HF was significantly higher pre-competition ($p=0.009$). RMSSD did not show significant difference ($p=0.96$).
3	*Villas-Boas et al. (2016)*	Startle test (loose exercise)	HR, LF/HF, LF, HF, PSD	64s	Blood Cortisol	Poor	Following the test, HR ($P=0.0101$), LF ($p=0.0002$) & LF/HF ($p=0.0066$) were higher. No significant changes in cortisol. Horses demonstrated flight response.
4	*Janczarek et al. (2019)*	Five exercise tests with varying presence/behaviour of an audience (ridden)	RMSSD, HR, LF, HF, LF/HF	16 Min (walk) 17Min (trot) 2 Min (canter) 20 Min (recovery)	Salivary Cortisol	Good	The measured factors and interaction between them were significant in the case of all parameters ($P < 0.01$). $P<0.05$ only for LF/HF.
5	*Schmidt et al. (2010)*	Before (loose in stable), during (during travel) and after transport (at liberty in stable)	RR, SDRR, RMSSD, SD1, SD2	30 Min	Salivary Cortisol	Moderate	On each 2-d transport cortisol increased significantly over time ($P< 0.001$). On the first day of outbound transport RR ($p<0.05$), SDRR ($p<0.05$), RMSSD ($p<0.01$), SD1 & SD2 ($P<0.01$) decreased significantly over time. For other days of transport, changes in HRV indices were varied.
6	*Schmidt et al. (2010b)*	12-week training plan (ridden & handling exercise)	SDRR, RMSSD, SD1, SD2	5 Min	Salivary Cortisol	Moderate	Cortisol concentration immediately after training was significantly correlated neither with the RR interval nor with HRV variables obtained during mounting of the horse by a rider. During the riding phase of the program cortisol was significantly correlated with RR ($p<0.01$), RMSSD ($p<0.05$), SD1 ($p<0.05$) and SD2 ($p<0.001$) but not SDRR.

Table 5-5: Continued.

#	Articles	Experiment (setting)	HR/HRV indices	HRV Time Interval (Analysis)	Other Measure(s)	Agreement	Details
7	*Kędzierski et al. (2017)*	Horses exposed to massage/music (at liberty in stable)	HR, LF/HF, RMSSD	10 Min Rest 10 Min Prep 10 Min Walking	Salivary Cortisol	Unclear	All of the relaxing methods influenced the studied parameters at various levels.
8	*Parker et al. (2010)*	Validation in three conditions (loose in field, at liberty in stable & stationary in stable)	VLF, LF, HF, Total, PNSI, SNSI, RMSSD, pNN50	512 consecutive IBIs	ECG	Moderate	Standing: significant effect of measurement type on RMSSD ($p<0.05$). Stable: significant effect of measurement type on RMSSD ($p<0.05$). Field: significant effect of measurement type on mean HR ($p=0.01$), RMSSD ($p<0.05$) & pNN50 ($p<0.01$). There was no significant effect of measurement type on frequency domain indices during any of the conditions.
9	*Ille et al. (2014b)*	Validation (at liberty in stable)	HR, RR, SDRR, RMSSD	1 Min 2 Min 5 Min 30 Min	ECG	Excellent	Correlations between RR interval, HR, and all HRV variables obtained with ECG and Polar HRMs were highly significant ($P< 0.001$) at all recording times. Pearson's coefficient of correlations was higher than 0.9 at all times.
10	*Becker-Birck et al. (2013)*	Dressage & show-jumping competition (ridden)	HR, SDRR, RMSSD	5 Min	Salivary Cortisol	Moderate	Cortisol concentrations increased significantly in response to each of the competitions ($p<0.001$). HR increased significantly in response to the competitions on all 3 days ($p<0.001$). No significant difference in SDRR in response to competition. RMSSD significantly decreased for competition and on competition day 2 only ($p<0.05$).
11	*Schmidt et al. (2010c)*	One hour journey in a van or trailer (during travel)	RR, SDHR, SDRR, RMSSD, SD1, SD2	30 Min	Salivary Cortisol	Good	With the onset of transport, salivary cortisol concentrations increased. With the onset of transport: SDHR increased ($p<0.05$) RR interval decreased ($p<0.05$), RMSSD decreased ($p<0.05$) & SD2 increased ($p<0.05$). SD1 did not change significantly.

Table 5-5: Continued.

#	Articles	Experiment (setting)	HR/HRV indices	HRV Time Interval (Analysis)	Other Measure(s)	Agreement	Details
12	*Becker-Birck et al. (2013b)*	Lunging in three head/neck variants: loose, close to vertical & behind vertical (handling exercise)	RR, SDRR, RMSSD	5 Min	Salivary Cortisol	Good	Lunging of horses in all three variants did not have any differential effect on cortisol release or HRV.
13	*Schmidt et al. (2010d)*	Horses transported over the same 200km journey four times (during travel)	RR, SDRR, RMSSD, SD1, SD2	30 Min	Salivary Cortisol	Moderate	Significant increase in cortisol concentrations occurred during each transport ($P<0.001$) at onset and over time. In response to onset of transport: RR interval decreased ($p<0.05$) SDRR increased ($P<0.05$). RMSSD, SD1 & SD2 did not significantly change in response to onset of transport.
14	*Von Lewinski et al. (2013)*	Performance and rehearsal (ridden)	HR, SDRR, RMSSD	1 Min	Salivary Cortisol	Moderate	In response to both the public performance and an identical rehearsal, cortisol ($P<0.001$) and HR ($p<0.001$) increased significantly. RMSSD decreased significantly for both public performance and rehearsal ($P<0.001$). SDRR did not change significantly in response to performance or rehearsal.
15	*Christensen et al. (2014)*	Standardised dressage test with three variations of head/neck position: loose, vertical & low, deep & round (ridden)	HR, RMSSD, LF/HF	9 Min	Salivary Cortisol	Good	The average HR, RMSSD and LF/HF did not differ between treatments.
16	*Ille et al. (2013)*	Standardised jumping course with different ability levels of horse/rider (ridden)	SDRR, RMSSD	1 Min	Salivary Cortisol	Good	Cortisol increased significantly during riding ($p<0.001$). SDRR & RMSSD decreased significantly during riding ($P<0.001$).
17	*Pasing et al. (2013)*	Stallion semen collection using dummy mare (handling exercise)	RMSSD	1 Min	Salivary Cortisol	Good	Heart rate significantly increased in response to semen collection ($P<0.001$). RMSSD & cortisol did not differ between days or change over time.

Table 5-5: Continued.

#	Articles	Experiment (setting)	HR/HRV indices	HRV Time Interval (Analysis)	Other Measure(s)	Agreement	Details
18	*Ille et al. (2014)*	Standardised jumping course in two variations: male rider, female rider (ridden)	SDRR, RMSSD	1 Min	Salivary Cortisol	Good	Cortisol increased significantly (P<0.001) in response to the task. SDRR and RMSSD decreased during walk and remained low during trot, canter and jumping (P<0.001). Sex of the rider did not affect cortisol, HR, SDRR and RMSSD of the horse.
19	*Squibb et al. (2018)*	Two novel handling tests (handling exercise)	SDRR	Not stated	IRT	Unclear	No significant findings reported.
20	*Wulf et al. (2013)*	Reduced-size microchip implantation (stationary)	HR, SDRR, RMSSD	1 Min	Salivary Cortisol	Poor	HR increased (P<0.01) at disinfection for microchip implantations and control treatments. SDRR increased at microchip and control treatments (P<0.05). No significant differences were found for RMSSD or cortisol.
21	*Ijichi et al. (2018)*	Novel tests with familiar or unfamiliar handler (handling exercise)	SDRR	Not stated	IRT	Good	No statistically significant difference in behaviour or any indicator of stress was found.
22	*Erber et al. (2013)*	Changes in husbandry over a period of 9 days (at liberty in stable)	SDRR, RMSSD	5 Min	Salivary Cortisol	Good	Cortisol differed significantly between days (P<0.001), and the most pronounced release occurred on the day of transfer to individual stalls. SDRR & RMSSD decreased immediately after individual stabling.
23	*Flaköll et al. (2017)*	Ear and Lip Twitching (stationary)	SDRR, RMSSD, HF, LF, LF/HF	5 Min (Early) 10 Min (Late)	Salivary Cortisol	Moderate	Early phase lip twitch = HR & LF/HF significantly decreased, RMSSD significantly increased. Late phase lip twitch = HR & LF/HF increased significantly, RMSSD & SDRR decreased significantly. Ear twitch (early & late phase): HR & LF/HF significantly increased & RMSSD & SDRR decreased. No significant change in cortisol for lip twitch. Ear twitch = cortisol significantly higher than baseline & control.
24	*Ijichi et al. (2019)*	Effects of calming supplement on loading (handling exercise)	SDRR, RMSSD	Not stated	IRT, Salivary Cortisol	Good	There were no significant differences in physiology between treatment and control.

Table 55-6: Article information including sample size, equipment used and their respective quality scores.

#	Articles	Sample	HRM Make & Model	Sensor Type	Quality Score
1	*Lenoir* et al *(2013)*	n=36	Polar S810i	Polar Electrode Set*	78.6
2	*Bohák* et al *(2018)*	n=8	Polar RS800CX	Polar H2 Sensor Belt	71.4
3	*Villas-Boas* et al *(2016)*	n=6	Polar RS800G3	Polar*	100
4	*Janczarek* et al *(2019)*	n=12	Polar RS800CX	Polar*	57.1
5	*Schmidt* et al *(2010a)*	n=7	Polar S810i	Polar Electrode Set*	78.6
6	*Schmidt* et al *(2010b)*	n=16	Polar S810i	Polar Electrode Set*	86.7
7	*Kędzierski* et al *(2017)*	n=60	Polar RS800CX	Polar*	60
8	*Parker* et al *(2010)*	n=6	Polar S810i	Polar Electrode Set*	78.6
9	*Ille* et al *(2014b)*	n=14	Polar S810i	Polar Electrode Set*	85.7
10	*Becker-Birck* et al *(2013)*	n=13	Polar S810i	Not Stated	73.3
11	*Schmidt* et al *(2010c)*	n=24	Polar F810i	Polar Electrode Set*	78.6
12	*Becker-Birck* et al *(2013b)*	n=16	Polar S810i	Polar Electrode Set*	85.7
13	*Schmidt* et al *(2010d)*	n=8	Polar S810i	Polar Electrode Set*	64.3
14	*Von Lewinski* et al *(2013)*	n=6	Polar S810i	Polar Electrode Set*	78.6
15	*Christensen* et al *(2014)*	n=15	Polar RS800CX	Polar Equine Wearlink Belt	85.7
16	*Ille* et al *(2013)*	n=16	Polar S810i	Polar Electrode Set*	80
17	*Pasing* et al *(2013)*	n=16	Polar S810i	Polar Electrode Set*	78.6
18	*Ille* et al *(2014a)*	n=8	Polar S810i	Polar Electrode Set*	73.3
19	*Squibb* et al *(2018)*	n=46	Polar V800	Polar Belt*	78.6
20	*Wulf* et al *(2013)*	n=12	Polar S810i	Not Stated	50
21	*Ijichi* et al *(2018b)*	n=46	Polar V800	Polar Belt*	85.7
22	*Erber* et al *(2013)*	n=8	Polar S810i	Polar Electrode Set*	85.7
23	*Flaköll* et al *(2017)*	n=12	RS800G3	Polar Belt*	86.7
24	*Ijichi* et al *(2019)*	n=10	Polar V800	Polar Belt*	85.7

*no further details provided

5.3.2 Agreement between HRM and ECG data

A total of three studies that were conducted in order to validate HRM devices using ECG were included in this review. All of which tested the Polar S810i (Ille et al, 2014b; Lenoir et al, 2017; Parker et al, 2010). Overall, agreement between ECG and HRM derived HRV data was varied and was dependent on a variety of factors including time intervals, movement of the subjects and the HRV indices used. None of the validation studies stipulated what type of sensor was used to collect the HRM data from the horses, but it appears from the study methods that they all used a Polar electrode set, with the particular model not stated.

Lenoir et al (2017) collected data for 36 ridden horses during a standardised exercise test including a warm-up (walk and trot) and canter. The study reported that agreement between the ECG and HRM data was poor (LF, HF, SDNN, RMSSD), with exception of HR and RR-interval indices.

Parker et al (2010) conducted a study to test agreement between HRM and ECG data in three different test conditions: loose in the field, at liberty in the stable and standing still in the stable. Results demonstrated that during standing, there was no significant difference between IBI, HR, and pNN50 however RMSSD was significantly different ($p<0.02$) between uncorrected and corrected Polar data (no difference between Polar and ECG). Pairwise comparisons for 'during standing' indicated a closer agreement between uncorrected than corrected Polar data and ECG. During 'liberty in the stable', only mean RMSSD resulted in a significant difference ($p<0.05$) between corrected and uncorrected Polar, but not ECG. Pairwise comparisons for 'liberty in the stable' indicated a closer agreement between corrected than uncorrected Polar data and ECG. During 'loose in the field' significant differences for measurement type were found for mean HR ($p=0.01$), RMSSD ($p<0.05$) and pNN50 ($p<0.01$) (between all measurement types). Pairwise comparisons indicated that corrected Polar data had closer agreement to ECG than uncorrected Polar data. Overall, corrected Polar data showed closer agreement to ECG than uncorrected Polar data, however during standing and 'at liberty in stable' settings the Polar devices demonstrated good agreement with ECG.

Ille et al (2014b) study demonstrated a strong agreement between Polar and ECG recording systems. The study collected data from 14 stationary, non-restrained horses. Results reported significant correlations between RR-interval, HR, SDRR and RMSSD ($p<0.001$). The study included comparisons between the two recording systems for intervals of one, two, five and 30 minutes, with significant correlations for all recording times ($p<0.001$). Although all recording times were significantly correlated, Ille et al (2014b) reported that the strength of correlation increased with increasing recording time (i.e. recording interval of 30 minutes exceeded 0.99 for all determined parameters).

5.3.3 Agreement between HRM and other methods of stress/arousal assessment

For the remaining 21 studies, stress/arousal measures included alongside HRM derived HR/HRV data included salivary cortisol (n=17), IRT (n=3) and blood cortisol (n=2), with three studies using more than one of these additional measures.

Agreement of HRM derived HR/HRV and salivary cortisol was varied. The majority of studies (75%) demonstrated 'Good' (n=10) and 'Moderate' (n=8) agreement between HRV and other measures of stress/arousal. The remaining studies were categorised as demonstrating 'Poor' (n=3), 'Unclear' (n=2) or 'Excellent' (n=1) agreement. Regarding studies categorised as demonstrating 'Good' agreement between HR/HRV and other measures, 81.8% measured salivary cortisol and 18.2% measured IRT (core temperature - eye). For studies categorised as 'Moderate', 75% measured salivary cortisol, 12.5% measured blood cortisol and 12.5% measured ECG alongside HRM derived HR/HRV. Studies categorised as demonstrating 'Poor' agreement used blood cortisol (33.3%), ECG (33.3%) and salivary cortisol (33.3%). Lastly, studies categorised as 'Unclear' measured IRT (50%) and salivary cortisol (50%) in combination with HRM derived HR/HRV.

5.3.4 Study setting

The majority of studies included data collection within a ridden exercise setting (n=9), with the remainder of study settings including handling/loose exercise (such as lunging, startle test at liberty in arena, semen collection and loading on to transport) (n=8), at liberty in stable (n=6), during transport (n=4) and stationary (n=2). Finally, one study (n=1) included data collection while horses were loose in the field.

For studies carried out in a ridden exercise setting, 44.4% were categorised as demonstrating good agreement between HR/HRV indices and other measures of stress/arousal, 44.4% moderate agreement and 11.1% poor agreement. Studies that were carried out in an unridden exercise setting were categorised as 66.7% good agreement, 16.7% poor agreement and 16.7% agreement unclear. Studies carried out during transport were categorised as 66.7% moderate agreement and 33.3% good agreement. For studies that involved the subjects at liberty in the stable, 33.3% were categorised as good agreement, 33.3% excellent agreement and 33.3% agreement unclear. Studies that carried out measurements with the subjects in a stationary setting were categorised as 50% moderate agreement and 50% poor agreement. The final study which took measurements in three settings of loose in field, at liberty in stable and stationary in stable was categorised as showing moderate agreement between HR/HRV indices and other measures of stress/arousal.

5.4 Discussion

There are only three studies included in this review that tested the reliability of data derived from HRM devices in comparison to the gold standard ECG, therefore these are the only studies included that can offer an entirely objective view of the precision of IBI data obtained from HRM devices. These studies use a variety of methods in relation to the study setting, HR/HRV indices used, equipment and statistical analysis. Due to the limited research available that investigates the validity of HRM devices against the gold standard of ECG, this review was designed to include studies that measured other validated measures of stress/arousal. It is proposed that if the HR/HRV findings are in agreement with other objective measures of stress/arousal then this will provide an indication of the reliability of HRM devices for the assessment of stress/arousal in horses.

5.4.1 HR/HRV Indices

5.4.1.1 Heart rate

HR represents the frequency of the cardiac cycle, reflecting the number of contractions in a given unit of time (usually one minute; expressed as beats per minute) (Watson, 1983). Parker et al (2010) reported that HR as obtained by HRM devices demonstrated acceptable agreement with ECG in both stationary and at liberty in the stable settings. Poor agreement was found for HR data collected whilst subjects were at liberty in a field (Parker et al, 2010). Findings reported by Ille et al (2014b) were in agreement with Parker et al (2010), with simultaneous recordings from HRM and ECG demonstrating good agreement for HR values whilst subjects were at liberty in individual stables. Lenoir et al (2017) expanded on the findings reported by Ille et al (2014b) and Parker et al (2010) by carrying out a study to compare HRM and ECG data in ridden, exercising horses. HR demonstrated good agreement between ECG and HRM in a warm-up phase which included walk and trot, with decreased (poor) agreement within the canter phase (Lenoir et al, 2017). The findings of these studies indicate that HRM devices are a consistently valid tool for assessment of HR in horses during non-exercising settings, and that the devices can also obtain reliable data during some ridden exercise settings (walk and trot).

Increased HR is a normal physiological response to exercise (indicating sympathetic activity) (Taelman et al, 2008). As such, HR is a valuable tool for consideration of exercise intensity in horses (Vincent et al, 2006). Considering the literature, HRM devices may be a useful alternative tool to ECG in this context (for exercise paces up to a speed of trot). However, HR analysis has minimal value as an independent measure in the context of stress/arousal assessment. For example, an increase in HR can be a result of a reduction in parasympathetic nervous system (PNS) activity as well as an increase in sympathetic nervous system (SNS) activity, however it is most often caused by a combination of simultaneous changes in activity from both of these systems (von Borell et al, 2007). The balance between PNS and SNS activity is complex, and while HR offers an overview of the effects of these components it is of limited use for accurately assessing sympathovagal regulation in particular (von Borell et al, 2007). For this reason, it is difficult to assess the validity of HR measured in non-validation studies within this review (due to lack of comparable data from an ECG, for example). Additional research is needed to confirm the reliability of HRM devices in exercise settings (using ECG) as the available literature that include exercise in their study design for this purpose is currently limited.

5.4.1.2 Time domain indices

5.4.1.2.1 RR-interval

RR-interval is the time elapsed between two successive R-waves of the QRS complex as expressed on an ECG (von Borell et al, 2007). RR-interval reflects the activity of the sinus node and the autonomic nervous system (Lanfranchi & Somers, 2010). Ille et al (2014b) reported that simultaneous recordings from HRM and ECG demonstrated strong agreement for mean RR-interval of non-exercising horses (at liberty in stable) which presented near identical values. Lenoir et al (2017) reported that mean RR-interval demonstrated good agreement between HRM and ECG during the warm-up phase of ridden exercise (walk and trot), but poor agreement during canter. The study by Lenoir et al (2017) supports and expands upon the findings reported by Ille et al (2014b), as it was demonstrated that HRM derived RR-interval data is not only reliable in a non-exercising setting, but also during a ridden exercise setting. It is however difficult to make firm conclusions for the validity of RR-interval data as obtained by HRM devices as there is limited literature available. Parker et al (2010) did not include RR-interval in their study. Regardless, considering the literature that is available it appears that RR-interval as obtained by HRM devices is reliable in some settings such as horses that are at liberty in the stable, and horses ridden in walk and trot. Further research is needed to enable more definitive validation.

Four other studies included in the review (Becker-Birck et al, 2013b; Schmidt et al, 2010a, c, d) included RR-interval in their analysis however it would not be appropriate to draw conclusions on the validity of this calculation from these studies as a decrease (for example) in RR-interval is reported to indicate increased SNS activity, decreased PNS activity, or a combination of both (Hainsworth, 1995; Schmidt et al, 2010d), thus it would be difficult to draw conclusions on RR-interval in combination with other measures of stress/arousal such as cortisol.

5.4.1.2.2 RMSSD

The root mean square of successive differences between normal heartbeats (RMSSD) reflects the beat-to-beat variance in HR and is used to estimate PNS activity (vagal tone) (Shaffer et al, 2014). An increase in RMSSD indicates a shift toward PNS activity, therefore it will be increased in more relaxed individuals and decreased in less-relaxed individuals (Schmidt et al, 2010a). Previous studies have advised that RMSSD is one of the most informative parameters to reflect short-term PNS activity, and thus is recommended for analysis of five-minute, one-minute, 30-second or ten-second intervals (Shaffer & Ginsberg, 2017; von Borell et al, 2007).

Parker et al (2010) reported that RMSSD had poor agreement between simultaneously recorded HRM and ECG data for all settings included in the study. However, on closer assessment of the results for ‘stand’ and ‘stable’ settings presented, it appears that the significant differences relate to uncorrected

HRM data compared with corrected HRM data, as opposed to HRM data in comparison to ECG data (Parker et al, 2010). This indicates that there was in fact no significant difference between RMSSD as obtained by HRM or ECG during 'stand' or 'stable' setting (Parker et al, 2010). RMSSD values presented within the Parker et al (2010) study also include large SD values for all measurement types which, in combination with a sample size of only six horses indicates that the data should be interpreted with caution. Nevertheless, the study findings appear to indicate that HRM devices can be a valid tool for measurement of RMSSD during 'stand' and 'stable' settings (Parker et al, 2010). In contrast, the findings for the 'field' setting report significant differences between HRM (uncorrected) and ECG data, indicating that this setting may not be suitable for obtaining reliable RMSSD data from a HRM (Parker et al, 2010). Ille et al (2014b) reported that simultaneous recordings from HRM and ECG demonstrated excellent agreement for RMSSD, with no significant difference between the recording systems at any time. Correlations for RMSSD were also highly significant at all recording times (Ille et al, 2014b). Furthermore, Bland-Altman analysis confirmed that the two measurement types were within acceptable range of the 95% confidence intervals (Ille et al, 2014b). The findings reported by Ille et al (2014b) offer evidence that HRM devices are a valid tool for measuring RMSSD in non-exercising horses. The study demonstrates a higher level of academic rigour in the clear presentation of findings, in comparison to Parker et al (2010), and offers a larger sample size, indicative that the results may be more reliable. Lenoir et al (2017) found no acceptable agreement between RMSSD values obtained from ECG and HRM devices for any of the conditions tested. The study by Lenoir et al (2017) consisted of an exercise test including a warm-up of walk and trot, a canter phase, and a gallop phase. The evidence presented by this study, and the findings of Ille et al (2014b) and Parker et al (2010) indicate that HRM devices are a valid tool to collect RMSSD data from horses at rest, but are not suitable for collecting RMSSD data during exercise.

Of the non-validation studies within this review (n=21), 86% included calculation of RMSSD within their analysis, indicating that this is a prevalent choice when considering HRV analysis in horses. This is supported in recent studies into the validity of HRV indices in humans. For example, Thomas et al (2019) found that RMSSD performed well as a marker of vagal activity when subjects partook in tests that required breathing changes, indicating that this measure may be the most reliable during exercise/arousal situations. Many of the studies within this review include testing conditions whereby the horse is moving/exercising or arousal (and thus a change in breathing rate) may be prompted, such as travelling (Schmidt et al, 2010a, b, c, d), semen collection (Pasing et al, 2013), novel handling/startle tests (Ijichi et al, 2018b; Squibb et al, 2018; Villas-Boas et al, 2016), ridden exercise (Becker-Birck et al, 2013; Bohak et al, 2018; Christensen et al, 2014; Ille et al, 2013, 2014a; Janczarek et al, 2019; Lenoir et al, 2017; Schmidt et al, 2010b; Von Lewinski et al, 2013) and during procedures such as twitching (Flakoll et al, 2017) and microchip implantation (Wulf et al, 2013); which are all likely to affect breathing rate of subjects.

The majority of studies which included RMSSD obtained from HRM devices within their analysis found good agreement with this measure of HRV in comparison to other measures of stress/arousal. Janczarek et al (2019) investigated horse and rider reaction to variance in the presence and behaviour of an audience and found that Salivary Cortisol (SC) was significantly higher during the 4th research variant whereby the audience was increased in number and were required to move around and talk. The authors found that RMSSD was in agreement with SC, with this value being significantly lower in the 4th research variant than all other variants of the study (during walk and trot). Additionally, Schmidt et al (2010c) reported that horses who travelled for one-hour had significantly lower SC than horses who travelled for three-, or eight- hours. The study also reported that RMSSD was significantly lower for horses travelling for one-hour in comparison to horses who travelled for three-, or eight-hours, in agreement with the SC findings (Schmidt et al, 2010c). Furthermore, Von Lewinski et al (2013) investigated whether SC or HRV parameters differed for horses being ridden in a public versus a rehearsal performance. They found that RMSSD significantly decreased during both activities in agreement with SC which significantly increased in response to the activities (Von Lewinski et al, 2013). Alternatively, some studies have demonstrated agreement between HRM derived RMSSD and SC by finding no significant differences for either measure; Ijichi et al (2019) found no significant differences in RMSSD or ocular (eye) surface temperature (IRT) for horses who were loaded on to a trailer with and without a calming supplement. An earlier study by Ijichi et al (2018b) also found no significant differences in RMSSD, IRT or SC for horses' response to a familiar and unfamiliar handler during novel object tests. The findings discussed here suggest that RMSSD derived from HRM devices can be reliable in representing change in (or lack of) stress/arousal in horses. Some studies however do not report agreement between SC and RMSSD; Bohak et al (2018) found elevated SC in horses on the morning of a competition (versus mornings that entailed training only), indicating an anticipatory response from horses, which was attributed to the horses witnessing familiar procedures on the yard associated with competition days. The authors found no significant change in RMSSD pre-competition however, which could reflect lack of validity of this measure when derived from HRM devices (Bohak et al, 2018). Findings from Christensen et al (2014) study also demonstrated poor agreement between RMSSD and SC, whereby SC was significantly higher when horses were ridden in a low, deep and round head/neck position in comparison with a loose frame (loose reins); there was no significant difference in RMSSD for these conditions. Considering the findings of the validation studies (Ille et al, 2014b; Lenoir et al, 2017; Parker et al, 2010) it could be presumed that the RMSSD calculations within Christensen et al (2014) study may have been affected by the horses being exercised (ridden), however other studies that found agreement between SC and RMSSD included horses who were being ridden (Janczarek et al, 2019; Von Lewinski, 2013). It may be that RMSSD calculated from HRM derived data during exercise does not sufficiently correlate with ECG to produce accurate identification of values but does typically reflect directional change (i.e. increase or decrease of PNS activity). Thus, for studies which aim to quantify whether certain situations are more or less stressful than one another, the parameter is suitable if derived from HRM devices. The literature also suggests that RMSSD is reliable when data has been obtained with subjects in a stationary setting, thus it is recommended that RMSSD is calculated from HRV data which has been obtained from HRM devices whilst subjects are in stationary conditions, for the best chance of reliable data. This reliability of this parameter may also be affected by the time-period that is used for analysis; this is considered in section 5.4.2.3.1.

5.4.1.2.3 SDNN

The standard deviation of the IBI of normal sinus beats (SDNN) removes 'abnormal' beats (heartbeats that are outside the right atrium's sinoatrial node). Like RMSSD, SDNN reflects PNS activation, however SDNN is more accurate for long term measures (24 hours) (Shaffer & Ginsburg, 2017). A higher SDNN value indicates a shift towards PNS activity, thus lower SDNN values indicate increased stress/arousal. Of the studies included within this review, Lenoir et al (2017) was the only study to include analysis of SDNN. Lenoir et al (2017) found no acceptable agreement between SDNN collected from ECG and HRM devices. The study tested the devices during exercise, indicating that HRM devices are not suitable for collecting SDNN data during exercise. Considering the findings of the other validation studies which have most often reported good agreement between the two devices at rest (Ille et al, 2014b; Parker et al, 2010), it would be beneficial for future studies to analyse SDNN data collected at rest between ECG and HRM to enable evaluation of agreement of this component between the two devices in resting conditions.

5.4.1.2.4 SDRR

The standard deviation of the IBI's for all sinus beats (SDRR) includes abnormal/false beats (as opposed to SDNN which removes them). As with SDNN, SDRR is more accurate for longer time-periods such as 24 hour recordings (Shaffer & Ginsberg, 2017) and lower values of this parameter indicate a shift towards SNS activity, although this parameter is affected by both the SNS and PNS. Some studies have stated that time intervals of five-minutes can be utilised for analysis of SDRR, however should still be considered as a reflection of long-term variability of cardiac activity even in this context (von Borell et al, 2007). Ille et al (2014b) was the only validation study included in this review that included SDRR. The study reported good agreement between ECG and HRM data for the parameter SDRR, indicating that SDRR measured by HRM is reliable in horses whilst loose in boxes (non-restrained but non-exercising).

Becker-Birck et al (2013b) investigated the effect that three different head and neck positions had on the acute stress of 16 German sport horses during lunging. The authors reported that SC significantly increased during the warm-up phase of lunging and further increased when side reins were attached to the horse and the experimental phases began (Becker-Birck et al, 2013b). They also found comparable findings for the HRV parameter SDRR which was calculated from HRM derived HRV data, however the parameter only significantly decreased during the experimental phase of two of the head and neck positions as opposed to all three, thus their findings found moderate agreement between SC and SDRR (Becker-Birck et al, 2013b). Von Lewinski (2013) conducted a study to identify whether stress response of horses differed between a training session and a public performance. They found that SC increased significantly (from baseline) in response to both the public performance and identical training session, however, SC did not differ significantly between the training session and the public performance. In contrast, SDRR did not change significantly in response to either activity (from baseline) and also did not differ dependent on whether it was a training session or a public performance. The inconsistency in SDRR results within Becker-Birck et al (2013) and Von Lewinski et al (2013) studies (regarding agreement with SC) could be explained by Ille et al (2014b) findings whereby SDRR obtained from HRMs was correlated with ECG, but only in resting conditions. Lunging/riding horses may create too much movement; the study by Becker-Birck et al (2013b) included walk, trot and canter for horses during lunging and the study by Von Lewinski et al (2013) consisted of horses completing 'airs above the ground' movements in which the horse leaves the ground, which may have interfered with the quality of the HRV recordings that were obtained using HRM devices. Erber et al (2013) also included SDRR within their study which investigated the stress response of horses after moving from grouped housing to individual stables. They found that SC significantly increased on the days where horses were moved from group housing to individual stables, however SDRR did not demonstrate any significant difference between any days.

Becker-Birck et al (2013b) and Erber et al (2013) utilised five-minute intervals for HRV analysis and Von Lewinski et al (2013) utilised one-minute intervals, which may not be suitable for analysis of SDRR. Authors have previously advised that SDRR be used for analysis of long-term variability in HRV, such as 24 hours (Schmidt et al, 2010b; Shaffer & Ginsberg, 2017). This could have contributed to the lack of agreement between SC and SDRR in the studies considered here. In consideration of the findings within this review, it is advised that SDRR is used for long-term analysis of autonomic nervous system activity and that if HRM devices are used to obtain this data then horses should be in non-exercising conditions.

5.4.1.2.5 pNN50

The percentage of adjacent NN intervals that differ from each other by more than 50 ms (pNN50) is indicative of PNS activity; pNN50 can be used for short-term recordings but RMSSD offers a better assessment of Respiratory Sinus Arrythmia (RSA), so is often the favoured parameter to use. RSA is the speeding and slowing of the heart by the vagus nerve (PNS), which results from respiration (HR speeds up during inhalation and slows down during exhalation) (Karemaker, 2009).

Parker et al (2010) was the only study included in this review that included pNN50, reporting no significant main effects of measurement type (ECG/HRM) on pNN50 in horses during a stationary (restrained) or loose (stable) setting. Significant main effects were found when data was recorded from horses loose in a field (Parker et al, 2010). These findings indicate that the parameter pNN50, as derived from HRM data is reliable when horses are restrained or loose in a stable, but are not acceptable when subjects were loose in a field, indicating that movement of the subjects significantly affects the accuracy of pNN50 as derived from HRM devices. The authors did not state the activities of subjects whilst in the 'loose in field' condition however (Parker et al, 2010), thus it would be beneficial for future validation studies to consider the reliability of this parameter in controlled exercise settings such as walk, trot and canter.

5.4.1.3 Frequency domain indices

5.4.1.3.1 VLF

It is not currently well understood which physiological mechanisms are responsible for changes within very-low-frequency (VLF) (Shaffer & Ginsberg, 2017), however it has been reported that the SNS influences the amplitude and frequency of this band (Shaffer et al, 2014). Parker et al (2010) were the only study within this review to analyse this parameter, finding no significant differences of measurement type (ECG/HRM) on the parameter VLF in any of the testing conditions, indicative that this parameter may be reliable when obtained from HRM data. Further research is needed to confirm as the study by Parker et al (2010) was the only one to assess this parameter and the study was limited in sample size (n=6).

5.4.1.3.2 LF, HF and LF/HF ratio

The low-frequency band (LF) is affected by both the SNS and the PNS (Shaffer & Ginsberg, 2017; Task Force, 1996; von Borell et al, 2007), which makes biological explanation of this parameter a challenge. Previous studies are contradictory in their explanation of LF; for example, Rietmann et al (2004) and Bachmann et al (2003) stated that LF reflects mainly SNS activity, in that a decrease in this parameter indicates increased SNS activation. In contrast, Ohmura et al (2001) and von Borell et al (2007) state that LF is affected by both the PNS and the SNS. Pharmacological blockade of PNS in horses has revealed that LF is indeed affected by both the PNS (Ohmura et al, 2001) and the SNS (Kuwahara et al, 1996). Due to the LF parameter being affected by both PNS and SNS the results of studies that include this variable along with indicators of SNS activity such as SC will not be discussed relevant to how reliable this parameter is as obtained by HRM devices.

The high frequency band (HF) is widely accepted to reflect PNS activity in mammals (Després et al, 2002; Shaffer & Ginsberg, 2017; von Borell et al, 2007), whereby an increase in this parameter indicates a rise in PNS activity. HF corresponds with HR variations seen in response to the respiratory cycle, indicating that this parameter represents RSA and is not a sole reflection of cardiac vagal (PNS) control (Grossman & Taylor, 2007). It is therefore imperative that respiration rate is considered when utilising this HRV parameter (von Borell et al, 2007).

Villas-Boas et al (2016) conducted a startle test on six Brazilian sport horses and found a significant decrease in HF but no significant difference in Blood Cortisol (BC) in response to the stimuli (abrupt opening of umbrella). Blood was taken at 30 and 60 minutes after the startle test for BC analysis whereas the significantly low value of HF was found immediately after the test had occurred, which could be why the two measures do not appear to be in agreement (Villas-Boas et al, 2016). In fact, the HF recorded 30-minutes after the startle test appears to demonstrate a significantly higher value than immediately after the startle test, indicating that the horses have recovered and there has been a shift back towards PNS activity (in agreement with the lack of significant change in BC, 30 minute post-startle test) (Villas-Boas et al, 2016). It is not entirely clear from the study results whether this is the case however, as the labels on the figures do not match the symbols/explanations given in the figure label (Villas-Boas et al, 2016). Flakoll et al (2017) stated that they calculated LF and HF within their study however there does not appear to be any results provided for these measures with only the LF/HF ratio results stated. Janczarek et al (2019) found that HF was significantly lower when horses were ridden at walk in front of a walking and talking audience (in comparison with no audience, a silent audience, an audience who were stationary but were talking and an audience that were silent but walking). This finding is in agreement with the SC values within the same study, whereby SC was significantly higher during the exercise whilst the audience was walking and talking, indicating that this condition provoked the most heightened stress response in horses (Janczarek et al, 2019). The SC value encompasses the entire exercise condition however (SC taken just before the cool-down walk, after the horses had walked, trotted and cantered), whereas the HRV calculations were taken during each individual pace (i.e. walk, trot and canter), thus the results are not directly comparable (Janczarek et al, 2019). Additionally, the HF results during trot and canter are more varied than for during walk which may indicate lack of validity of the data during these paces, in consideration of the findings of previous validation studies which found poor agreement between HRM and ECG in conditions where subjects were exercising/moving (Ille et al 2014b; Lenoir et al, 2017).

For studies that investigated validity of HRM devices, Parker et al (2010) showed no significant differences of measurement type (ECG/HRM) on the parameters LF or HF in any of the testing conditions (standing, stable and field). Lenoir et al (2017) found some agreement between LF and HF obtained from ECG/HRM data during a 'warm-up' stage but overall, agreement was inadequate. In consideration of the findings from studies included within this review, the agreement between ECG/HRM is affected by the setting at which they are obtained, namely the amount of movement from the horse. LF and HF may be suitably valid from a HRM in stationary or steady (e.g. loose in a field or during ridden walking) exercise, but the evidence that is currently available indicates that the data is not reliable when recorded during exercise at speeds faster than trot.

Previous studies into methods of measuring HRV in horses have suggested using the LF/HF ratio to measure SNS activity, with an increase in the LF/HF ratio reported to be associated with a shift towards SNS dominance (Stucke et al, 2015; von Borell et al, 2007). Bohak et al (2018) reported that baseline LF/HF was significantly higher in horses on the morning of competition compared with the morning of a training day, the authors also reported that SC was significantly higher on the morning of competition days, thus the measures were in agreement that horses were exposed to anticipatory stress on the morning of competition days. Villas-Boas et al (2016) found that the LF/HF ratio significantly increased in horses immediately after a startle test (abrupt opening of umbrella) however no significant differences were found for BC. As previously mentioned, there were discrepancies in the time point at which HRV and BC were analysed (immediately after startle, and 30-minutes after startle, respectively), which could explain why the two measures were not in agreement within this study (Villas-Boas et al, 2016). Flakoll et al (2017) investigated the response of 12 horses to two different twitching procedures which were administered for ten-minutes each. The authors found that during lip twitch, the LF/HF ratio of horses was significantly lower than baseline during the first five-minutes of the procedure, but significantly higher than baseline in the secondary five-minutes of the procedure, indicating a trend towards SNS activation, however no significant change in SC in response to the procedure were noted (Flakoll et al, 2017). For the ear twitch condition, the authors found a significant increase in the LF/HF ratio in comparison with baseline for the entire ten-minute procedure, they also found that SC was significantly higher in response to this procedure (Flakoll et al, 2017). The findings of Flakoll et al (2017) demonstrate moderate agreement between HRM derived LF/HF and SC. Regarding the results of the lip twitch procedure, it could be that the stress response in the horse was so short-lived or to such a small degree that it was undetectable in SC analysis (Flakoll et al, 2017). Furthermore, research into SC analysis in cows has reported that there is a ten-minute time lag between peak cortisol concentrations in plasma and saliva (Hernandez et al, 2014), which may highlight the necessity to delay SC collection after exposure to potential stimuli. Flakoll et al (2017) collected saliva from horses within their study immediately after the procedure, which could have affected the results seen in their analysis of SC. Alternatively, the HRM data may have contained errors which resulted in a spurious finding. Nonetheless, the findings for the ear twitch condition are in agreement (regarding SC and LF/HF), which adds merit to the validity of LF/HF analysis from HRM derived HR/HRV data.

Recent studies in humans have suggested that LF, HF and LF/HF are poor measures of SNS activity as they do not correlate with electrodermal activity (Thomas et al, 2019), which is a reliable quantifier of SNS activity (Ghiasi et al, 2020). It is valuable to apply the findings from studies on humans to other mammals such as horses due to comparable control of vagal tone (PNS) and neural modulation of emotional response across all Mammalia (Mott et al, 2020; von Borell et al, 2007). Furthermore, these measures are influenced by the respiratory rate of the species, therefore respiratory rate should be considered when selecting the power for assessment of these HRV indices. For example, von Borell et al (2007) recommend that for horses, the frequency bands for HF should be set at 0.13 to 0.26 Hz (which corresponds to a respiratory rate of eight to sixteen breaths per minute). The recommendation by von Borell et al (2007) highlights that respiration rate should be controlled for when utilising these HRV parameters, and the frequency bands should be altered as such. Lenoir et al (2017) utilised a HF power frequency band of 0.07-0.6 Hz as recommended by Kuwahara et al (1996), however this recommendation followed a study where subjects were resting in a stable; in contrast, Lenoir et al (2017) recorded data from horses during exercise. It is reasonable to assume that the breathing rate of horses during exercise would be different to horses during rest, therefore this method may have affected the validity of Lenoir et al (2017) findings. There is currently a lack of literature on which frequency bands are appropriate for horses during different intensities/speeds of exercise. For the reasons discussed here, LF, HF and LF/HF should be used with caution when attempting to assess stress/arousal in horses.

5.4.1.3.3 Total, PNSI and SNSI

The results for studies that includes Total, PNSI and SNSI are in agreement, so they will be discussed simultaneously here. Total power (Total) is the sum of the energy in all other frequency bands (Shaffer & Ginsberg, 2017). Parasympathetic nervous system indicator (PNSI) (HF/total power) is used to quantify vagal activity (von Borell et al, 2007) and SNS indicator (SNSI), also known as the LF to HF ratio, is used to reflect sympathetic activity (von Borell et al, 2007).

Parker et al (2010) found no significant differences of measurement (ECG/HRM) on the parameters Total, PNSI or SNSI in any of the testing conditions (standing, stable and field), indicating that HRM devices are reliable for recording data to be used for these parameters in the above settings. The authors do warn however that the lack of significant differences found for frequency domain indices (VLF, LF, HF, Total, PNSI and SNSI) may not necessarily mean that the recording systems are equivalent, due to the highly sensitive nature of frequency domain indices (Parker et al, 2010). No other studies included within this review analysed any of these HRV parameters.

5.4.1.4 Non-linear measures

5.4.1.4.1 SD1 and SD2

Two non-linear measurements are included in the studies within this review: SD1 and SD2. SD1 has previously been shown to be closely correlated to RMSSD (Ciccone et al, 2017) and SD2 has been shown to closely correlate with SDNN (Guzik et al, 2007; Mott et al, 2020).

SD1 is said to represent instantaneous (short-term) changes in PNS activity; a decrease in this parameter reflects reduced PNS activity (Schmidt et al, 2010c, d; von Borell et al, 2007). For studies utilising HRM devices to obtain HRV data; Schmidt et al (2010b) assessed stress in horses during a 12-week training schedule and reported that SD1 decreased in comparison to baseline during lunging. The authors also found that SC significantly increased in response to lunging on two occasions (out of nine in total), when compared with the first day that a rider mounted the horses (Schmidt et al, 2010b), indicating some agreement between SD1 and SC, however the results were inconsistent. Schmidt et al (2010c) reported that SC was significantly higher in horses travelling for eight-hours as opposed to horses travelling for one-, or three and a half-hours. Results for SD1 were partially comparable, with the parameter being significantly lower for horses travelling for eight, and three and a half hours in comparison to horses travelling for just one hour (Schmidt et al, 2010c), suggesting that travelling for one hour was the least stressful condition for horses. Furthermore, Schmidt et al (2010d) also analysed SD1 and found no clear changes in the parameter over time whilst horses were transported over a 200km route (approximately four-hours of travel) on four separate occasions. In contrast, the SC of horses significantly increased with each successive journey (Schmidt et al, 2010d). The studies that included SD1 obtained by HRM devices show inconsistent agreement with SC, indicative that this parameter may not be reliable when obtained as such. This is supported by validation studies, for example, Lenoir et al (2017) reported poor agreement for SD1 between data recorded from ECG and HRM, indicating that HRM derived data is not reliable for calculation of this measure. It is however important to note that Lenoir et al (2017) study only included conditions whereby the subjects were being exercised (ridden), thus it would be beneficial for future validation studies to assess this parameter from HRM data obtained at rest.

SD2 is said to reflect long-term variability (minimum of five-minute recordings) and reflects SNS activity (von Borell et al, 2007). An increase in this parameter reflects activation of the SNS (Schmidt, 2010c; von Borell et al, 2007). Schmidt et al (2010a) assessed the stress response in horses on a two-day outbound journey and a two-day return journey seven days later. The study reported that SD2 (obtained from HRM derived data) increased significantly in horses on the first hour of both the outbound and return journey. They also found that SC significantly increased on each two-day transport, although this measure increased further at mid- and end- of transport, indicating that the two measures were not entirely in agreement. Schmidt et al (2010c) reported no significant differences in SD2 between horses travelling for one-, three and a half-, or eight-hours. This finding was in contrast to the SC reported for horses within this study which was significantly higher between all lengths of journey (Schmidt et al, 2010c), further indicating that this parameter does not demonstrate good agreement with SC (from HRM derived data). This is supported by the validation study conducted by Lenoir et al (2017) who found poor agreement for SD2 between data recorded from ECG and HRM, indicating that HRM derived data is not reliable for calculation of this parameter. It is however important to note that Lenoir et al (2017) study only included conditions whereby the subjects were being exercised (ridden), and no conditions where subjects were stationary. Further research is required to clarify whether non-linear measures of HRV such as SD1 and SD2 as derived from HRM devices are reliable if data is collected whilst subjects are stationary, in line with the findings of other HRV indices.

5.4.2 Study design and methods

5.4.2.1 Activity of subjects during data collection

The three validation studies included were designed in a way that highlighted the validity of HRM devices in different testing conditions (regarding activity of the equine subjects). Due to this being a key part of these studies, this has been discussed throughout each individual variable in section 5.4.1, however a summary is also provided here for completeness. This section also gives some consideration to studies included within the review which analysed HRM derived HR/HRV data in combination with other measures of stress/arousal.

5.4.2.1.1 Stationary (restrained/loose in stable)

The strongest agreement between HRM and ECG data has been reported for stationary settings, where the horse is not exercising. Stationary settings within the studies included horses loose in individual stables (Ille et al, 2014b) and horses that were restrained. It therefore appears that the horse can be moving around a small space such as a stable, but not carrying out physical exercise; to ensure accuracy of HRM data. HR and all-time domain indices included in the relevant validation studies (RR, RMSSD, SDRR, pNN50) demonstrated good agreement between ECG and HRM in a stationary setting (restrained/unrestrained), indicating that HR and time domain indices as derived from HRM data is reliable when subjects are in a non-exercising setting. This is supported with literature that used HRM devices to collect HR/HRV data in combination with other measures of stress/arousal, such as the studies by Wulf et al (2013) and Flakoll et al (2017) who found moderate-good agreement between the two measurement types. Other studies however have demonstrated mixed agreement between HRM derived HR/HRV and SC, such as Schmidt et al (2010a, b, c, d). It is important to note however that the validation studies are the gold standard for assessing the quality of HRM devices and as such should take precedent over the findings of other studies. There are also challenges in accurately assessing the agreement between HRM derived HR/HRV data and other physiological measures such as SC due to the difference in the way these measures are regulated in the body, i.e. the fast acting, instantaneous nature of the nervous system versus the slower, long acting nature of the endocrine system and the subsequent release of hormones into bodily fluids such as saliva (Peeters et al, 2011).

5.4.2.1.2 Ridden exercise

There was only one study that included ridden exercise within the three validation studies included in this review; Lenoir et al (2017) included HR, RR, SDNN, RMSSD, SD1, SD2, LF, HF and LF/HF analysis within their study, with only HR and RR-interval indices demonstrating acceptable agreement during a warm-up phase of walk and trot and a canter phase, indicating that reliability of HRM derived HRV data is generally poor during ridden exercise, with the exception of one HRV parameter, and HR. It would have been beneficial for the study to separate the warm-up phase into individual walk and trot phases to enable researchers to distinguish whether the reliability of the data differs between the two speeds of exercise. Furthermore, it may have been beneficial to include stationary recordings with a rider mounted, to investigate whether the presence of tack and a rider affects the reliability and validity of HRM derived data when the horse is stationary. These findings are supported by other non-validation studies within the review; for example, Bohak et al (2018) recorded HR/HRV during exercise using a HRM device and found that these data were uninterpretable, perhaps affected by the speed at which the horses were travelling during recording (45-50km/h), which also caused displacement of the HRM electrodes. Regardless of the accuracy of data, HRV may not be suitable for assessment of stress/arousal during high speed/intensity exercise in horses as it has been previously reported that HRV above HR's of 120-130bpm is regulated by non-neural mechanisms, thus assessment of neural states such as stress/arousal would be inappropriate in these conditions (Physick-Sheard et al, 2000).

A number of studies demonstrated moderate-good agreement between HR/HRV as obtained by HRM devices and SC during exercise settings that include trotting, cantering and jumping (Becker-Birck et al, 2013b; Ille et al, 2013, 2014a; Janczarek et al, 2019; Von Lewinski et al, 2013), however this was inconsistent with findings differing between HRV parameters used (discussed in depth in section 5.4.1). In consideration of the literature within this review, it is recommended that HRM devices are used to collect HR/HRV data from horses in stationary conditions. Further research is needed to clarify specific methodological considerations for recording HR/HRV data from HRM devices during exercising conditions, such as the effect of tack, equipment used (i.e. saddle, roller), rider, HRM fitting procedures and pace of the horse.

5.4.2.1.3 Loose in field

Parker et al (2010) collected data from horses whilst loose in a field, which demonstrated poor agreement for HR and all included time domain variables (RMSSD, pNN50), however good agreement was demonstrated for all included frequency domain variables (VLF, LF, HF, Total, PNSI, SNSI). These findings appear to corroborate with the findings of other studies that found poor agreement between time domain indices derived from HRM and ECG devices whilst horses are moving (Lenoir et al, 2017). It is however difficult to fully evaluate the findings of Parker et al (2010) study without further information on what the horses' activity level was during this setting, although it could be assumed that there was some movement in line with known horse behaviour in a field setting. For example, the setting of loose in field could have included subjects walking, trotting, cantering, rolling and pawing which are known equine behaviours in this context (Eerdekens et al, 2020).

5.4.2.2 Equipment

All studies included in this review used Polar (Polar Electro Öy, Finland) HRM devices, indicating that this manufacturer is the preferred choice for Equine HR/HRV analysis research (Ille et al, 2014b; Lenoir et al, 2017; Parker et al, 2009). Polar devices are also well cited as the chosen HRM device in other farm animal studies including goats, sheep, pigs, calves and cattle (von Borell et al, 2007). Polar previously produced equine specific HRMs with two different styles of sensor available; an elasticated chest belt (similar to what is used for human HRM recordings), and a transmitter with two separated electrodes (von Borell et al, 2007), both of which are included in the studies within this review. Both styles of device rely on being correctly fitted to optimise the accuracy of recorded data. Currently, only elasticated belt sensors appear to be available on the Polar website, so the electrode sets may have been discontinued.

5.4.2.2.1 HRM receiver

There are a variety of models of Polar receiver devices available. The majority of studies (58%) included within this review utilised the Polar S810i, with the most recent studies that utilised this device being published in 2014 (Ille et al, 2014a, b). The majority of recent studies (published 2018 onwards) appear to use the Polar V800 which is the most updated version of the Polar Equine HRM device (Ijichi et al, 2018b, 2019; Squibb et al, 2018), however two of the studies published during this time utilised the RS800CX (released in 2002), a much earlier model than the V800 (released in 2014) (Bohák et al, 2018; Janczarek et al, 2019). The Polar V800 has not currently been validated in horses but has demonstrated excellent agreement with ECG data in humans. Giles et al (2016) stated that the Polar V800 was improved in accuracy when used in humans, in comparison to previous Polar models, indicating that recent technological improvements may have improved the accuracy of the device for measuring HRV parameters. Furthermore, the studies within this review that utilised the Polar V800 all demonstrated good agreement between HR/HRV parameters and other physiological measure of stress/arousal (Ijichi et al, 2018b, 2019; Squibb et al, 2018), although the agreement in these studies was due to a lack of significant findings for any of the measures, so the agreement lacks strength. Nonetheless, it seems reasonable to expect that the technology will have been developed (for the better) over the span of 12-years and although there are currently no validation studies available that assess the reliability of the Polar V800, recent studies have utilised this device for assessment of stress/arousal in horses. Mott et al (2020) found a significant moderate positive correlation between change in spontaneous eye blink rate (SBR) between baseline and a sham clipping treatment and change in SC, and a significant strong negative correlation between SBR and RMSSD (obtained from a Polar V800 HRM). Although the authors do not report a correlation result for RMSSD and SC, the authors have concluded that SBR is significantly associated with SC, and thus the correlation between RMSSD and SBR would suggest that the measures are all in agreement in the context of their representation of autonomic nervous system activity. Furthermore, McDuffee et al (2019) published a study which investigated the repeatability of HRV data derived from a Polar V800 by collecting data in a test-retest approach whereby horses were guided through routine activities whilst HRV data was collected. The authors concluded that HRV parameters obtained from the Polar V800 HRM are statistically reliable, indicating that they are consistent and thus raising the merit of these devices (McDuffee et al, 2019).

5.4.2.2.2 HRM sensor

All the studies within this review which gave information on the sensor used stated that they utilised a Polar sensor. There are two main types of Equine sensor from the manufacturer Polar; one is an electrode set which consists of two separate electrodes (one positive and one negative), and the other is an elasticated belt which has integrated electrodes. 54% of the studies within this review utilised an electrode sensor set (n=13), 25% used an elasticated belt sensor (n=6), 13% stated that they used a Polar sensor but did not stipulate which style (n=3) and 8% of studies within the review did not provide any information on the sensor used (n=2). Both types of sensor offered by Polar are considered to utilise 'contact electrodes' which are applied to the horses body in combination with conductive gel, as opposed to clip electrodes (which may stimulate a startle response in horses as they are clipped to the skin), or adhesive electrodes (which would require the horses skin to be shaved of hair) (Stucke et al, 2015). Fitting the contact electrodes correctly is crucial to ensure valid measurement of RR-intervals (Stucke et al, 2015). Contact electrodes may move to different positions on the horse's body due to movement of the animal, which could result in artefacts (Stucke et al, 2015). This may explain why these devices produce data that is significantly different than ECG data (particularly in exercising conditions) which typically uses adhesive electrodes and are therefore unlikely to move once they have been put in place (Parker et al, 2010). It is therefore recommended that regardless of the type of HRM sensor used to collect HRV data that horses are stationary during the period of time which will be used for analysis, to ensure electrodes maintain contact with the horses skin.

5.4.2.3 Data handling

5.4.2.3.1 Time-period

The study by Parker et al (2010) calculated HR/HRV indices from recordings of 512 'beats' (equivalent to approximately 15 minute recordings in horses, if the horses resting HR is 35bpm) rather than recordings of a specific time-period, presumably to allow true synchronicity between the recordings from each type of device (as synchronising the recordings is mentioned in the study methods). Ille et al (2014b) calculated HR/HRV indices from recordings of one-, two-, five- and 30-minutes and Lenoir et al (2017) used five-minute recordings. Of the non-validation studies included within this review, the majority of studies used five- (Becker-Birck et al, 2013, 2013b; Erber et al, 2013; Flakoll et al, 2017; Schmidt et al, 2010b; Villas-Boas et al, 2016) or one-minute (Ille et al 2013, 2014a; Pasing et al, 2013; Von Lewinski et al, 2013; Wulf et al, 2013) intervals for analysis of HRV parameters (with one study using 64 seconds, comparable with one-minute intervals; Villas-Boas et al, 2016). Notably, three of the studies included in this review did not stipulate the time intervals that they used for HRV analysis (Squibb et al, 2018; Ijichi et al, 2018b, 2019) which means that their methods cannot be appraised adequately.

For the five studies that utilised one-minute intervals for calculation of RMSSD (from HRM devices), four of them reported good agreement between this parameter and SC values (Ille et al, 2014a; Pasing et al, 2013; Von Lewinski et al, 2013; Wulf et al, 2013), with one demonstrating moderate agreement between the two measures (Ille et al, 2013). In contrast, of the four studies that utilised five-minute intervals for calculation of SDRR, only two demonstrated good agreement between the parameter and SC values (Ille et al, 2013, 2014a), with the other two reporting poor agreement between SC and SDRR (Von Lewinski et al, 2013; Wulf et al, 2013). It is important to consider the time-periods used for analysis within these studies because the methods used could implicate the validity of the study findings. For example, Shaffer and Ginsberg (2017) recommend that SDRR is used for recording periods of no less than 24-hours in humans because shorter periods would limit representation of slower processes within the body such as the cardiovascular systems response to a diverse range of stimuli (e.g. environment or workload), indicating that perhaps the accuracy of this HRV parameter in particular should not be assessed from recordings of less than 24 hours. von Borell et al (2007) stated however that SDRR can be calculated for five-minute periods for HRV analysis in animals. This could explain why there is varied agreement between the SDRR parameter and other measures of stress/arousal for studies that have utilised time intervals of less than five-minutes for their analysis, whereas good agreement is demonstrated for studies that utilise one-minute periods for analysis of RMSSD, which is the recommended time-period to use for analysis of this parameter in the literature (see section 5.4.1.2.2).

The variety in methods used in this context between the studies highlights the fact that there is currently no standardised method for managing and analysing HR/HRV data for the assessment of stress/arousal in horses. Furthermore, the recommendations on how to analyse HRV data are also varied which further demonstrates the lack of standardised analysis techniques.

5.4.2.3.2 Correction

Correction refers to the process of correcting IBI data for artefacts (missing, extra or misaligned beats) that occur due to misidentification of R-waves and ectopic beats (abnormal waveform caused by a skipped beat, for example) (Cheung, 1981; von Borell et al, 2007). Artefacts can occur due to insufficient skin-electrode conductance, noise from muscular contraction (action potentials), faults with equipment and interference from electromagnetic energy in the surrounding environment (Cheung, 1981; von Borell et al, 2007). Therefore, it is recommended that IBI data should be edited to ensure correct identification of IBI's and correction of artefacts (von Borell et al, 2007). When preparing ECG data for analysis, researchers can manually correct data using simple visual correction or by using automated algorithms that are integrated into dedicated HRV analysis software programs.

For validation studies included within this review, Parker et al (2010) used correction methods whereby type one-five errors were detected and corrected (for both ECG and 'corrected' HRM data set), as described by Marchant-Forde et al (2004) in their validation study in pigs. Types one-three errors are described as single IBI discrepancies from the ECG data, either negative or positive, and types four and five errors are described as a sequence of either 'missing' or 'extra' IBIs in the series (Parker et al, 2010). For the HRM data, Lenoir et al (2017) used the manufacturer software (Polar Pro Trainer 5), stating that they corrected the data with the set up "very high" filter power and a minimal protection zone of "one beat per minute (bpm)", with no further information on how these filters alter the data. Lenoir et al (2017) then input the data from both the HRM and the ECG through a home-made algorithm which was programmed to recognise five types of errors, as described for manual correction by Parker et al (2010). Finally, Lenoir et al (2017) input both ECG and HRM data into Kubios HRV software (Biomedical Signal Analysis and Medical Imaging Group, Department of Applied Physics, University of Eastern Finland, Kuopio, Finland) where artefact correction was implemented using the custom filter of the program set at 0.3, which identifies RR-intervals differing from the previous RR-interval by more than 30%, as artefacts. Ille et al (2014b) corrected incorrect R-wave detections on the ECG recording as described by Jonckheer-Sheehy et al (2012) and then utilised the same automated artefact and detrending procedure on Kubios software as described by Lenoir et al (2017). Automated filters such as the one described for Kubios act as a computerised version of the same, manual, process as described by Marchant-Forde et al (2004).

All three validation studies present variations in their analysis methods for correcting ECG and HRM data however there are some common methods between the studies such as the correction of type one-five errors as described by Marchant-Forde et al (2004) which is adopted by two of the validation studies included within this review (Lenoir et al, 2017; Parker et al, 2010). Furthermore, the automated artefact correction described by Ille et al (2014b) in their validation study is well cited in literature that includes HRV analysis in horses, with 75% (n=18) of the other studies included within this review describing this technique within their methodology. Additionally, all but one of these studies utilised Kubios software to perform this artefact correction method (Janczarek et al, 2019 utilised the same method but performed the correction using Polar Pro Trainer software).

In contrast, the validation study conducted by Parker et al (2010) did not implement any automated artefact correction; this could be due to the study being carried out at an earlier date when correction software had not yet been established. Nonetheless, there does not appear to be a standardised method of data correction for HRV in horses, which calls into question the repeatability and reliability of the studies. Without a standardised method of handling and correcting the data it is difficult to offer a true comparison of the validation studies. Variance of these methods could significantly alter the results. It would therefore be beneficial for future studies to develop a standardised method of correction to enable more rigorous validation of the equipment in question. This is supported in the review carried out by Stucke et al (2015) which evaluated the pros and cons of different methods of HRV analysis in horses; concluding that data management and analysis methods differed considerably between studies. Stucke et al (2015) also stated that the outcomes of HRV analysis could be affected not only by the accuracy of the IBI measurements but also the analysis methods, highlighting the importance of establishing standardised methods. Furthermore, von Borell et al (2007) stated that use of automated correction tools should be used with caution, as it is difficult to distinguish between normal, successive IBI's that have biological differences (such as ectopic beats which are common in horses due to their high parasympathetic tone), from artefacts, without reference to the full ECG (Patteson, 1996; von Borell et al, 2007). Further research is needed to clarify exactly how the commonly used artefact correction methods described here can affect the validity of HRV parameters as obtained by HRM devices. In the interim, the methods described by Ille et al (2014b) appear to be the most suitable technique of correction, due to the majority of studies available utilising this technique.

5.4.2.3.3 Detrending

'Trend' is the measure of how stationary the system is during recording (i.e. the stability of HRV modulations within the recording) (Task Force, 1996; von Borell et al, 2007). Instabilities in the HRV recording can have unwanted effects on HRV indices as the statistical properties (such as mean and standard deviation) will not be constant as a function of time. Data that presents with these changes are known as 'non-stationary' data and is not uncommon in HRV recordings (especially in unstable testing conditions; i.e. in-field testing), thus should be considered prior to analysis (Berntson et al, 1997; Task Force, 1996). The removal of these non-stationary trends is known as detrending, this process can be easily performed before analysis using a *smoothness priors* detrending method. The *smoothness priors* method is described in detail by Tarvainen et al (2002). Detrending has been shown to reduce distortion of time- and frequency- domain analysis of HRV (Tarvainen et al, 2002).

Of the validation studies, Ille et al (2014b) and Lenoir et al (2017) detrended HRV data using Kubios software which follows the *smoothness priors* approach as described by Tarvainen et al (2002), with the smoothness parameter set to 500ms as recommended (Tarvainen et al, 2002; Tarveinen & Niskanen, 2008). For other studies within this review which included the use of HRM devices for obtaining HR/HRV data in combination with other measures of stress/arousal, 79% described the same methodological approach for detrending data (n=19), with all but one performing this approach using Kubios software. It would be beneficial for future studies to assess how the common method of detrending as described here affects the validity of data as obtained by HRM devices. The study by Parker et al (2010) is the only study to include 'corrected' and 'uncorrected' data from HRM devices, with mixed agreement with the gold standard ECG. Furthermore, this study did not utilise the software or methods commonly used in recent studies (i.e. *smoothness priors* approach, using Kubios), thus updated validation studies that consider these techniques and their effect on the quality of HRM data are needed.

5.4.2.4 Other methodological considerations

There are many other methodological considerations when using HRM devices to collect IBI data, which will be discussed in brief here.

One study within this review provided information on the body condition of horses that were used. Villas-Boas et al (2016) stated that the six horses within their study had 'appropriate body condition scores' ranging from 5.0 to 5.5, however the authors did not state which body condition scoring system was used. If, for example, the Henneke et al (1983) Body Condition Scoring System was used (where one = poor/emaciated and nine = extremely fat), then the horses within Villas-Boas et al (2016) study would be in 'moderate condition'. It is probable that this is the scoring system that was utilised by Villas-Boas et al (2016) as other, commonly used body scoring systems typically only range from one to five (e.g. Carroll & Huntington, 1988). Hernández-Vicente et al (2021) conducted a study on the validity of a Polar HRM sensor in humans of different ages, body composition and fitness level, and found that participants with a higher trunk fat percentage showed the highest error in HRV indices, indicative that the validity of the device was negatively affected by higher body fat. It would therefore be beneficial for future validation studies to investigate the effect of varied body compositions (regarding fat) in horses on the efficacy of HRM devices to collect valid HRV data. Additionally, it would be useful for authors who conduct studies using HRM devices to provide information regarding the body condition of their sample which may be beneficial for future evaluation of how this factor affects the validity of HRM devices.

As discussed in section 5.4.2.2 the method of fitting HRM equipment could affect the reliability of data obtained from HRMs. The optimal fitting of sensors (in terms on location on the body) is well described in the literature (see section 5.4.2.2), however some aspects of this procedure do not appear to be standardised. For example, only 34% (n=5) of the non-validation studies within this review mention the use of a gel (i.e. exploratory, conductive, ultrasonography, transmission) to aid in maintaining contact between the electrode and the horses skin (Christensen et al, 2014; Erber et al, 2013; Flakoll et al, 2017; Janczarek et al, 2019; Pasing et al, 2013). In contrast, 76% of these studies did not mention the use of such a product. Indeed, use of contact gel is recommended by validation studies to improve the validity of data obtained from HRM devices on horses (Ille et al 2014b; Parker et al, 2010) and thus should be utilised. Two studies within this review mentioned moistening the electrodes with water, but did not state the use of any gel (Ijichi et al, 2018b; Squibb et al, 2018), it is not currently known whether water would be sufficient to maintain contact between electrodes and the horses skin however it would be beneficial for future validation studies to include this in their considerations.

Parker et al (2010) and Marchant-Forde et al (2004) advised that the coat (hair) should be newly clipped to further enhance the contact between the electrode and the horse's skin however none of the studies within this review (aside from Parker et al, 2010) describe clipping the horses in their studies to improve the electrode contact. Nonetheless, studies such as Ille et al (2014b) validated the use of HRM devices in stationary settings using ECG and did not mention clipping or shaving horses' hair. It would be beneficial for future validation studies to compare the validity of HRM devices for obtaining HR/HRV data in horses with varying degrees of hair coverage which would further enable standardisation of the method for using these devices in horses, along with the other suggestions already stated within this review.

5.4.3 Limitations to the study and future improvements

5.4.3.1 Study limitations

1. The study only utilised two databases to conduct the literature search, thus additional databases may have yielded further studies to be included. It is important to note however that only two further studies were identified through other sources which suggests that the search strategy was adequate.
2. The study is limited by the research available. Additional studies were included that used other validated measures of stress in horses. This was done to add strength to the review however it is important to consider that our assessment of the agreement between HR/HRV results and other validated measures of stress (such as SC) is subjective, as in most cases research studies had not reported results for correlations between the two measures. We utilised an approach whereby if studies reported that the horse was more/less stressed in a specific time-interval, from both the results of HR/HRV and other measures of stress, then this was considered as agreement between the two measures, and thus to our understanding offered evidence for the validity of HRMs in assessing stress in horses. Further validation studies (that test HRM with gold-standard ECG) would thus add strength to a review such as this and would avoid the need to include a subjective assessment of other forms of research.

5.4.3.2 Future improvements

This review has revealed several areas of this field of study that require development. Further validation studies are needed to assess the validity of HRM devices depending on different methodological techniques, in comparison with the gold standard ECG. Our suggestions for future research in this context are as follows:

1. Assess the effect of different hair thickness (or lack of) on the validity of HRM derived HR/HRV data.
2. Assess the effect of the use of conductive gel, water, or no application of substance to the skin, on the validity of HRM derived HR/HRV data.
3. Assess the effect of horse body composition (particularly fat) on the validity of HRM derived HR/HRV data.
4. Assess the effect of different paces of exercise (of the horse) on the validity of HRM derived HR/HRV data. Studies should consider ridden and unridden exercise and should assess each pace/type of exercise individually, for the avoidance of any doubt.
5. Assess the effect of sensor type on the validity of HRM derived HR/HRV data (i.e. elasticated belt in comparison with electrode set).
6. Assess the validity of the most up to date HRM devices (e.g. Polar V800)
7. If subjects are loose in any study setting (e.g. in a stable, or in a field), their respective movement/behaviours should be recorded and described by study authors.

5.4.4 Recommendations

In consideration of the findings within this review, and in the absence of any further validation studies, the following points are recommended for the use of HRM devices to record HR/HRV data in horses:

1. Electrode gel should be used to aid conductivity between the electrode and the horse's skin, as advised in previous studies.
2. HRM devices should only be used to analyse HR/HRV data from horses in stationary settings.
3. RMSSD appears to be the most reliable parameter to reflect short-term stress/arousal in horses and thus should favoured. Recordings of at least one- and up to -five minutes are recommended for this parameter.
4. Artefacts in the data should be corrected by identifying RR-intervals differing from the previous RR-interval by more than 30%, as an artefact. The most cited method in the literature to conduct this correction is by using the automated correction method on Kubios software which should be set at 0.3.
5. The *smoothness priors* approach should be used to detrend data. This will ensure that instabilities are corrected, which can have a detrimental effect on HRV indices if not addressed. The most cited method in the literature for conducting the *smoothness priors* approach is by

using the automated function in Kubios software by setting the smoothness parameter to 500ms.

5.4.5 Contribution to knowledge

Research that utilises HRM devices for the assessment of HRV in horses is often published in academic literature with little regard as to the validity of these devices and appropriate methodological techniques. This study has reviewed existing literature and subsequently made recommendations for improving methodological techniques for the use of HRMs to assess stress in horses. The review has revealed that many published studies have not adopted appropriate methods for HR/HRV calculations in horses and as a result has offered recommendations which aim to inform future research. The recommendations offered in the review should therefore help in improving the quality of research in this field. Additionally, conducting the review has enabled suggestions to be made for future research which should continue to investigate the validity of HRM devices for assessment of HR/HRV in horses.

5.4.6 Conclusion

This review has identified key considerations when utilising HRM devices for HR/HRV analysis in horses. There is currently a lack of validation studies (particularly for up to date HRM models), however the studies that have assessed the validity of HRM devices are mostly in agreement; in that these devices are valid for analysis of HR/HRV if horses are in a stationary setting. Considering other available literature that has investigated HR/HRV data from HRM devices in combination with other measures of stress/arousal, the findings are contradictory and thus are a challenge to summarise succinctly. It is apparent however that certain indices of HRV can be reliable if measured in stationary settings and analysed in appropriate intervals of time. The validity of HR/HRV data from HRM devices appears to be dependent on a variety of factors, and it is clear from this review that this field of study is lacking in standardisation of methodology. Future studies should aim to assess the effect of different methodologies (i.e. the use of gel, clipping horses, varying degrees of exercise, body condition and data handling techniques) on the validity of data collected from HRM devices. In the interim, HRM devices are an accessible alternative to the gold-standard ECG and remain a useful tool for in-field assessment of stress/arousal when accompanied with correct methodology and analysis.

6. Stress of horse and rider at eventing competition and riders' feeling-states

6.1 Introduction

Stress at competition has the potential to affect performance, welfare and safety of horses and riders (Peeters et al, 2010). Previous research on the stress responses of horses to competition has mainly focused on the acute stress response following competition performance (Bartolomé et al, 2013; Negro et al, 2018; Valera et al, 2013). Studies have also investigated pre-competition stress in horses; for example, Ferlazzo et al (2012) investigated the stress response of horses to a show-jumping competition and found no significant difference between cortisol values immediately before the start of competition (9am) and basal values, suggesting that horses did not experience any pre-competition psychological stress. The authors stated that values were taken at 09:00am, just before the 'competition start', however the time between this measurement and the actual start of the competition for each horse is not stated. It is reasonable to assume that there must have been some variance in the sample which included 18 horses (Ferlazzo et al, 2012). It is unlikely that all 18 horses would have started their jumping-round at exactly the same time, thus these values may not truly represent 'immediately before' the competition start (Ferlazzo et al, 2012).

Cayado et al (2006) investigated the stress response of horses to a dressage or show-jumping competition and reported that horses competing in dressage had significantly higher values of blood cortisol at the warm-up area (prior to exercise) of the competition in comparison with baseline measures, indicative that dressage horses were exposed to psychological stress. The authors found no such difference for show-jumping horses (Cayado et al, 2006). Overall, there is a lack of research that investigates the time-period immediately before the horse begins the competition exercise (i.e. the jumping or dressage test). The time-period immediately before competition may be of importance when trying to assess psychological stress response in horses, as at this point they may be exposed to stressors such as other horses, novel stimuli (e.g. tents, jumps, flags, signs etc.) or pre-competitive arousal.

Peeters et al (2013) reported that salivary cortisol levels in horses were significantly higher than baseline 20-, 40- and 60-minutes after a jumping competition, however there was no significant difference between baseline measures and the start of the event (immediately prior to entering the competition ring), indicating that horses did not experience any pre-competition psychological stress. Peeters et al (2013) also analysed rider cortisol levels during their study and found no significant difference between baseline and pre-competition cortisol. The authors did however find that riders had significantly higher salivary cortisol 20-minutes after the jumping competition in comparison with baseline (Peeters et al, 2013), which is in agreement with known stress-responses to riding exercise in humans (Ille et al, 2013). Additionally, Ille et al (2013) investigated the stress response in horses and riders to a rehearsal and a public performance and although there were no significant differences in rider cortisol or the HRV parameter RMSSD between 30- and 15- minutes before each performance (indicating no pre-competitive psychological stress response), they did find that less-experienced riders had significantly higher cortisol levels and lower RMSSD in response to the task where they were riding a less-experienced horse (versus an identical task with a more experienced horse), indicating that riders can be susceptible to psychological stress during riding. Ille et al (2013) found that RMSSD was significantly lower in experienced riders in comparison with less-experienced riders, indicating that less-experienced riders were under increased emotional stress. The study reported that the level of experience of the rider did not significantly affect the RMSSD of the horse (Ille et al, 2013). These findings indicate that the horses were not affected by the riders' stress level, which may suggest that horses are impervious to rider stress. The study appears to involve horses and riders that have never been partnered before, therefore it may be that horses would be more affected by changes in the stress level of a rider that they are familiar with. Hausberger et al (2008) stated that good performance was dependent on effective cooperation between the rider and the horse. Furthermore, Thompson and Nesci (2013) found that eventing riders considered a familiar relationship with their horse as a form of risk mitigation, with riders attributing negative safety outcomes to 'bad' partnerships between horse and rider. These findings highlight that riders consider the relationship between themselves and their horses as important for risk-mitigation and poses the question of how much each member of the partnership affects the other? With eventing being a high-risk sport, it would therefore be beneficial to explore whether there is an association between partnered horse and rider physiological measures of stress. If there is an association between horse and rider stress, then future research would need to identify whether this is beneficial or detrimental to performance and risk. This information could then be used to mitigate the stress experienced by horses and riders and may reduce the risk of negative outcomes such as horse falls.

The use of HRV can be a viable alternative to salivary cortisol for assessing stress in horses (as discussed in Chapter Two, Section 2.2.2.1) and has also been validated for use in human athletes (Kim et al, 2018). HRV is particularly beneficial (in comparison with cortisol) for in-field competition testing whereby the time of day cannot be controlled for (See Chapter Two, Section 2.2.2.3). HRM devices can be a useful tool to collect this data in-field due to their minimal design and validity during stationary conditions in horses (See Chapter Five) and humans (Giles et al, 2016). The term 'stress' describes an organism's response to a stressor, such as physical exercise or novel stimuli (Bartolomé & Cockram, 2016). Hormones associated with stress are released as a normal (and necessary) physiological response to exercise, which aid in enhancing an animal's adaptation to their environment (Bartolomé & Cockram, 2016) (See Chapter Two, Section 2.2.1). An excess of these hormones however could be detrimental to performance and additionally can result in health problems in both humans and horses. Furthermore, repeated exposure to an excess of stress hormones (particularly when the biological systems have not recovered from previous exposures) can result in 'overtraining syndrome' which can have a detrimental effect on performance (de Graaf-Roelfsema et al, 2007). Overtraining syndrome has been reported in both humans (Angeli et al, 2004) and horses (McGowan & Whitworth, 2008).

As an increase in stress has been previously reported to have a detrimental effect on performance, it is plausible that horses and riders who experience high levels of stress may be at in increased risk of a horse fall. Before the direct effect of stress level and eventing cross-country performance can be investigated, research is needed to quantify the levels of stress that the horse and rider experience in response to the cross-country phase, with a particular focus on pre-competitive stress. Due to eventing encompassing three different phases of competition, it is expected that horse and rider will experience normal stress-responses (in the context of physical activity) before reaching the cross-country phase. To enable assessment of the acute stress response of horse and rider immediately prior to the cross-country phase HRV analysis is therefore ideal as this measure alters rapidly in response to stimuli (such as psychological stress or exercise), but also returns to baseline rapidly (less than 30-minutes) (Becker-Birck et al, 2013). In contrast, neuroendocrine mechanisms (such as cortisol) are longer acting and thus take longer (around 60 minutes) to return to baseline following physical exercise (Becker-Birck et al, 2013) and therefore may not be appropriate in the context of quantifying the stress response to one specific phase of eventing. When the study was first developed it was intended that HR/HRV would be considered during XC, however a review of the literature revealed that the HRM devices are not reliable for HR/HRV data collected in this context due to movement of the electrodes and the potential for HR of horse and rider to be above 120-130bpm (which is regulated by non-neural mechanisms) (See Chapter Five, Section 5.4.2). Thus, the study plan was altered to assess the stress/arousal of horse and rider combinations during certain time-periods at eventing competition. These time-periods were chosen to assess baseline measures at competition, and then values after the dressage and show-jumping phases, but prior to the cross-country phase (which is the phase of interest). Additionally, selected periods of time were chosen due to the viability that the horse and rider could be stationary for at least one-minute (to enable analysis of HRV).

Further to the measurement of stress via physiological measures, previous studies have utilised self-reporting questionnaires to assess self-confidence, self-efficacy, trait and state anxiety, and pre-competitive anxiety in riders (Beauchamp & Whinton, 2005; Trotter & Endler, 1999; Wolframm &

Micklewright, 2008), however the majority of this research has focussed on generalised/long-term quantification of these measures. Research in non-equestrian sports has found that a change in rated feelings can occur due to a single, acute bout of physical activity (Bezoian et al, 1994; Szabo et al, 1998), using the Exercise Induced Feeling Inventory (EIFI) which is a validated tool to measure changes in feeling states before and after exercise (Gauvin & Rejeski, 1993). Assessing how the feeling states of riders are affected by eventing competition may aid in understanding how the rider is psychologically impacted by this activity. Investigating feeling states and their association with physiological measures of stress may also be beneficial; for example, if feeling-states of the riders are significantly associated with physiological measures of stress/arousal, then management practices could be adopted to mitigate stress.

Previous studies have reported fence-level variables to have a significant effect on the risk of a horse fall. For example, fences with a frangible device, a drop-landing, a ditch in-front, a take-off or landing in water, a spread of more than two metres and angled fences have all been associated with increased risk of a horse fall (Barnett, 2016; Murray et al, 2005, 2006b; Singer et al, 2003). Furthermore, Murray et al (2006b) reported that riders that believed they had approached the fence too slow or too fast had a higher risk of falling than those who believed they approached the fence at an appropriate speed. Although this finding was anecdotal, it indicates that speed of approach to fences may affect the risk of a horse fall. It is not understood why certain fence types may affect the risk of a horse fall although authors have discussed that certain fence types may prompt the horse or the rider to approach with reluctance or apprehension which could increase the risk of a horse fall (Singer et al, 2003). Understanding the speed at which horses and riders' approach different styles of fences on the cross-country may therefore provide valuable information as to why specific fence types carry increased risk of a horse fall.

6.1.1 Aims, objectives and hypotheses

The first aim of the study is to investigate pre-competitive stress/arousal experienced by horses and riders at eventing competition and explore whether there is an association between stress/arousal of horse and rider combinations in these circumstances. The second aim of the study was to investigate rider feelings states at eventing competition and explore any association between the riders' feeling-states and horse/rider stress/arousal prior to the cross-country phase of eventing competition. The third aim of the study was to explore whether there was any difference in horse and rider speed of approach to cross-country fences depending on fence type.

The objectives were therefore (1) To measure HR/HRV of horse and rider combinations at baseline, during rest at competition, at the cross-country warm-up at competition and in the cross-country start box at competition, (2) To measure rider feeling states using the Exercise Induced Feeling Inventory before and after the cross-country phase of competition, (3) To record GPS data of horse and rider combinations' cross-country rounds' at eventing competition, (4) to map the cross-country courses completed by horse and rider combinations using GPS to identify the locations of fences on the course.

The hypotheses were (1) that stress will be significantly higher at eventing competition than at baseline in horses and riders (2) that there will be a significant association between horse and rider stress at eventing competition and (3) that there will be a significant association between horse/rider stress and rider feeling-states at eventing competition.

6.2 Pilot testing

Two pilot tests were carried out using HRM and GPS equipment. One full pilot test of baseline and competition data for a participant and their horse was completed to ensure that the equipment would not interfere with the horse or rider during exercise, and that the equipment would stay fitted correctly following exercise to enable analysis of data in-between, but not during exercise.

6.2.1 Pilot test one: baseline and competition pilot test

6.2.1.1. Introduction

The first pilot test was conducted to test one type of Polar sensor on the horse and one on the rider, to ensure that the HRM equipment stayed in position during exercise to enable stationary data collection from horses and riders after the cross-country warm-up. Additionally, to enable data recording of the horse and rider in the start-box of cross-country, equipment would then need to be subsequently worn around the cross-country course, it was therefore necessary to ensure (for safety reasons) that the equipment would not move or disrupt the horse or rider during the cross-country.

6.2.1.2 Materials and methods

A rider ('the participant': age 34, height 170cm, weight 57kg) volunteered to be part of the pilot study with her own horse ('the horse': age 8, height 164cm, weight 580kg). The participant was given documentation to read and sign before the testing commenced. The individual documents included a participant information sheet, participant consent form, participant disclaimer and a PARQ+ form (Appendix X).

6.2.1.2.1 Equipment

A list of the HR/HRV equipment and materials used during Pilot test one can be seen in Table 6-1.

Table 6-1: HR/HRV Equipment and materials used for Pilot test one.

Equipment	Used for	Horse or Rider?
Polar H7 Human Sensor Strap	HR	Rider
Polar RS400 Watch	HR Data Recording	Rider
Water	HR sensor	Rider
Polar H7 Equine Sensor Strap	HR	Horse
Polar M400 Watch	HR Data Recording	Horse
Spectra 360 Electrode Gel (Parker Laboratories)	HR Sensor	Horse

6.2.1.2.2 Fitting the polar H7 equine sensor strap

The equine sensor that was tested during this pilot test was the Polar H7 Equine Sensor Strap. This sensor is a large elasticated strap which is strapped around the horse's body (Figure 6-1). The sensor section of the belt (see Figure 6-1, where 'Polar' logo is located on strap), is placed on the horses left side, just behind the girth, parallel to the lower section of the horse's shoulder. The saddle was positioned on top of the sensor strap. Additional, smaller elasticated straps were attached from the girth to the sensor, which are designed to prevent the sensor from slipping back whilst the horse is moving. The electrode is a rubber section visible on the underside of the strap, this section was moistened with electrode gel to ensure adequate contact between the electrode and the horse's skin as recommended (See Chapter Five, Section 5.4.2.4).

Figure 6-1: Polar H7 Equine Sensor Strap fitted to a horse.

6.2.1.2.3 Fitting the polar H7 human sensor strap

The human sensor used for this pilot test was the Polar H7 Human Sensor Strap. This sensor is an elasticated strap that is fitted around the rider's chest. The sensor section of the strap was moistened with water to ensure adequate connection between the rider's skin and the sensor. The sensor was then placed over the sternum of the rider and the strap was fastened on the left side of the rib cage (Figure 6-2). The strap was adjusted for a close fit, to ensure suitable contact with the skin.

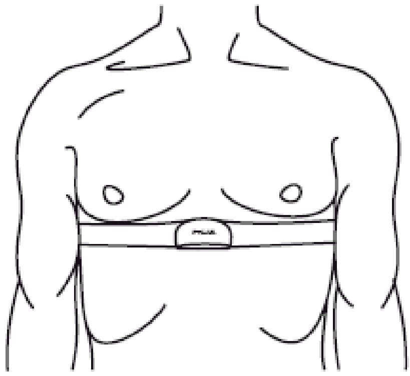


Figure 6-2: Positioning of the heart rate strap on a participant (human).

6.2.1.2.4 Obtaining resting HR data from horse and rider

After having the sensor fitted, the horse was left in its stable to habituate for 15-minutes. Previous research has suggested a minimum habituation period of five-minutes for horses wearing this sensor (Ijichi et al, 2018b, 2019; Squibb et al, 2018), and in consideration of the horse's familiarity with wearing equipment in this area of the body (e.g. girth, roller), a 15-minute habituation period was deemed sufficient. The horses resting HR was then recorded for 60-seconds as per HRV methods outlined by Shaffer and Ginsberg (2017). Once the rider's sensor was fitted, they were asked to remain seated for 15-minutes to habituate to the monitor and were instructed to avoid talking or using any electronic devices during this period as recommended by Powell et al (2020). The rider's resting HR was then recorded for 60-seconds. Upon completion of the basal HR data collection the rider tacked up the horse and both horse and rider then re-located to a riding arena. The watch receivers (Polar RS400 and Polar M400) were then set to record and were checked to ensure that they were picking up the signal from their respective sensor. The watch receivers were worn on the rider's wrists (one on each wrist) to ensure adequate connection to each respective sensor. The rider was instructed to exercise the horse *'typical of an intense exercise session for the horse being prepared for competition'* in line with methods used by Serrano et al (2002). Horse and rider HR was recorded throughout the exercise session and for five-minutes thereafter. The data was stored on the watches and was downloaded by the researcher at a later time, to a computer. The equipment did not move during or following on from the exercise session and the rider reported that they did not feel that the equipment interfered with themselves or their horse. Upon completion of the baseline data collection, arrangements were made to meet the participant at a British Eventing competition to test the equipment in the same way, but at competition.

6.2.1.2.5 Competition data collection (HR)

On the day of competition, the sensors were fitted to the horse and rider as described in Section 6.2.1.2.2 and 6.2.1.2.3. following completion of the show-jumping phase. Once the equipment was fitted and checked, the devices were then set to record. The horse and rider then went to the cross-country warm-up area. The horse and rider were stationary for five-minutes at the cross-country warm-up area and then completed a warm-up. The horse and rider were then called to the cross-country start box where they remained stationary within the start box for approximately three minutes before being counted down to begin the cross-country. Upon completion of the cross-country and once the horse and rider had come back to a walk, the recording was stopped. At this point the data collection was now complete, and the equipment was removed from the horse and rider.

6.2.1.2.6 Competition data collection (rider questions)

During this pilot study, the rider was asked to answer the rider questions (see Appendix XI) while they were waiting at the cross-country start box and then again once they had completed their cross-country round. Finally, a debrief letter was given to the participant (see Appendix XII). These questions were tested in this context to check that the rider could answer them at these time-periods without any interference to the time at which they would start in the cross-country.

6.2.1.3 Results

Several methodological issues were noted during pilot testing and an action plan was made to resolve these issues (Table 6-2).

Table 6-2: Issues noted during pilot testing and how they were resolved.

Issue	Resolution
Large clip on equine heart rate monitor which may cause chaffing injury to horse.	Test alternative Equine HRM sensor set.
Equine heart rate monitor slipped back slightly.	Test alternative Equine HRM sensor set.
PH7 Equine strap lost signal of the horses HR several times during intended recording periods.	Test alternative Equine HRM sensor set.
Current watches not capable of recording HRV data.	Obtain watches that are capable of recording HRV data.
No organised way to handle all equipment.	Label and organise equipment into boxes.
Rider riding horse on arrival of researcher.	Create 'pre-study email' to explain to participants that the horse must be resting on arrival.
Noted that resting HR/HRV at competition as this may differ from at-home baseline measures.	Add competition baseline HR/HRV measures to methods for main study
Using note pad to write down times of resting heart rate is not efficient.	Create templates that can be filled in during field testing.

6.2.1.3.1 Rider HR data

The HR data collected from the rider produced data throughout the entire recording, indicative that the sensor did not lose signal, regardless of intense exercise between intended analysis periods (e.g. one-minute stationary at warm-up and one-minute stationary in cross-country start box). It was noted however that the sensor was only set to record the data once every 60 seconds (Figure 6-3), which would not be suitable for intended analysis.

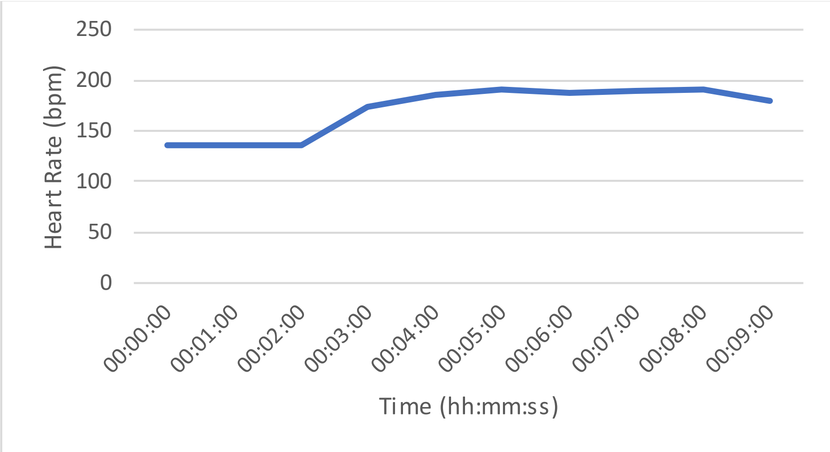


Figure 6-3: Rider heart rate during the cross-country phase of competition.

6.2.1.3.2 Horse HR data

The HR data collected from the horse had some periods of time where the sensor lost signal of the horse's HR however these periods appeared to be during exercise (cross-country round and then trotting to cool-down thereafter), which was not the intended period for analysis (Figure 6-4).

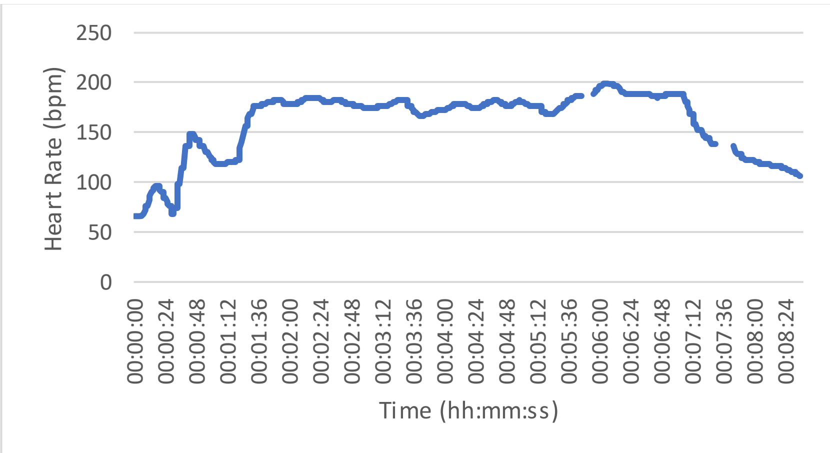


Figure 6-4: Horse heart rate during the cross-country phase of competition.

Resting and peak HR values for both horse and rider can be seen in Table 6-3. Both the horse and rider had a higher HR values at competition than they did during training.

Table 6-3: Heart rate at rest and peak values during training and competition for horse and rider.

	Rest (home)	Training		Competition	
		Min	Max	Min	Max
Horse	46 bpm	46	188	66	199
Rider	95 bpm	104	174	136	191

6.2.1.3.3 Rider self-perceived mood

Prior to the cross-country phase the participant reported the maximum level of anxiety (see Table 6-4). Upon finishing the cross-country round, the participant reported their anxiety was at the lowest level during their cross-country round (see Table 6-5). Rider feedback stated that they did not feel disrupted by these questions, and there was no perceivable delay to their cross-country start as a result of these questions being asked.

Table 6-4: Results for rider questions before cross-country.

Question	Not at All 1	2	3	Very 4	5
Do you feel physically fatigued right now?			X		
Do you think your horse is physically fatigued right now?		X			
How would you rate your level of anxiety right now?					X
Are you eager to win/get placed on this horse?	X				
Do you feel that your horse is responding well to you today?			X		

Table 6-5: Results for rider questions after cross-country.

Question	Not at All 1	2	3	Very 4	5
Did you feel that your cross-country round was difficult?	X				
Did you feel anxious during your cross-country round?	X				
Rate your concentration level during your cross-country round				X	
Do you think you met the optimum time?			X		
Do you feel that your horse responded well to your aids during your cross-country round?					X

6.2.1.4 Discussion

Pilot test one highlighted some problems in the HR data collection methodology. An action plan was developed to solve these issues to ensure that the main study methods were efficient and reliable. The questions regarding rider mood were quick and efficient for riders to answer and demonstrated changes in rider mood, so remained the same for the main study methods.

6.2.2 Pilot test two: HRM equipment

It was noted during Pilot test one that the signal of the horse's heart rate was lost several times during exercise (cross-country phase and subsequent cooldown), which may indicate that the electrodes would move following on from the cross-country warm up which would affect the validity of the analysis period we intended to use in the cross-country start box. Additionally, there was the risk that due to the design of the sensor, the strap could slip back over the horses back legs which could cause the horse to panic and potentially injure itself or the rider. Additionally, the watches used in Pilot test one were not capable of recording HRV, so a new type of equine sensor and new watch receivers were tested during Pilot test two to enable analysis of horse and rider HRV. The receiver devices were also checked to ensure that they were set to sample every second, as the receiver watch used for the rider in pilot test one was mistakenly set to sample once every 60-seconds. Furthermore, an additional Polar watch was tested to record GPS information from the horse and rider.

Although it was not intended to analyse data from any point at which the horse or rider were exercising, it was vital that the equipment stayed in place so that the equipment was correctly fitted to obtain HRV data whilst subjects were stationary. As the equine sensor lost signal during the cross-country within Pilot test one, this could indicate that this sensor is vulnerable to being displaced or losing contact as a result of exercise, which could also occur during the cross-country warm-up. It was vital that the equipment remained correctly fitted after the cross-country warm up so that reliable data could be collected whilst the horse and rider were stationary in the cross-country start box, thus a new sensor was tested for Pilot test two.

6.2.2.1 Materials and methods

A different type of equine HR sensor available from Polar was obtained so that it could be tested for its ability to remain correctly fitted and maintain signal during and thus following, exercise. New watches were also obtained that were capable of recording HRV from the sensors and were tested during Pilot test two.

6.2.2.1.1 Equipment

A list of materials used during Pilot test two can be seen in Table 6-6. An image of the Polar H7 Equine electrode sensor set can be seen in Figure 6-5.

Table 6-6: Equipment and materials used for Pilot test two.

Equipment	Used for	Horse or Rider?
Polar H7 Equine Electrode Sensor Set	HR/HRV	Horse
Polar V800 Watch	HR/HRV	Horse
Spectra 360 Electrode Gel (Parker Laboratories)	Sensor	Horse
Polar H7 Human Sensor Strap	HR/HRV	Rider
Polar V800 Watch	HR/HRV	Rider
Water	Sensor	Rider
Polar V800 Watch	GPS	Horse & Rider

Figure 6-5: Polar H7 Equine Electrode Sensor Set.

6.2.2.1.2 Fitting the Polar H7 equine electrode sensor set

The positive electrode was located at the right shoulder and the negative electrode at the middle of the left thorax as described by Schmidt et al (2010a). The saddle was placed on top of the positive electrode, and the girth was placed over the negative electrode, thus keeping them in place. Electrode gel was used to cover the entire area of both electrodes to ensure good contact with the horse's body as recommended (Chapter Five, Section 5.4.2.4). The wires and receiving sensor were all strapped up together in a Velcro pouch that was then strapped to the breastplate of the horse (Figure 6-6). An additional polar V800 watch was attached to the horse's breastplate to record GPS data including the horse and rider speed, location and altitude, as it was intended at this point that it may be possible to link this with GPS map data for each cross-country course.

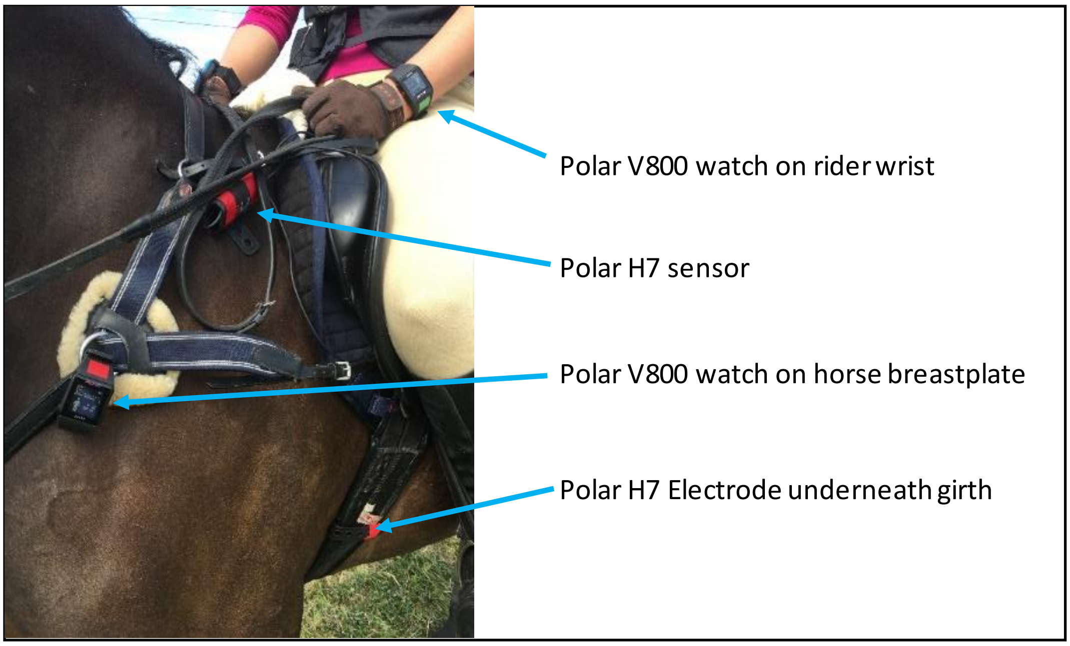


Figure 6-6: Polar H7 Equine Electrode Sensor Set fitted to a horse.

Figure 6-7: Satellite view of the all-weather galloping track.

6.2.2.1.3 Procedure

The test took place on a half mile oval all-weather galloping track (Figure 6-7) with one participant (age 51, height 164 cm, weight 62 kg) and one horse (age 9, height 180 cm, weight 625kg). The rider was instructed to ride at a canter/gallop pace, but with changes in speed around the track at the locations identified prior, including halting and re-establishing canter/gallop. The rider rode four laps of the track, equivalent to the time of a typical BE80-100 cross-country course 435-475 meters per minute (Figure 6-8).

Figure 6-8: Horse and rider galloping on the all-weather track.

6.2.2.2 Results

The horse HR/HRV data collected using the new type of equine sensor was continuous throughout the recording with no loss of signal (Figure 6-9). The new type of watch also successfully recorded rider HRV and HR with no loss of signal (Figure 6-10). GPS data was continuous with no loss of signal, changes in speed were recorded at the identified points on the track which confirmed that the GPS device could demonstrate changes in speed at specific points.

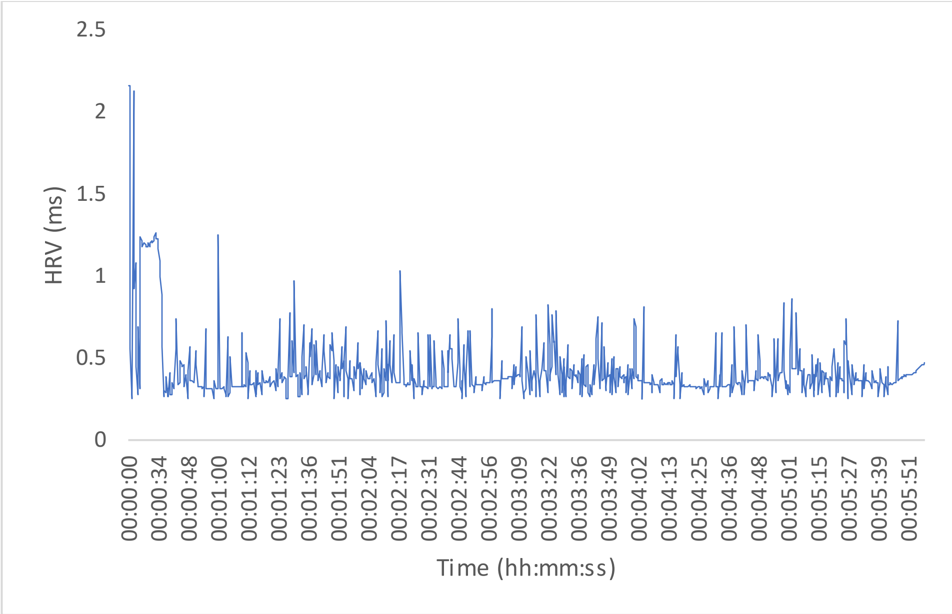


Figure 6-9: Horse heart rate variability during training exercise, raw data which represents the time between successive RR-intervals (in ms).

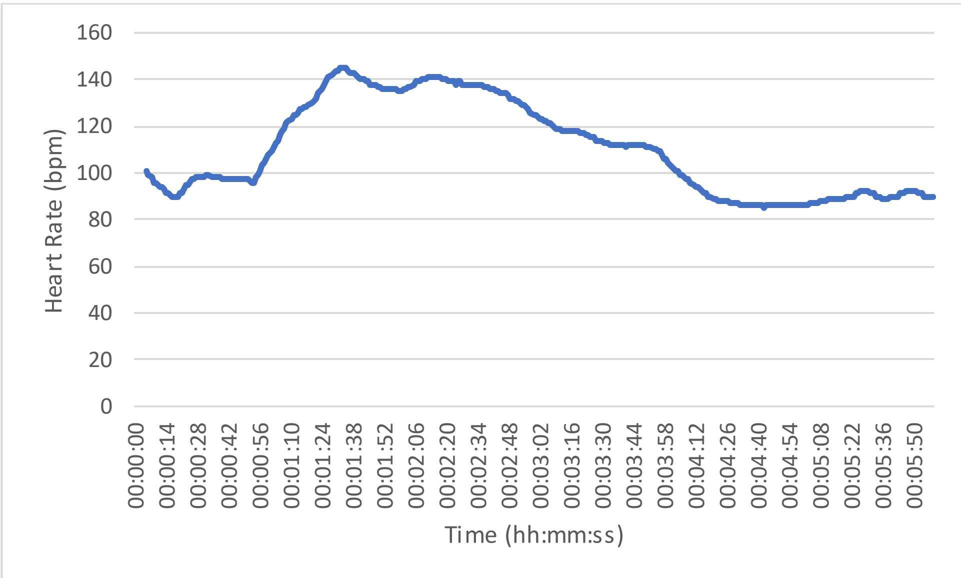


Figure 6-10: Rider heart rate during training exercise.

6.2.2.3 Discussion

The pilot test confirmed that the Polar H7 Equine electrode sensor set could maintain connection during riding exercise; indicative that the equipment did not move or lose connection during high speed exercise and thus would be sufficient to collect data whilst subjects are stationary, following exercise. The recordings appeared consistent, and signal was not lost at any point. The rider reported that the equine electrode set posed no disruption to riding. The electrode set did not appear to affect the horse in any manner, such as freedom of movement or irritation. Due to the findings of Pilot test one and two the Polar H7 Equine electrode sensor set was chosen to record horse HR and HRV data for the main study. The Polar H7 Equine sensor strap was used to collect resting data from the horse due to the ability of the strap to be used independently, without the need for any tack which could affect the horses resting data. During Pilot test one, the Polar H7 equine sensor strap did not lose signal or move during resting measurements in horses and thus was deemed suitable to use in this context.

6.3 Materials and methods

6.3.1 Ethics

All research was approved by the appropriate ethics committees at the University of Central Lancashire:

Animal Welfare and Ethics Review Board (AWERB)

Reference: RE/15/05

Date Approved: 30.06.16

Science, Technology, Engineering, Medicine and Health (STEMH) ethics

Reference: STEMH 483

Date approved: 15.08.2016

6.3.2 Materials

HR/HRV Equipment used during the main study can be seen in Table 6-7.

Table 6-7: HR/HRV and GPS equipment used during the main study.

Equipment	Used for	Horse/Rider?	During?
Polar H7 Equine Electrode Sensor Set	HR/HRV	Horse	Mounted*
Polar H7 Equine Sensor Strap	HR/HRV	Horse	Unmounted*
Polar V800 Watch	HR/HRV	Horse	All instances
Spectra 360 Electrode Gel (Parker Laboratories)	HR/HRV (Sensor)	Horse	All instances
Polar H7 Human Sensor Strap	HR/HRV	Rider	All instances
Polar V800 Watch	HR/HRV	Rider	All instances
Water	HR/HRV (Sensor)	Rider	All instances
Polar V800 Watch	GPS	Horse & Rider	All instances

*Polar equine sensor strap was used for instances where no rider or tack was on the horse (i.e. resting at home and resting at competition).

6.3.2.1 Fitting the HR and HRV equipment to horse and rider

HR and HRV equipment were fitted to horse and rider as per the methods outlined in Section 6.2.1.2.2 and 6.2.1.2.3.

6.3.2.2 Data collected

Several different types of data were collected from horse and rider at competition. See Table 6-8 for types of data collected and an explanation of each in the text thereafter.

Table 6-8: Details of data collected from horse and rider during research testing (March – October 2017).

	Measure	When	Where
Horse	HR/HRV	@ Rest	Home
	HR/HRV	@ Rest	Competition
	HR/HRV	Cross-country warm up Cross-country start box	Competition
Rider	HR/HRV	@ Rest	Home
	HR/HRV	@ Rest	Competition
	HR/HRV	Cross-country warm up Cross-country start box	Competition

HR and HRV were selected due to their use in non-invasively quantifying stress of horses and humans (Giles et al, 2016; Schmidt et al, 2010a; von Borell et al, 2007). The HR and HRV of both horse and rider were recorded simultaneously, allowing analysis of any potential effect that the horse and rider have on each other's physiological response. The mood of the rider was analysed using the Exercise Induced Feeling Inventory (EIFI) questionnaire due to its validity in assessing the feeling states that occur in combination with physical activity (Gauvin & Rejeski, 1993). The psychological response of riders at eventing competition is not yet understood so this information is valuable in developing an understanding of the potential stress that event riders' experience. Further questions were developed for the purpose of the research to collect information on the rider's motivation to win and their thoughts on their own and their horses' performance that day. The rider was also asked if they noticed any frangible pins on the course. Barnett (2016) reported that there was an increased risk of a horse and rider partnership having a horse fall at a frangible fence than at a fixed fence. The reason behind this increased risk may be attributed to the rider's knowledge of the frangible device, perhaps giving them the confidence to ride the fence faster or in a riskier style knowing that a rotational fall is less likely. The other potential reason for this increased risk is that it could be assumed that course designers will use frangible devices on the most dangerous fences and therefor more falls will happen on these specific fences. Collecting data on the rider's knowledge of the presence of frangible fences will assist in understanding this increased risk.

6.3.2.3 Recruitment of participants

An advert was produced to invite riders who compete in British Eventing competition to volunteer to participate in the study. The advert was shared using social media platforms Facebook and Twitter. The advert was sent to industry professionals and pages with a large social media following, who posted the advert to their accounts. The advert used on social media can be seen in Appendix XIII.

British Eventing agreed to offer an incentive to any riders who applied to take part in the study. The incentive was the potential to win a year's free British Eventing registration for one rider and one horse (worth £215 - £310 dependent on horse current grade). The incentive was drawn as a prize draw at the end of the 2017 eventing season, once all data collection at competition had ceased. All riders who applied to take part in the study were included in the prize draw, regardless of their inclusion in the study. A number was assigned to each individual who had applied and a random number generator was used to select the winner. The winner and British Eventing were then informed and arrangements made for the winner to utilise their prize during the 2018 eventing season.

An online questionnaire format of application form was used for riders who wanted to apply to take part in the study. The website 'survey monkey' (Survey Monkey Inc. San Mateo, California, USA) was used to collect applications, the form can be seen in Appendix XIV. Once applications had been gathered, a recruitment sample frame (Appendix XV) was developed and used to select participants with a range of demographics in mind, such as age, sex and competition level; to attempt to obtain a sample that is representative of the general population of eventing horses and riders. The sample cannot be truly representative of the general population however, due to the nature of the recruitment process, requiring participants to volunteer. Participants that are willing to volunteer for studies may represent a certain bias within a population.

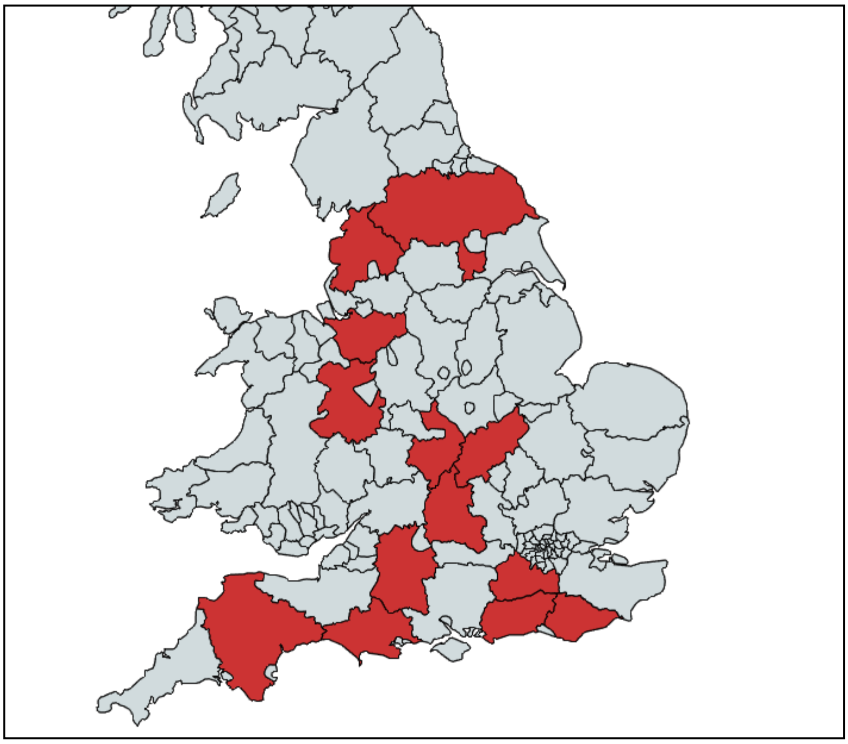


Figure 6-11: Map displaying counties where participants were located in the UK (highlighted in red).

A convenience sampling approach was conducted whereby regions that had several volunteers were selected for inclusion. This was done to enable multiple horse/rider data collections at (presumably) matched locations, due to riders travelling to competitions closest to their respective region. Participants that were selected to be included in the study were then emailed and informed that they had been selected and a mutually suitable date was arranged for baseline data collection. The locations of participants can be seen in Figure 6-11. Participant recruitment was set at a number of 16 participants which was deemed the maximum that the lead researcher could collect data from during one season of eventing. Any additional participants who fit the criteria but were not selected were asked if they consented to being on a waitlist. The waitlist was created so that if any participants had to withdraw from the study for any reason then the first participant on the wait list would be contacted in the hope that they would replace the withdrawn participant.

The plan for this part of the study was to follow the 16 participants as they competed throughout the eventing season, allowing data from horse and rider partnerships to be collected at more than one competition. This was planned to enable a larger data collection which would account for any incomplete data. Incomplete data collections were expected due to the nature of the sport, i.e. eliminations and withdrawals before cross-country. Furthermore, this would enable analysis of data between different competitions which would aid in determining whether values seen are consistent across different competitions. The number of competitions was not capped but a minimum of two competitions was planned to be recorded for each horse and rider partnership. It was intended that repeated measurements of horse and rider combinations at multiple competitions would enable investigation into whether the placing (in the competition) of the horse and rider prior to the cross-country start affects the stress that they experience. It may have been beneficial to sample an increased number of horse and rider combinations at one point in time however it was agreed with the governing body that we were permitted to recruit participants on a voluntary basis only, by advert of the study. It was agreed that we would not approach eventing riders individually. Furthermore, we stipulated to participants that we would not require them to compete at any specific event and instead would attend any competitions that they were planning to attend regardless of the study (Appendix X) and thus could not request that participants all attend a particular event (for our own convenience). This approach was adopted due to the dangerous nature of the sport; we intended to interfere with horse and rider combinations as little as possible and did not want to be liable for any accidents that may occur.

6.3.3 Methods

6.3.3.1 Study participants

Descriptive information is presented in Table 6-9 for study participants. Of the total number of study participants, nineteen (n=19) horses and fifteen (n=15) riders had resting HR/HRV data successfully collected (i.e. at own location). Fifteen (n=15) horses and thirteen (n=13) riders had data collected at a minimum of one competition. Competition levels included BE90, BE100, Novice and Intermediate. Participants that did not have any data collected at competition were withdrawn due to horse (n=4) or rider (n=2) injury, thus preventing competition entry. Differing numbers of participants were used for different statistical analyses depending on whether relevant data had been successfully collected. Participants used for statistical analyses and their descriptive information are detailed within the relevant results sections.

Table 6-9: Descriptive information for the study sample.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex	Breed
Horse	19	8.74 ± 2.33	165.45 ± 5.42	561.05 ± 43.06	Mare (n=4) Gelding (n=15)	ISH (n=7) TB (n=4) Connemara (n=1) Dutch WB (n=3) Belgian WB (n=1) Holsteiner (n=1) Connemara X TB (n=2)
Rider	15	31.27 ± 9.25	173.76 ± 6.70	67.83 ± 8.86	Male (n=3) Female (n=12)	N/A

6.3.3.2 Baseline data collection

The lead researcher travelled to each participant's horse's location to collect baseline data from the horse and rider, this was either the participants own home where the horse was kept or at a livery yard or field. The location had to be where the horse was kept usually, to minimise any variability in the horses resting data. Before data collection could commence the participant was asked to read, complete and sign various documentation, see Table 6-10.

Table 6-10: Documentation to be read, completed and signed by participant.

	Read	Information required from participant	Signature required
Participant Information Sheet	✓		✓
Participant Consent	✓		✓
Participant Disclaimer	✓		✓
Participant Health Information	✓	✓	
Horse Health Information	✓	✓	
PARQ+	✓	✓	✓

Documents listed in Table 6-10 can be seen in Appendix X. Any questions that the participants had regarding the study were also answered during this time. Upon completion of all the documentation baseline measurements were collected.

6.3.3.2.1 Resting data - horse

All baseline data was collected at each horse's own yard, in their own stable. It was assumed that the horse would produce reliable baseline data in this familiar environment. Methods used for collecting resting HR and HRV data from the horses are outlined in Section 6.2.1.2.4.

6.3.3.2.2 Resting data – rider

Baseline data were collected for the rider as per methods described in Section 6.2.1.2.4. On the same day of baseline data collection all horse and rider combinations were required to ride in the equipment. Procedures were followed as described in Section 6.2.1.2.4 (however data was not recorded). This enabled riders to confirm that the equipment did not interfere with themselves or their horse, prior to wearing the devices at eventing competition.

Upon completion of the paperwork and the baseline data collection, BE was contacted by the lead researcher to inform them that this horse and rider would be taking part in the study. Participants were informed that BE would be in contact with them via email to provide a letter of consent (see Appendix XVI for consent template), for partaking in the research at competition.

6.3.3.3 Competition data collection

A total of 25 competitions were attended during the 2017 eventing season. Data collections were only obtained at 20 of these, no data was collected at five events due to:

- horse injury before cross-country phase
- horse and rider combination eliminated prior to cross-country phase
- rider illness
- competition abandoned due to bad weather
- horse and rider combination withdrawn from competition prior to the cross-country phase.

Incomplete data collections occurred due to:

- equipment malfunction
- horse and rider eliminated or retired during the cross-country

The data collection at competition comprised of data of rider perception, physiological data from horse and rider and course information (GPS mapping). Figure 6-12 is a flow chart describing the order of tasks completed at each competition, with a detailed explanation of each phase of data collection in the subsequent text.

Figure 6-12: Flow chart of tasks completed at competition data collection.

6.3.3.4 Manual GPS mapping of the cross-country

The lead researcher arrived at competitions early in the morning so that a GPS trail of the cross-country could be done prior to the start of competition. The researcher used an Apple iPhone 6S with the App 'CrossCountry App'. The app recorded the GPS trail walked on foot by the researcher. The researcher used the app to mark out exactly where each fence was on the cross-country course, pictures were also taken of each fence and it was noted if the fence had a frangible device fitted.

6.3.3.5 Resting HR/HRV data at competition

Resting data was collected before the horse and rider commenced any phases of the competition as per the methods outlined in Section 6.2.1.2.4 for collecting resting data at home.

6.3.3.5.1 Horse

The horse had no tack or riding equipment (e.g. boots) on at this time and the recording was taken for 60-seconds. Once the recording was complete the equipment was removed from the horse.

6.3.3.5.2 Rider

The horse was either held by someone else or tied in a safe place during the rider's resting data recording which was taken for 60-seconds. After the recording was complete the equipment was removed from the rider.

6.3.3.6 Exercise Induced Feeling Inventory (EIFI)

The EIFI was used in two instances. The first instance was immediately after the rider had their resting HR and HRV recording completed (before any phases of competition had been completed). The rider was asked to complete the EIFI themselves and hand back the completed questionnaire to the researcher. The second instance of EIFI was used after all three phases were completed by the horse and rider. The rider was asked to complete an EIFI questionnaire upon returning to their transport following on from the cross-country round. The rider was asked to fill in the questionnaire themselves and then give the completed questionnaire to the researcher.

6.3.3.7 HR/HRV data collection prior to cross-country and GPS tracking during cross-country

Once the horse and rider had completed the dressage and show-jumping phases the researcher returned to re-fit the necessary data collection equipment for the cross-country phase, as per methods outlined in Section 6.2.1.2.5. Electrical tape was used to firmly tape any wires together to prevent any nuisance to the rider. Additionally, the watch faces were taped over to prevent the rider from being able to view any live data whilst riding, as this could be a distraction and potential safety concern.

A third Polar V800 watch was attached to the horse or rider to record the GPS information of the horse and rider during cross-country. The GPS recording on the Polar V800 recorded GPS location, speed and altitude. The data recorded using Polar V800 watches was stored on the watches and later downloaded to a computer to be analysed.

The researcher and the horse and rider met at the cross-country warm up where the researcher set the polar watches to record. On arrival at the cross-country warm up, the horse and rider stood still for a minimum of one-minute, so that a one-minute HR/HRV sample could be used for analysis. The rider then commenced the warmup until they were called to the cross-country start box. Riders stood in the start box for a minimum of one-minute (to enable a one-minute sample of HR/HRV to be collected for analyses) before being counted down by the official, to begin the cross-country. Upon completion of the cross-country the researcher was waiting at the end of the course so that the watches could be stopped from recording.

6.3.3.8 Rider questions before and after cross-country

The participants were asked to answer questions regarding their current state of mind immediately before and immediately after they completed their cross-country round. These questions were designed in Likert scale format to ensure that time restrictions were adhered to during the countdown to start the cross-country at the start box (see Appendix XI). The questions were asked immediately before and after the cross-country round and were designed to collect descriptive data on how the participant perceived the performance of themselves and their horse at that moment. Questions prior to the cross-country included querying the riders' thoughts on their own and their horses fatigue level at that current moment, as well as their eagerness to do well. Questions after the cross-country asked the rider to rate the difficulty of their completed cross-country round, as well as the anxiety that they felt during the exercise. The lead researcher read these questions out loud to the rider and the rider would give a numerical response from a scale of one to five (one being strongly disagree and five being strongly agree). Furthermore, the researcher made note of any additional (non-mandatory) safety equipment that the rider was wearing such as an air jacket or a stopwatch. The time that the horse and rider began and finished the warm up, waited at the start box, started and finished the cross-country were all noted by the researcher as these moments were key for the analysis of the HR and HRV data.

6.3.3.9 Statistical analysis

All statistical analyses were conducted using SPSS (IBM SPSS Statistics for Windows, Version 26.0) unless otherwise stated.

6.3.3.9.1 Rider questions before and after cross-country

Data collected from the rider questions before and after cross-country are displayed for descriptive purposes only.

6.3.3.9.2 HR/HRV: data preparation

From the recorded RR-intervals, HR (Mean, Minimum and Maximum) and the HRV time-domain variable RMSSD (root mean square of successive RR differences) were calculated using Kubios HRV software (Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland). Kubios settings were adjusted in-line with established procedures from previous studies (Schmidt et al, 2010a; Tarvainen et al, 2002). Artefact correction was set to custom level 0.3, which identifies RR-intervals differing from the previous RR-interval by more than 30%, as artefacts (Lenoir et al, 2007). Additionally, data were detrended following the *smoothness priors* method as described by Tarvainen et al (2002). Specifically, the smoothness parameter within the Kubios software was set to 500ms. A full explanation of the HRV parameter utilised and HRV analysis methods can be found in

Chapter Five, Section 5.4.2.3. HR and HRV data were analysed for four periods of 60-seconds (Table 6-11).

Table 6-11: Time-periods for HR and HRV analysis.

Time-period	Explanation
One	60 seconds, Rest at Home
Two	60 seconds, Rest at Competition
Three	60 seconds, at the cross-country warm up (prior to warm up commencing)
Four	60 seconds, at (inside) the cross-country start box

6.3.3.9.3 HR/HRV during different time-periods at competition

For analysis of the difference between HR/HRV variables between different time-periods at eventing competition, all horse and riders' first measurement at competition was included, this enabled a larger sample size as it did not depend on horses and riders having data collected from multiple competitions. Prior to statistical analysis data were tested using the Shapiro-Wilks test of normality (Appendix XVII). Parametric data were then inspected for outliers. Any parametric data that included outliers violated the assumptions of an ANOVA and thus a Friedman's test was used in these circumstances to prevent loss of data. This resulted in all HR/HRV data being analysed for difference between time-periods at eventing competition using a Friedman's test. Post-hoc pairwise comparisons were performed with a Bonferroni correction for multiple comparisons.

6.3.3.9.4 Difference between HR/HRV for matched time-periods at competition one and two

For analysis of the difference between HR/HRV variables during different time-periods at two different competitions, only horses and riders who had data collected at two competitions were included (due to lack of data beyond two competitions). Any data from horses and riders at a third or fourth competition were therefore not included in this analysis. Prior to statistical analysis, data were tested using the Shapiro-Wilks test of normality (Appendix XVII). Parametric data were inspected for outliers; any parametric data that included outliers violated the assumptions of a Paired-T Test and thus a Wilcoxon signed-rank test was utilised to prevent loss of data in these circumstances. Prior to input into a Wilcoxon-signed rank test, data were checked using histograms to determine whether the distribution of differences between the two related groups were symmetrical in shape. Non-parametric data were analysed for differences between competition one and two using a Wilcoxon signed-rank test. Effect sizes for results of Wilcoxon signed-rank tests were calculated using the following formula as recommended by Rosenthal (1994):

$$r = \frac{Z}{\sqrt{N}}$$

Parametric data were analysed for differences between competition one and two using a Paired-samples T-test. Effect sizes for results of Paired-samples T-Tests were calculated using the following formula as recommended by Cohen (1998):

$$d = \frac{mean_D}{SD_D}$$

6.3.3.9.5 Association between horse and rider RMSSD

To investigate the association between horse and rider RMSSD at time-period three and four, all combinations first complete data collection (i.e. competition one) were included. Time-period three and four were utilised as these were the only time-periods where the riders were mounted on the horses. RMSSD was analysed to investigate whether there was an association between horse and rider stress, due to this parameter reflecting PNS activity. Prior to statistical analysis, data were tested using the Shapiro-Wilks test of normality which revealed all variable combinations intended for analysis to include non-parametric data (Appendix XVII). Scatter plots were visually inspected to determine if a monotonic relationship existed between relevant variables before data were analysed using a Spearman's rank-order correlation.

6.3.3.9.6 Exercise Induced Feeling Inventory

To investigate whether there was any difference in EIFI scores prior to and following eventing competition, all riders first complete EIFI data collection (i.e. competition one) were included. Participant scores were calculated for each subscale from the responses given (Positive Engagement, Revitalisation, Tranquillity and Physical Exhaustion). The scores for each subscale were labelled as 'Pre-competition or 'Post-competition so that analysis could be done to compare the scores before and after the cross-country phase of competition. Prior to statistical analysis, data were checked using histograms to determine whether the distribution of differences between the two related groups were symmetrical in shape. A Wilcoxon signed-rank test was then conducted to investigate the difference between rider matched scores prior to (Pre) and following (Post) the eventing competition. Effect sizes for results of Wilcoxon signed-rank tests were calculated using the following formula as recommended by Rosenthal (1994):

$$r = \frac{Z}{\sqrt{N}}$$

6.3.3.9.7 Exercise Induced Feeling Inventory (Pre and Post cross-country) between competition one and two

To investigate whether there was any difference in EIFI scores pre and post competition between competition one and two, all riders that had two complete EIFI data collections from two competitions were included. Participant scores were calculated for each subscale from the responses given (Positive

Engagement, Revitalisation, Tranquillity and Physical Exhaustion). The scores for each subscale were labelled as 'Pre-competition or 'Post-competition' so that analysis could be done to compare the scores before and after the cross-country; scores were then split into 'Competition 1' and 'Competition 2'. Prior to statistical analysis, data were checked using histograms to determine whether the distribution of differences between the two related groups were symmetrical in shape. A Wilcoxon signed-rank test was then conducted to investigate whether there was a difference between rider matched scores prior to (Pre) and following (Post) the competition between two competitions. Effect sizes for results of Wilcoxon signed-rank tests were calculated using the following formula as recommended by Rosenthal (1994):

$$r = \frac{Z}{\sqrt{N}}$$

6.3.3.9.8 Association between horse and rider RMSSD and the Exercise Induced Feeling Inventory

Horse and rider RMSSD values were linked to the relevant (matched) rider EIFI scores and analysed for correlation. Due to this analysis containing one ordinal and one continuous variable, a non-parametric test was deemed appropriate. Prior to analysis, scatter plots were visually inspected to determine if a monotonic relationship existed between relevant variables. A Spearman's rank-order correlation was then conducted.

6.3.3.9.9 Power analyses

Post-hoc analyses of power were conducted on correlations using conducted using RStudio, developed by RStudio Team (2015), and the R programming language by the R Development Core Team (2008). The pwr.r.test function was utilised from the pwr library, which implements power analysis as outlined by Cohen (1988). The sample size, correlation coefficient and p-value were utilised to calculate the power of each relevant study using this function.

6.4 Results

6.4.1 Rider questions before and after cross-country

6.4.1.1 Sample

The sample included thirteen unique riders (n=13). Information regarding subjects included in this analysis can be seen in Table 6-12. This sample included riders competing at BE90 (n=2), BE100 (n=7), Novice (n=2) and Intermediate (n=2).

Table 6-12: Descriptive information for the study sample of rider questions before and after cross-country.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex
Rider	13	32.73 ± 9.76	175.71 ± 6.82	70.14 ± 9.14	Male (n=3) Female (n=10)

6.4.1.2 Descriptive statistics

6.4.1.2.1 Rider questions before cross-country

Descriptive results for rider questions before cross-country can be seen in Table 6-13 and Table 6-14.

Table 6-13: Descriptive statistics for rider questions before cross-country (likert-scale).

Question	Median	IQR
'Your level of fatigue?'	2.00	1.00
'Horses level of fatigue?'	2.00	1.00
'Your level of anxiety?'	3.00	2.00
'Your eagerness to do well?'	5.00	1.00
'Horses level of response to you today?	4.00	1.00

Table 6-14: Descriptive statistics for rider questions before cross-country (yes/no answers).

Question	Yes n (%)	No n (%)
Rider aware of frangible pins?	5 (38.46%)	8 (61.54%)
is this horse for sale?	1 (7.69%)	12 (92.31%)
Is rider wearing a watch?	8 (61.54%)	5 (38.46%)
Is rider wearing an air jacket?	5 (38.46%)	8 (61.54%)
Is this the first horse to be ridden around the course by this rider?	12 (92.31%)	1 (7.69%)
Is rider aware of dressage score?	8 (61.54%)	5 (38.46%)
Has rider looked at overall scores in tent?	3 (23.08%)	10 (76.92%)

6.4.1.2.2 Rider questions after cross-country

Descriptive results for rider questions after cross-country can be seen in Table 6-15 and Table 6-16.

Table 6-15: Descriptive statistics for rider questions after cross-country (1 to 5 Likert scale).

	Median	IQR
'Difficulty of cross-country round?'	3.00	2.00
'Level of anxiety during cross-country?'	2.00	2.00
'Level of concentration during cross-country?'	5.00	0.00
'Do you think you met the optimum time?'	2.00	3.75
'How well did the horse respond to you during cross-country?'	4.00	2.00

Table 6-16: Descriptive statistics for rider questions before cross-country (yes/no answers).

	Yes n (%)	No n (%)
'Were there any fences that the horse attempted to refuse?'	3 (23.08%)	10 (76.92%)
'Did rider meet the optimum time?'	3 (23.08%)	10 (76.92%)

6.4.2 HR/HRV during different time-periods

6.4.2.1 Subjects

The sample included thirteen unique horses (n=13), thirteen unique riders (n=13) at competitions of BE90 (n=2), BE100 (n=7), Novice (n=2) and Intermediate (n=2) level. Information regarding subjects included in this analysis can be seen in Table 6-17.

Table 6-17: Descriptive information for the study sample of HR/HRV during different time-periods.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex	Breed
Horse	13	8.69 ± 1.93	165.92 ± 5.20	561.54 ± 44.27	Mare (n=2) Gelding (n=11)	ISH (n=5) TB (n=3) Connemara (n=1) Danish WB (n=2) Belgian WB (n=1) Holsteiner (n=1)
Rider	13	32.73 ± 9.76	175.71 ± 6.82	70.14 ± 9.14	Male (n=3) Female (n=10)	N/A

6.4.2.2 Descriptive statistics: horse

Descriptive statistics for Horse HR/HRV variables are displayed in Table 6-18.

Table 6-18: Descriptive statistics for horse HR/HRV during different time-periods. Mean/Median and SD/IQR are provided as appropriate for normality (non-parametric data denoted by grey background).

		Time-period 1	Time-period 2	Time-period 3	Time-period 4
Mean HR	Mean/Median	36.26	41.30	54.86	115.01
	SD/IQR	± 3.38	5.20	23.22	± 26.99
Min HR	Mean/Median	35.21	39.69	46.25	100.94
	SD/IQR	± 3.10	5.57	12.81	± 23.67
Max HR	Mean/Median	38.10	44.96	68.18	131.72
	SD/IQR	± 4.53	5.20	64.10	± 35.54
RMSSD	Mean/Median	23.51	27.46	22.42	4.59
	SD/IQR	9.84	19.28	28.00	4.59

6.4.2.3 Descriptive statistics: rider

Descriptive statistics for Rider HR/HRV variables are displayed in Table 6-19.

Table 6-19: Descriptive statistics for rider HR/HRV during different time-periods.

		Time-period 1	Time-period 2	Time-period 3	Time-period 4
Mean HR	Mean/Median	72.23	110.56	115.25	139.52
	SD/IQR	20.44	± 18.84	± 20.79	± 18.49
Min HR	Mean/Median	67.19	101.55	102.14	130.31
	SD/IQR	21.12	± 19.57	± 14.65	± 17.83
Max HR	Mean/Median	81.44	118.67	129.03	146.96
	SD/IQR	± 15.85	± 18.98	± 30.39	± 20.35
RMSSD	Mean/Median	20.99	10.28	11.75	4.43
	SD/IQR	± 7.78	± 5.78	± 5.05	± 1.70

6.4.2.4 Statistical analyses

6.4.2.4.1 Rider HR/HRV during different time-periods at eventing competition

Mean HR

A Friedman test was run to determine if there were differences in Mean HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Mean HR was statistically significantly different at the different time-periods $\chi^2(3) = 27.109$, $p<0.001$. Post-hoc analysis revealed that time-period four (Median = 149.82) was significantly higher than time-period one (Median = 72.23) ($p<0.001$) and two (Median = 115.95) ($p=0.049$). Time-period three (Median = 117.39) was also significantly higher than time-period one ($p=0.006$) (Figure 6-13).

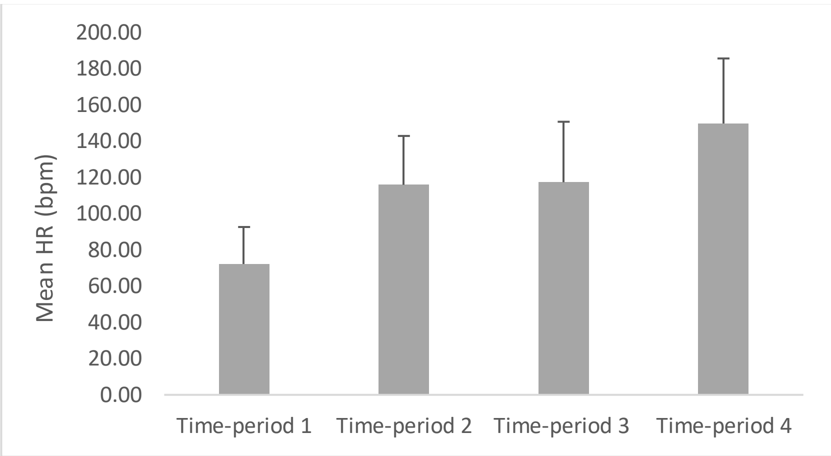


Figure 6-13: Median values for rider Mean HR during each time-period. Error bars represent interquartile range.

Min HR

A Friedman test was run to determine if there were differences in Minimum HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Minimum HR was statistically significantly different at the different time-periods $\chi^2(3) = 26.891$, $p<0.001$. Post-hoc analysis revealed that time-period one (Median = 67.19) was significantly lower than time-period two (Median = 107.03) ($p=0.018$) and time-period four (Median = 132.33) ($p<0.001$). Time-period three (Median = 108.19) was also significantly lower than time-period four ($p=0.018$) (Figure 6-14).

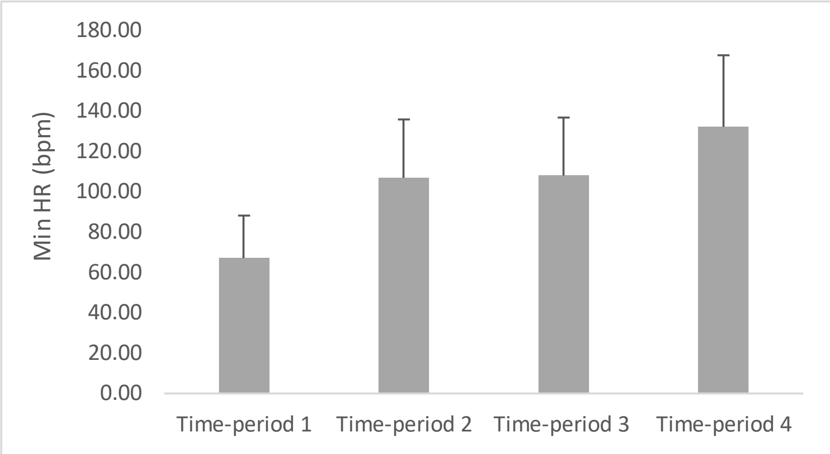


Figure 6-14: Median values for rider Min HR during each time-period. Error bars represent interquartile range.

Max HR

A Friedman test was run to determine if there were differences in Maximum HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Maximum HR was statistically significantly different at the different time-periods $\chi^2(3)$ = 25.473, p<0.001. Post-hoc analysis revealed that time-period one (Median = 80.45) was significantly lower than time-period two (Median = 123.41) (p=0.049), three (Median = 128.87) (p=0.006) and four (Median = 157.07) (p<0.001) (Figure 6-15).

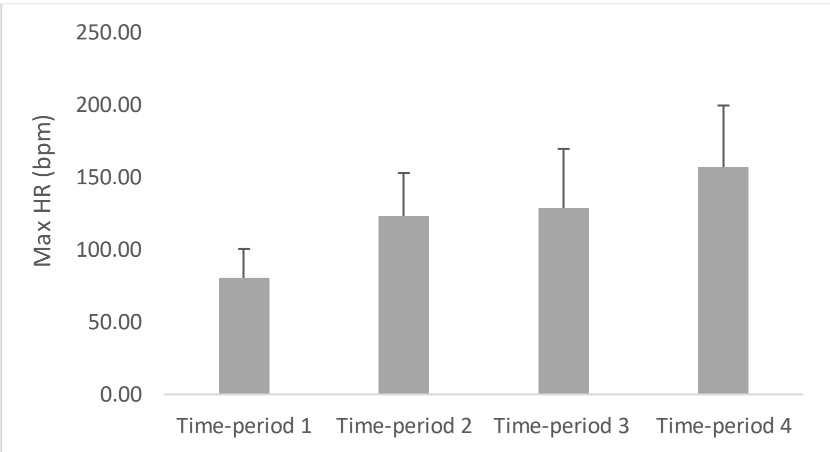


Figure 6-15: Median values for rider Max HR during each time-period. Error bars represent interquartile range.

RMSSD

A Friedman test was run to determine if there were differences in RMSSD during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. RMSSD was statistically significantly different at the different time-periods $\chi^2(3)$ = 20.127, p<0.001. Post-hoc analysis revealed that time-period four (Median = 4.46) was significantly lower than time-period one (Median = 22.86) (p<0.001) and time-period three (Median = 11.53) (p = 0.049) (Figure 6-16).

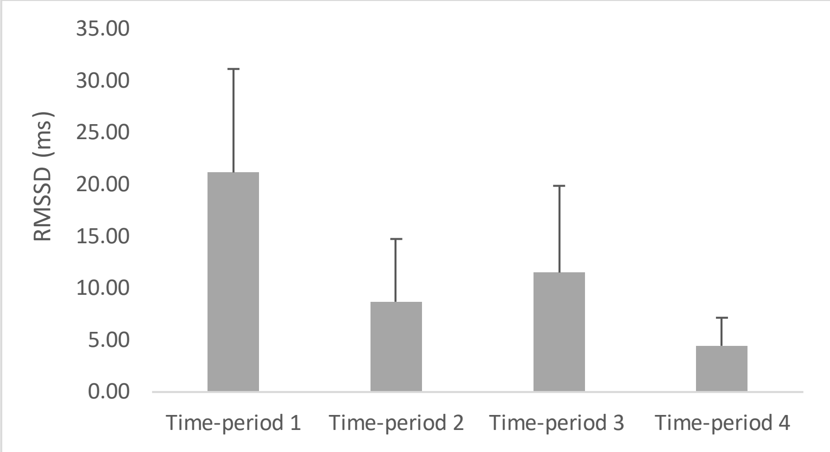


Figure 6-16: Median values for rider RMSSD during each time-period. Error bars represent interquartile range.

6.4.2.4.2 Horse HR/HRV during different time-periods at eventing competition

Mean HR

A Friedman test was run to determine if there were differences in Mean HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Mean HR was statistically significantly different at the different time-periods $\chi^2(3) = 36.692$, $p<0.001$. Post-hoc analysis revealed that time-period four (Median = 112.04) was significantly higher than time-period one (Median = 35.71) ($p<0.001$) and two (Median = 41.23) ($p<0.001$). Time-period three (Median = 54.86) was also significantly higher than time-period one ($p=0.002$) (Figure 6-17).

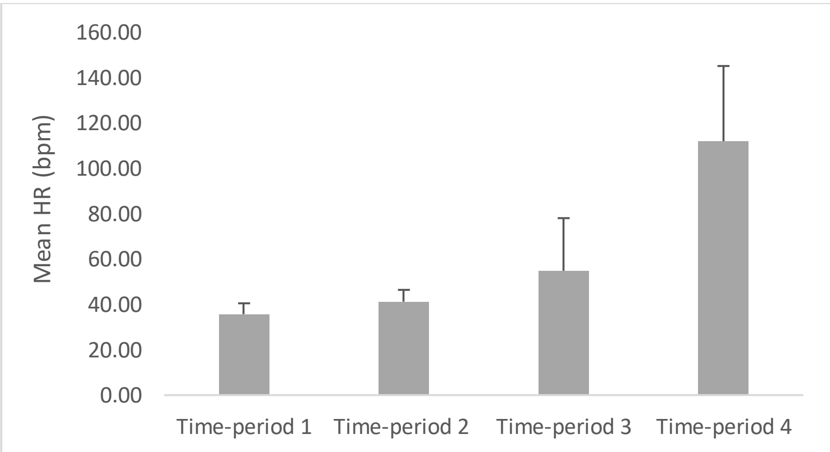


Figure 6-17: Median values for horse Mean HR during each time-period. Error bars represent interquartile range.

Min HR

A Friedman test was run to determine if there were differences in Minimum HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Minimum HR was statistically significantly different at the different time-periods $\chi^2(3) = 34.200$, $p<0.001$. Post-hoc analysis revealed that time-period four (Median = 104.15) was significantly higher than time-period one (Median = 34.70) ($p<0.001$) and two (Median = 39.69) (<0.001). Time-period three (Median = 46.25) was also significantly higher than time-period one (p=0.002) (Figure 6-18).

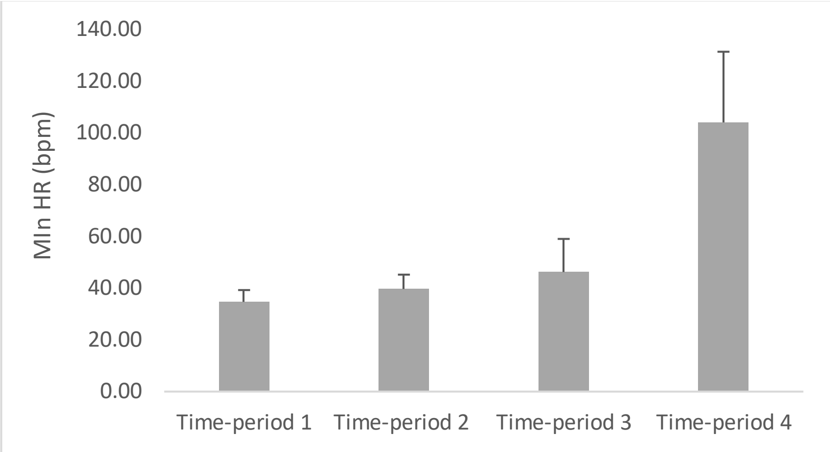


Figure 6-18: Median values for horse Min HR during each time-period. Error bars represent interquartile range.

Max HR

A Friedman test was run to determine if there were differences in Maximum HR during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Maximum HR was statistically significantly different at the different time-periods $\chi^2(3) = 29.215$, $p<0.001$. Post-hoc analysis revealed that time-period four (Median = 125.05) was significantly higher than time-period one (Median = 37.71) ($p<0.001$) and two (Median = 44.96) ($p=0.009$). Time-period three (Median = 68.18) was also significantly higher than time-period one ($p=0.001$) (Figure 6-19).

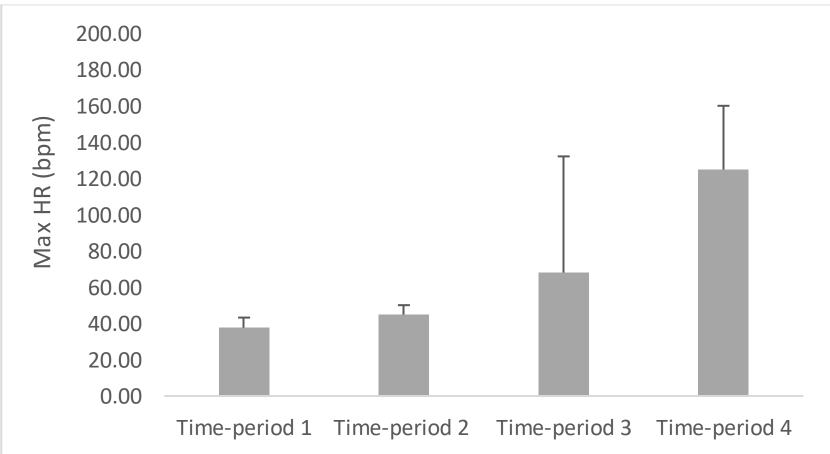


Figure 6-19: Median values for horse Max HR during each time-period. Error bars represent interquartile range.

RMSSD

A Friedman test was run to determine if there were differences in RMSSD during four different time-periods. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. RMSSD was statistically significantly different at the different time-periods $\chi^2(3) = 23.492$, $p<0.001$. Post-hoc analysis revealed that time-period four (Median = 4.59) was significantly lower than time-period one (Median = 23.51) ($p=0.001$), two (Median = 27.46) ($p<0.001$) and three (Median = 22.42) ($p<0.001$) (Figure 6-20).

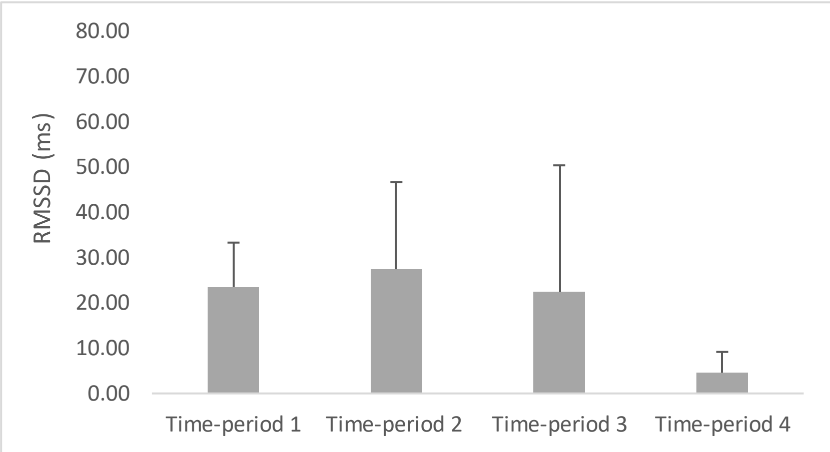


Figure 6-20: Median values for horse RMSSD during each time-period. Error bars represent interquartile range.

6.4.3 Differences between HR/HRV during different time-periods at two eventing competitions

6.4.3.1 Subjects

The sample included eight unique horses (n=8) and seven unique riders (n=7). Information regarding subjects included in this analysis can be seen in Table 6-20. The time between competition one and competition two ranged from 14 to 35 days (mean = 23 ± 7.98 days). Competitions of BE90 (n=2), BE100 (n=3), Novice (n=2) and Intermediate (n=2) were included.

Table 6-20: Descriptive information for the study sample of HR/HRV during different time-periods at two different competitions.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex	Breed
Horse	8	8.13 ± 1.55	167.77 ± 4.78	565.63 ± 43.71	Mare (n=1) Gelding (n=7)	ISH (n=4) TB (n=1) Danish WB (n=1) Belgian WB (n=1) Holsteiner (n=1)
Rider	7	31.00 ± 6.95	174.89 ± 7.27	69.50 ± 10.27	Male (n=2) Female (n=5)	N/A

6.4.3.2 Statistical analyses

6.4.3.2.1 Differences in rider HR/HRV during different time-periods at two eventing competitions

For data analysed by Wilcoxon signed-rank test, the difference scores were approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. For data analysed with a Paired-samples T-Test, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. No statistically significant differences were found for rider HR/HRV variables at different time-periods between two eventing competitions (Table 6-21).

Table 6-21: Differences in rider HR/HRV during different time-periods at two different competitions. Paired T-Tests (denoted by white background) and Wilcoxon tests (denoted by grey background) are used as appropriate for normality.

Variable	Competition	Mean/Median	SD/IQR	t/Z	P	Effect Size
Mean HR						
Time-period two	1	110.95	22.53	-0.477	0.650	-0.180
	2	115.26	13.99			
Time-period three	1	117.39	22.36	-0.338	0.735	-0.090
	2	118.87	14.57			
Time-period four	1	139.35	16.19	0.945	0.381	0.357
	2	136.12	11.58			
Min HR						
Time-period two	1	101.89	24.02	-0.176	0.866	-0.067
	2	103.83	15.36			
Time-period three	1	105.59	13.45	-0.507	0.612	-0.507
	2	105.48	18.72			
Time-period four	1	130.95	15.81	1.177	0.284	0.445
	2	125.52	10.96			
Max HR						
Time-period two	1	118.12	22.25	-1.082	0.321	-0.409
	2	126.11	17.61			
Time-period three	1	132.86	31.40	0.000	1.000	0.000
	2	129.25	31.23			
Time-period four	1	146.25	15.23	-0.127	0.903	-0.048
	2	146.85	9.98			
RMSSD						
Time-period two	1	10.95	7.18	0.720	0.498	0.272
	2	8.52	3.67			
Time-period three	1	12.01	8.20	-1.183	0.237	-0.316
	2	7.31	4.76			
Time-period four	1	5.29	3.88	-0.507	0.612	-0.316
	2	5.05	3.12			

6.4.3.2.2 Differences in horse HR/HRV during different time-periods at two eventing competitions

For data analysed by Wilcoxon signed-rank test, the difference scores were approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. For data analysed with a Paired-samples T-Test, no outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Competition two elicited a statistically significant median increase in horse Minimum HR at time-period three compared to competition one (z=2.24, p=0.025). No other statistically significant differences were found for horse HR/HRV variables at different time-periods between two eventing competitions (Table 6-22).

Table 6-22: Differences in horse HR/HRV during different time-periods at two different competitions. Paired T-Tests (denoted by white background) and Wilcoxon tests (denoted by grey background) are used as appropriate for normality.

Variable	Competition	Mean/Median	SD/IQR	t/Z	P	Effect Size
Mean HR						
Time-period two	1	40.64	4.66	-1.120	0.263	-0.280
	2	38.82	6.54			
Time-period three	1	51.26	11.49	-1.540	0.123	-0.385
	2	71.68	26.04			
Time-period four	1	112.73	32.71	-0.965	0.367	-0.341
	2	122.15	39.26			
Min HR						
Time-period two	1	39.17	4.56	-1.260	0.208	-0.315
	2	38.19	4.91			
Time-period three	1	44.52	9.65	-2.240	0.025*	-0.560
	2	57.31	33.50			
Time-period four	1	100.66	28.73	-0.234	0.822	-0.083
	2	103.09	36.88			
Max HR						
Time-period two	1	43.90	5.72	-0.980	0.327	-0.245
	2	39.44	8.07			
Time-period three	1	75.17	33.25	-1.303	0.234	-0.461
	2	149.86	42.80			
Time-period four	1	120.26	30.32	-1.820	0.069	-0.455
	2	171.20	70.38			
RMSSD						
Time-period two	1	30.06	12.42	0.751	0.477	0.266
	2	26.19	15.05			
Time-period three	1	26.46	6.65	-0.169	0.866	-0.042
	2	16.36	53.24			
Time-period four	1	4.48	9.88	-0.980	0.327	-0.245
	2	5.78	5.26			

6.4.4 Association between horse and rider RMSSD

6.4.4.1 Subjects

The sample included eleven matched horse and rider combinations (n=11). Information regarding subjects included in this analysis can be seen in Table 6-23. Competitions of BE90 (n=3), BE100 (n=5), Novice (n=2) and Intermediate (n=1) were included.

Table 6-23: Descriptive information for the study sample of association between horse and rider RMSSD.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex	Breed
Horse	11	8.73 ± 2.00	165.68 ± 5.92	565.45 ± 46.50	Mare (n=2) Gelding (n=9)	ISH (n=6) TB (n=2) Danish WB (n=1) Belgian WB (n=1) Connemara (n=1)
Rider	11	32.73 ± 9.76	175.71 ± 6.82	70.14 ± 9.14	Male (n=3) Female (n=8)	N/A

6.4.4.2 Statistical analysis

Preliminary analysis showed the relationship to be monotonic, as assessed by visual inspection of a scatterplot. No statistically significant association between horse and rider RMSSD at time-period three or four were found (Table 6-24).

Table 6-24: Spearman rank correlation of horse and rider RMSSD during time-period three and four at eventing competition.

		Median	IQR	r_s	P
Time-period three	Horse	21.97	7.77	0.118	0.729
	Rider	11.53	8.37		
Time-period four	Horse	4.48	3.29	0.027	0.937
	Rider	4.46	2.71		

6.4.4.3 Power of the study

The alpha level used for this analysis was $p < 0.05$. Post-hoc power analysis revealed that the statistical power of the study was 0.75 for RMSSD at time-period three, and 0.94 for RMSSD at time-period four.

6.4.5 GPS data

Due to technical difficulties the GPS data that was used to record information on fence location and type was lost before it could be downloaded to be analysed (Mobile phone application – CrossCountryApp). Due to the loss of the GPS data that had the fence locations the GPS data recorded of the horse/rider trail of the cross-country could not be analysed for the approach to specific fences. The GPS data of the horse and rider trail of the cross-country was reviewed to see if the fences could be located using the speed information alone but this was not possible as the sample rate of the GPS was too slow (1 sample per second). Using this GPS data alone would have entailed speculation and estimation and would not have been scientifically accurate. For this reason, the GPS data was entirely omitted from analysis.

6.4.6 EIFI pre and post competition

6.4.6.1 Subjects

The sample included thirteen unique riders (n=13). Information regarding subjects included in this analysis can be seen in Table 6-17, Section 6.4.2.

6.4.6.2 Statistical analysis

The difference scores were approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. Rider tranquillity was statistically significantly higher after (Post) competition than before (Pre) competition (z=-2.129, p=0.033). No other statistically significant differences were found for Pre and Post competition EIFI scores (Table 6-25).

*Table 6-25: Wilcoxon signed-rank test for pre and post competition values of the four subscales from the EIFI at all competitions. A * denotes statistical significance at p<0.05.*

Pre & Post Cross-Country	Median	IQR	Z	p	Effect Size
Revitalisation					
Pre	6.00	3.50	-0.136	0.892	-0.03
Post	6.00	4.00			
Tranquillity					
Pre	6.00	4.50	-2.129	0.033*	-0.42
Post	7.00	3.00			
Physical Exhaustion					
Pre	3.00	5.00	-0.990	0.322	-0.19
Post	5.00	4.00			
Positive Engagement					
Pre	9.00	3.50	-0.804	0.421	-0.16
Post	9.00	4.00			

6.4.7 EIFI pre and post competition: differences between two competitions

6.4.7.1 Subjects

The sample included eight unique riders (n=8). Information regarding subjects included in this analysis can be seen in Table 6-26. Competitions of BE90 (n=2), BE100 (n=3), Novice (n=1) and Intermediate (n=2) were included.

Table 6-26: Descriptive information for the study sample of differences between rider EIFI at two different competitions.

	N	Age (mean ± SD)	Height (mean ± SD)	Weight (mean ± SD)	Sex
Rider	8	29.38 ± 7.91	174.89 ± 7.27	68.31 ± 10.08	Male (n=2) Female (n=6)

6.4.7.2 Statistical analysis

The difference scores were approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. No statistically significant differences were found for Pre and Post competition EIFI scores between two eventing competitions (Table 6-27).

Table 6-27: Wilcoxon signed-rank test for differences in Pre and Post competition rider EIFI subscales between competition one and two.

	Competition	Median	IQR	Z	p	Effect Size
Revitalisation						
Pre	1	5.00	4.00	-0.426	0.670	-0.107
	2	5.50	1.75			
Post	1	6.00	6.25	-1.581	0.114	-0.145
	2	7.00	2.00			
Tranquillity						
Pre	1	5.50	4.25	-0.256	0.798	-0.064
	2	5.50	2.50			
Post	1	7.50	2.50	-0.447	0.655	-0.112
	2	8.00	1.75			
Physical Exhaustion						
Pre	1	1.50	5.25	-0.368	0.713	-0.092
	2	3.00	5.25			
Post	1	5.50	4.00	-1.466	0.143	-0.367
	2	3.00	5.25			
Positive Engagement						
Pre	1	9.00	5.75	-0.368	0.713	-0.237
	2	7.00	6.25			
Post	1	9.50	5.25	-1.73	0.084	-0.433
	2	12.00	2.75			

6.4.8 Association between RMSSD and EIFI

6.4.8.1 Subjects

The sample included eleven matched horse and rider combinations (n=11). Information regarding subjects included in this analysis can be seen in Table 6-23, Section 6.4.4.1.

6.4.8.2 Descriptive statistics

Descriptive statistics for horse and rider RMSSD can be seen in Table 6-24, Section 6.4.4.2. Descriptive statistics for rider EIFI scores are displayed in Table 6-28.

Table 6-28: Descriptive information for the study sample of association between RMSSD and rider EIFI subscales.

		Median	IQR
Pre	Revitalisation	4.00	4.00
	Tranquillity	6.00	4.00
	Physical Exhaustion	1.00	6.00
	Positive Engagement	9.00	4.00
Post	Revitalisation	5.00	7.00
	Tranquillity	8.00	3.00
	Physical Exhaustion	5.00	5.00
	Positive Engagement	9.00	6.00

6.4.8.3 Statistical analysis

6.4.8.3.1 Association between rider EIFI subscales and horse and rider RMSSD during time-period three

Preliminary analysis showed the relationship to be monotonic, as assessed by visual inspection of a scatterplot. There was a statistically significant, strong positive correlation between Horse RMSSD during time-period three and rider Positive Engagement Post competition, $r_s(9)= 0.837$, $p=0.001$. No other statistically significant differences were found for Pre and Post competition EIFI scores and horse and rider RMSSD during time-period three (Table 6-29).

*Table 6-29: Spearman Ranked Correlation for the four subscales of the EIFI (rider) and horse and rider RMSSD values at time-period 3 (cross-country warm-up). A * denotes statistical significance at p<0.05.*

			Horse RMSSD	Rider RMSSD
Pre	Revitalisation	r_s	0.550	-0.171
		p	0.080	0.615
	Tranquillity	r_s	0.240	-0.174
		p	0.478	0.609
	Physical Exhaustion	r_s	-0.272	0.000
		p	0.418	1.000
	Positive Engagement	r_s	-0.037	0.046
		p	0.914	0.893
Post	Revitalisation	r_s	0.327	-0.263
		p	0.326	0.435
	Tranquillity	r_s	0.280	-0.184
		p	0.403	0.588
	Physical Exhaustion	r_s	-0.139	0.088
		p	0.684	0.797
	Positive Engagement	r_s	0.837	-0.220
		p	0.001*	0.516

6.4.8.3.2 Association between rider EIFI subscales and horse and rider RMSSD during time-period four

Preliminary analysis showed the relationship to be monotonic, as assessed by visual inspection of a scatterplot. There was a statistically significant, strong positive correlation between Horse RMSSD during time-period four and rider Tranquillity Post competition, $r_s(9)= 0.786$, $p=0.004$. No other statistically significant differences were found for Pre and Post competition EIFI scores and horse and rider RMSSD during time-period four (Table 6-30).

*Table 6-30: Spearman Ranked Correlation for the four subscales of the EIFI (rider) and horse and rider RMSSD values at time-period 4 (cross-country start box). A * denotes statistical significance at p<0.05.*

			Horse RMSSD	Rider RMSSD
Pre	Revitalisation	r_s	0.208	-0.217
		p	0.540	0.521
	Tranquillity	r_s	0.235	-0.254
		p	0.487	0.452
	Physical Exhaustion	r_s	-0.048	0.416
		p	0.889	0.203
	Positive Engagement	r_s	0.493	-0.263
		p	0.123	0.435
Post	Revitalisation	r_s	-0.203	-0.115
		p	0.550	0.736
	Tranquillity	r_s	0.786	0.253
		p	0.004*	0.453
	Physical Exhaustion	r_s	0.573	0.152
		p	0.065	0.655
	Positive Engagement	r_s	0.196	-0.257
		p	0.563	0.445

6.4.8.4 Power of the study

The alpha level used for this analysis was $p < 0.05$. Results of post-hoc power analysis for correlations between rider EIFI and horse and rider RMSSD during time-period three and four are presented in Table 6-31 and Table 6-32, respectively.

Table 6-31: Post-hoc power analysis results for correlations between rider EIFI and RMSSD at time-period three.

		Horse	Rider
Pre	Revitalisation	0.53	0.67
	Tranquillity	0.59	0.66
	Physical Exhaustion	0.59	1.00
	Positive Engagement	0.92	0.90
Post	Revitalisation	0.54	0.57
	Tranquillity	0.56	0.65
	Physical Exhaustion	0.72	0.81
	Positive Engagement	NA	0.61

Table 6-32: Post-hoc power analysis results for correlations between rider EIFI and RMSSD at time-period four.

		Horse	Rider
Pre	Revitalisation	0.62	0.61
	Tranquillity	0.60	0.58
	Physical Exhaustion	0.89	0.53
	Positive Engagement	0.53	0.58
Post	Revitalisation	0.63	0.76
	Tranquillity	NA	0.58
	Physical Exhaustion	0.53	0.69
	Positive Engagement	0.64	0.58

6.5 Discussion

The first aim of the study was to investigate pre-competitive stress/arousal experienced by horses and riders at eventing competition and explore whether there is an association between stress/arousal of horse and rider combinations in these circumstances. The second aim of the study was to investigate rider feeling states before and after the cross-country phase of eventing competition and explore any association between the riders' feeling states and horse/rider stress/arousal prior to the cross-country phase of eventing competition. The third aim of the study was to explore whether there was any difference in horse and rider speed of approach to cross-country fences depending on fence type.

To our knowledge, this is the first study to measure horse and rider stress prior to the cross-country at eventing competition. The highest levels of stress/arousal were identified in horses and riders immediately before the cross-country (in the start box). No significant differences were found for stress measures between two different competitions, indicating that the stress response is consistent across different competitions. No association between horse and rider stress was found at time-periods prior to the cross-country at competition, indicating that they do not affect one-another in the context of physiological stress.

To our knowledge, this is the first study to investigate rider's feelings-states at eventing competition. Tranquillity was significantly higher in riders after the cross-country in comparison with before. No significant differences were found for any of the EIFI scores between competition one and two, indicating that the riders' feelings states were consistent between two different competitions. Horse stress at the cross-country warm-up was significantly positively correlated with rider positive engagement following the cross-country round. Additionally, horse stress at the cross-country start box was significantly positively correlated with rider tranquillity after the cross-country round, indicative that horse stress may influence riders' feeling states. No other statistically significant correlations were found between horse/rider stress measures and rider EIFI.

6.5.1 Rider HR/HRV at competition

The rider had the lowest recorded HR during rest at home with a gradual increase over rest at competition, before the cross-country warm up and at the cross-country start box, with maximum HR values increasing over time-periods in this order. An increase in rider Mean HR during rest at competition in comparison to rest at home supports findings of a previous study that reports HR alterations due to fear and anxiety prior to BMX sports competition (Mateo et al, 2012). Increases in HR are mainly caused by physical activity but decreases in HRV indicate a stress response (Lewinski et al, 2013), therefore it is useful to use HRV measures to quantify psychological stress during sporting competition.

High levels of anxiety during sport competition has been widely reported in people (Gould et al, 1983; Sonstroem, 1984) and psychological stress such as this has been reported to influence heart rate and heart rate variability (Taelman et al, 2008). Pre-competitive anxiety has been reported to have negative effects on performance in sports such as golf (Weinberg & Genuchi 1980), with participants who reported low levels of competitive trait anxiety performing better than those who reported high levels. Competitive state anxiety may be related to the general responses and activation of a person's physiological systems to competition and could therefore be associated with functions within the ANS, and more precisely the SNS (Mateo et al, 2012). As discussed in Chapter Two, Section 2.2.2.3, HRV is primarily modulated by the autonomic nervous system and is sensitive to changes in emotional state (Mateo et al, 2012).

RMSSD values decrease due to inhibition of parasympathetic activity under stress conditions. As RMSSD is the most sensitive HRV parameter, it is useful for short duration recordings and is therefore valid as an indicator of pre-competitive emotional state (Morales et al, 2013). A decrease in RMSSD can be an indicator of anxiety (Mateo et al, 2012). In the current study, rider RMSSD was significantly lower at the cross-country start box than at rest (at home) and the cross-country warm up. These findings suggest that the rider experiences the highest levels of stress during the time-period within the cross-country start box. Mateo et al (2012) studied BMX riders at rest and at competition and reported that RMSSD values were significantly lower 20 minutes before competition than at rest. The results of the current study support the finding by Mateo et al (2012), indicating that eventing riders experience pre-competitive anxiety similar to what is seen in other sports persons such as BMX riders, although in the current study the finding was immediately prior to the beginning of the competition. Lewinski et al (2013) stated that riders experienced minimum RMSSD values of 3.8 ms during a dressage performance. In comparison, the eventing riders within the current study experienced minimum RMSSD values of 2.13 ms, indicating that eventing riders may experience more extreme levels of stress and anxiety whilst waiting at the cross-country start box than riders who are riding in a dressage performance.

The reason for the high levels of stress and anxiety experienced by riders at the cross-country start box is not clear and can only be speculated upon. Lewinski et al (2013) discussed that riders may experience heightened stress during a dressage performance due to them being influenced by the expectations of the spectators and any increased demands of their trainers. Eventing riders may also experience these psychological stressors but additionally they will be aware of the risk involved in the cross-country phase of eventing, so they are not only predisposed to the anxiety of wanting to perform well but also to complete the cross-country safely, without injury to themselves or their horse.

Alternatively, the results may indicate a normal anticipatory reaction from the riders. van Paridon et al (2017) stated that SNS activity (e.g. reflected by HRV parameters) is linked to challenge and effort in humans however hypothalamic-pituitary-adrenal (HPA) activity (e.g. reflected by cortisol) is linked to lack of control, harm and unpredictability. Dickerson and Kemeny (2004) reported however that cortisol is linked to psychological stressors such as motivation and goal-relevant performance, indicating that HPA activity can also be linked to positive stressors. Previous studies have reported a strong anticipatory rise in HPA activity in extreme sports. For example, Meyer et al (2015) investigated the cortisol response in first-time compared with experienced sky divers to a sky dive and found that the average cortisol response demonstrated an increase of 45% from baseline measures to 15 minutes before the sky dive. Indeed, even the experienced sky divers (median of 208 previous jumps) had significant increases in cortisol prior to the sky dive, indicating that they had not habituated to the experience (Meyer et al, 2015). These findings may support the statement by van Paridon et al (2017), as it would be reasonable to assume that the feelings experienced in anticipation of jumping out of a plane may be linked to fear. As RMSSD is linked to SNS activity, we could speculate that the low values seen in the current study are linked to the challenge and effort (in line with van Paridon et al, 2017) that is imminent in the cross-country phase of competition, rather than negative emotions such as fear and anxiety. Additionally, there is evidence that a moderate increase in stress can enhance performance, such as increasing reaction times (Taylor et al, 2011). In fact, van Paridon et al (2017) reported that an inverted-U theory relationship exists between cortisol and performance, suggesting that a rise in stress is needed to aid performance, but that extreme increases in stress will be detrimental to performance.

It is difficult to draw similarities between this study and previous research, as there is no other research currently published on the mental stress/arousal that is experienced by riders at eventing competition. Further research is needed to understand how the stress response found in riders within the current study may affect performance. Furthermore, future research should be designed to measure the stress response of riders in combination with riders self-reported feelings/mood using tools that are directly relevant to the valence of stress as reported by previous studies (e.g. tools that measure anxiety, fear, motivation and goal orientation).

6.5.2 Horse HR/HRV at eventing competition

HR/HRV data has been previously utilised for research in equestrian eventing however this research has focused on the physiological demands of the sport (training and competition) (Kirsch et al, 2020; Lorello et al, 2017; Serrano et al, 2001, 2002; Valle et al, 2013). For example, Serrano et al (2002) said that mean HR ± SD of the horse during eventing cross-country was 195 ± 8, indicating that the cross-country is extremely physically demanding for the horse. In the current study, horse Mean HR was significantly higher at the cross-country start box than during rest at home and rest at competition. Additionally, horse Mean HR was significantly higher at the cross-country warm-up than during rest at home. Physical activity increases the heart rate of the horse (Bartolomé & Cockram, 2016), thus it is difficult to use HR alone as measure of mental stress. HRV values such as RMSSD reflect SNS and PNS activity and are therefore a valuable addition to HR measurements in assessing mental stress in horses (von Borell et al, 2007). To our knowledge the current study is the first to use HR/HRV analysis to quantify mental stress/arousal at eventing competition.

Although mean HR of the horse had the lowest values during rest at home (possibly indicating relaxation or lack of physical exertion), RMSSD was also low at this time-period (indicating stress). As the horse was not exercising during rest at home (nor had exercised immediately prior to the measurement) these findings indicate that the horse was experiencing some level of mental stress during this period (although not significantly different than other time-periods). Furthermore, the horse was not exercising at the start box at cross-country, which also suggests that the low HRV variable values for RMSSD at this time-period are indicative of the horse experiencing mental stress.

Horse RMSSD was significantly lower at the cross-country start box than during rest at home, rest at competition and the cross-country warm up. RMSSD is used to estimate high-frequency beat-to-beat variations that represent mainly PNS activity, with a reduction in this measure indicating decreased PNS activity (von Borell et al, 2007). The findings of the current study suggest that the horse experienced the highest stress levels at the cross-country start box. Previous studies into other equestrian sports have reported a stress/arousal response in horses to competitions. For example, Becker-Birk et al (2013) found that RMSSD of the horse significantly decreased during preparation for competition in comparison with basal values. The authors stated that the significant decrease in RMSSD was found whilst the horse was in a stable being prepared for the competition (grooming and saddling), indicating that the horse had an anticipatory response associated with the preparation for competition (Becker-Birk et al, 2013). The reason that horses experience the highest mental stress levels at the start box of cross-country could be because the horse is anticipating the cross-country round. All British Events have a cross-country start box which is typically made in the same design, so it could be assumed that horses such as the ones used in this study recognise the start box and produce an anticipatory reaction, as they have experience in eventing and have seen the start box many times.

Horses are known for their fight or flight instinct. It could be assumed that whilst horses are experiencing mental stress levels such as what have been found in this study they may be inclined to 'flight'. Lewinski et al (2013) suggested that if horses/riders are highly trained then the horses flight response can be contained, either by the horse who is adapted to coping with this level of stress, or the rider who is highly trained enough to be able to manage the horses flight response. Thus, horses may be experiencing a flight response in the cross-country start box but may not display behaviours associated with this. Riders may therefore have no knowledge of the mental stress their horse is experiencing.

The stress experienced by horses in eventing could either have a positive or negative effect on performance. During exercise, heart rate and plasma cortisol concentration is increased in the horse. As discussed in Chapter Two, Section 2.2.2.1, cortisol has many necessary functions that are beneficial to the horse for the adaption to exercise. However, high concentrations of cortisol during extended periods can be detrimental to the horse and can cause detrimental effects including immune suppression and muscle wasting (Bartolomé & Cockram, 2016). Additionally, long term increased cortisol concentration can alter the cortisol circadian rhythm in the horse, thus also affecting homeostasis (Bartolomé & Cockram, 2016). The results of the current study indicate that eventing horses could be predisposed to these detrimental effects if they are competed regularly, considering the high stress levels shown to be experienced by the horse at eventing competition. For research involving humans, tools can be used such as self-reporting mood or feelings questionnaires which can aid in researchers understanding of the valence of human physiological measures of stress/arousal. The valence of the stress experienced by horses however can only be speculated upon. In future, behavioural indicators of stress could be utilised in combination with physiological measures which may aid in understanding the valence of equine stress. It may be that horses are experiencing eustress (e.g. excitement) or distress (e.g. fear or anxiety). If the stress/arousal experienced by horses in eventing is excessive and repeated/prolonged then the valence of the stress (i.e. eustress or distress) may be irrelevant in the context or horse welfare, as the physiological response in the body will remain the same (thus predisposing those horses to the health problems associated with prolonged, heightened levels of glucocorticoids).

Becker-Birck et al (2013) also found that horse RMSSD values decreased over each day of competition in a three-day period, which suggests that the demands of the competition increased for the horse each day. The finding by Becker-Birck et al (2013) could be linked to Bartolomé and Cockram (2016) statement that prolonged exposure to stress can have a detrimental effect on the horse and interfere with the cortisol circadian pattern. Perhaps when horses compete in several, successive phases of competition they have not had adequate time to recover from each exercise, so the stress experienced by the horse increases with each exposure to exercise. This may mean that horses are beginning the cross-country phase in a sub-par physiological state which could affect their performance, and ultimately their safety. Further research is needed to identify acceptable levels of stress, and how often the horse can cope with these levels of stress/arousal without having a detrimental effect on health or welfare. Additionally, research should aim to identify whether the stress experienced by horses in the cross-country start box is beneficial, or detrimental to performance (and thus safety). The current study has identified that horses experience high levels of stress/arousal prior to the cross-country phase of competition, which warrants further investigation.

6.5.3 Association between horse and rider RMSSD

Equestrian sport is unique in that it requires the collaboration and teamwork of two non-related species. Lewinski et al (2013) said that a strong bond between horse and rider is a requirement for success in competitions when coping with emotional and physical challenges. Although there is information about horse and rider individual responses to competition, the effect they have on each other is much less understood (Lewinski et al, 2013). No association between horse and rider RMSSD at the cross-country warm up or the cross-country start box was found in the current study.

Riders have previously attested that their horses can detect and react to the rider's mood states, leading to a change in performance (Tenenbaum et al, 2002). However, the findings of the current study support the findings of previous studies; that horse and rider stress is not correlated (Ille et al, 2013). The majority of previous studies that have discussed the importance of the horse/rider relationship have come to their conclusions due to rider perceptions, so it could be that the rider perceives that the horse is affected by their emotional state, but in reality it is not the case.

Previous studies have considered how the physical actions of the rider affects the horse (e.g. use of the aids, asymmetry, training method utilised) and have reported significant effects on the performance or behaviour of the horse (McGreevy and Murphy, 2009), however it appears that this is the extent to which the rider impacts on the horse. From the evidence available, rider mental state does not appear to impact the mental state of the horse.

6.5.3.1 Power of the study

Cohen (1988) recommends power to be a minimum of 0.80 to ensure an 80% probability of detecting an effect when there is an effect to be detected. Thus, the power for horse and rider RMSSD correlation at time point three is slightly under the accepted measure, but it is unlikely that a biologically plausible larger sample size would have produced a different result. Furthermore, the power of the study for RMSSD of horse and rider at time-period four was adequate, which supports the notion that the lack in significant findings was not due to the sample size being too small.

6.5.4 EIFI

Riders had significantly higher tranquillity after completing the competition in comparison to before. In agreement with the findings of the current study, Annesi and Westcott (2007) found that women who engaged in an acute bout of weight-training exercise were significantly more tranquil than before the exercise. The authors also reported however that participants scored significantly higher in revitalisation, physical exertion, and positive engagement (Annesi & Westcott, 2007), which was not found in the current study. Previous studies have found that high levels of anxiety can have a negative effect on performance (Wolframm & Micklewright, 2009). If a rider is feeling less tranquil prior to the competition, then it could be assumed that they may be experiencing anxiety which could negatively affect their performance. This could also increase the risk for the rider during cross-country as if their performance is negatively affected then they may make a mistake or perform poorly and therefore be at an increased risk of a horse fall. These findings should be interpreted with caution, as tranquillity was the only subscale that was significantly affected by exercise (the three phases of competition), which may indicate poor validity for this tool (EIFI) in the context of eventing sport.

6.5.5 Association between horse and rider RMSSD and rider EIFI subscales

There was a significant positive correlation between horse RMSSD at the cross-country warm-up and rider positive engagement after the competition. Additionally, there was a significant positive correlation between horse RMSSD at the cross-country start box and rider tranquillity after the competition. Understanding the biological meaning of these findings cannot be done with ease; it could be that heightened horse RMSSD (i.e. lower stress) prior to the cross-country is a precursor for better performance of the horse during the cross-country phase. This may be why rider tranquillity and positive engagement (as measured following the cross-country phase) are positively correlated with horse RMSSD, although this can only be speculated upon. Notably, a total of 32 corelations were conducted between rider EIFI and horse and rider RMSSD with only two significant findings.

6.5.6 Power of the study

The power of the study for correlations between rider EIFI and horse and rider RMSSD were inadequate in most circumstances which may indicate that the sample size was not sufficient to make conclusions on these analyses.

6.5.7 Limitations to the study and future improvements

6.5.7.1 Study limitations

1. Due to the data for the study being collected in-field at eventing competitions there were many factors that could not be controlled for. For example, environmental conditions such as weather, temperature, ground condition and spectator presence could not be controlled. Rider feeling-states and HR/HRV could have been affected by several factors including menstrual cycle in women, personal (social) matters, the presence of family, friends or trainers and the horse’s general response to them that day. Horse HR/HRV could have been affected by sub-clinical injury or health problems, stress from travelling, the weather or the layout of the competition. The factors listed here are not exhaustive and are just an example of factors that cannot be controlled during in-field research.
2. One of the limitations of the study was the use of the EIFI. There are other, valid tools that would have been superior for assessing the mood/feelings of riders. For example, a tool that included assessment of anxiety and fear in riders prior to and immediately following the cross-country would have been more appropriate and would have enabled deeper evaluation of the valence of the stress that riders were experiencing. On reflection, the EIFI was not a suitable tool to use for this purpose. Additionally, there is a lack of research that has utilised the EIFI and validation studies of the tool are now dated.
3. Due to this being the first study that aimed to quantify horse and rider mental stress at eventing competition, the study was developed with a lack of relevant prior research to inform appropriate study design. It may have been beneficial to quantify horse/rider mental stress

during additional time-periods at the competition such as prior to the dressage and show-jumping phases. Inclusion of these time-periods would have provided further information on whether the stress response to the cross-country is uniquely extreme, or whether there is a cumulative effect of the three phases which is what causes the extreme values seen at the cross-country start box.

4. The study design may have limited the scope of the research. For example, it may have been beneficial to collect data from additional, unique horses and riders at competitions as certain statistical aspects of the study lacked statistical power. Additional researchers would be required to enable a larger sample size and the governing body would need to permit researchers to approach potential study participants rather than rely on a voluntary application process.
5. Finally, there is evidence for the validity of HRM's to collect HR/HRV data from horses in stationary conditions (see Chapter Five), however previous studies have not included analysis of HRM validity in-between exercise (which is what the current study included). It was assumed that if the HRM devices maintained contact and therefore signal with the electrical activity of the heart, then the HR/HRV data would be reliable when the horse was stationary; although we cannot be certain that this is the case. This is relevant to the time-period at the cross-country start box which was a particular period of interest within the study, thus the results should be considered as preliminary and as such should be used to inform future research and appropriate study design as opposed to being used to inform regulatory changes.

6.5.7.2 Future improvements

The current study has revealed several areas of this field of study that require development and further consideration. In consideration of the findings of the current study, our recommendations for future research are as follows:

1. Future studies should aim to measure stress during additional time-periods at eventing competition such as immediately prior to the other phases of competition.
2. Studies that aim to quantify mental stress in riders at eventing competition should use physiological measures in combination with appropriate psychological rating scales. Appropriate psychological rating scales should include assessment of feelings/moods of interest in the context of mental stress at competition, such as anxiety, fear and exciteme nt.
3. Future studies should aim to identify whether the mental stress that the horse and rider experience at competition affects their performance (including risk of injury/fall).

6.5.8 Recommendations

Due to the current study being the first study to measure the mental stress of horses and riders at eventing competition, the results are preliminary in nature. Due to this, recommendations for applying the study findings will not be made. Instead, suggestions are given for subsequent directions of research which will add to the body of research and enable recommendations for the sport to be made in the future (section 6.5.7).

6.5.9 Contribution to knowledge

The current study has identified that horses and riders experience high levels of stress at the cross-country start box at eventing competition. The mental stress of horses and riders at eventing competition has not (to knowledge) been documented using physiological measures of stress such as HRV, thus this study has made a significant and original contribution to knowledge. The study applied the recommendations put forward in Chapter Five, in the context of appropriate methodology for measuring Equine HR/HRV in-field, in addition to utilising this method to investigate any relationship between horse/rider partnership physiological stress. Data from this study suggests that both horses and riders experience extremely high levels of stress at the cross-country start box, which could have implications for performance, welfare and safety. As discussed, the valence of the stress experienced by horses and riders can only be speculated upon; however, the physiological cost (e.g. to health) of experiencing stress to this degree on a recurrent basis will not discriminate due to valence of emotions felt by horse or rider. Notably, there was no association between horse and partnered rider stress, suggesting that neither horse nor rider affect each other's stress level. There were however findings that horse stress at the cross-country warm-up and start box were associated with rider feelings-states following the cross-country round, in that the less stressed the horse was at these time points, the more tranquil/positively engaged the rider subsequently felt. These findings highlight a possible link between horse stress prior to the cross-country phase and the riders feeling-states after, which warrants further investigation to understand if this impacts performance or safety during the cross-country. The study findings are an important step towards further understanding the mental stress of horses and riders at eventing competition and can be used to develop and progress future research in this field.

6.5.10 Conclusion

This is the first study to assess the mental stress of horse and rider at eventing competition using physiological measures. Furthermore, the study has identified that horses and riders experience significantly higher levels of stress at the cross-country start box, than during other time-periods at eventing competition. The valence of the stress identified in the current study (that is; eustress or distress) is not currently understood. The study has highlighted that this field of research needs further development and consideration. An understanding of the mental stress experienced by horses and riders at eventing competitions is vital as injuries and fatalities continue to occur in the sport. Understanding the effect that stress has on the performance of horse and rider may enable mitigation of risk, thus research was needed to quantify stress in the first instance. Future research is required to develop recommendations for the sport, to ensure optimal performance (and thus reduction in risk) and welfare of human and animal athletes.

7. General Discussion

Horse falls in the cross-country phase of eventing continue to carry the highest risk of serious injury and fatality to the horse and rider. This is supported by the most up-to-date statistics from the eventing governing bodies. For example, the FEI (2021) state that for the 2020 eventing season, one in every four rotational horse falls resulted in serious injury/fatality to the rider, whilst one in every 31 non-rotational horse falls resulted in serious/fatal injury to the rider; making the overall risk of a serious/fatal injury to the rider from a horse fall, one in every 17 falls. Notably, in 2019 the FEI updated their definition of a serious injury to *"Serious injuries can be categorised as those that, in the opinion of the referring doctor, would require hospital admission for immediate treatment. Examples: major fractures (including all compound fractures, but excluding simple fractures of clavicle and wrist), crush injuries with suspicion of pneumothorax, ruptured spleen etc."* (the previous definition can be seen in Chapter Two, Section 2.1.1) (FEI, 2021a). Comparable information is currently not provided by BE however it is apparent from their most recent safety report that the proportion of riders fatally or seriously injured in the sport has risen yearly since 2017 (BE, 2020, May/June). Additionally, figures on BE's most recent report appear to show that a higher proportion of rotational horse falls occurred in the 2019 season than in 2017, and 2018 (BE, 2020, May/June). These data suggest that falls in the sport of eventing continue to be a concern and that efforts to identify contributing factors for horse falls must continue. Indeed, the FEI stated in 2021 that serious injuries are *"a big focus to eliminate"* (FEI, 2021a).

The first study (Chapter Four) within this thesis aimed to investigate risk factors associated with horse falls on the cross-country phase of one-day eventing competition in the UK, through a retrospective data analysis. To knowledge, the data analysis encompassed the largest data set ever analysed for horse falls in eventing. Subsequently, the analysis revealed nine previously unidentified risk factors that are significantly associated with the risk of a horse fall. Two of these risk factors have previously been reported for worldwide FEI competition; Barnett (2016) stated that male riders and higher levels of competition were associated with increased risk of a horse fall (mirroring findings of the current study), however these findings have never been reported for one-day events in the UK. Indeed, there are similarities between the current study and the audit conducted by Barnett (2016), however it is important to note that the Barnett (2016) audit encompassed one-, two, and three-day events which were held worldwide; adding an element of variance to the data that is not present in the current study. Furthermore, although the Barnett (2016) audit was conducted by experienced scientific researchers (adding strength to the findings), it has never been published in a scientific journal or been subject to peer review, which should be taken into consideration.

The current study utilised methods of analysis as inspired by risk factor analysis in horse racing. This novel approach to risk factor analysis in eventing yielded two risk factors in the final model; demonstrating that this approach should perhaps be adopted by future studies also. Horse starts in the previous 60-90 days to competition and the number of days since the riders last start were the two variables identified in the current study using the methodological approaches of racing risk factor analysis. The biological application of these variables is not easy to understand but their retainment in the final model warrants further investigation. It may be beneficial for future studies to alter these methods slightly, for example the time-periods of interest may require modification to ensure that they are representative of the sport of eventing.

Previous research has tended to focus on fence-level risk factors for horse falls in eventing and as such, several studies have identified fence-level risk factors, with clear similarities in the findings between studies. Thus, it is now necessary for other fields of expertise to contribute to the body of knowledge, for example the fields of engineering and physics, to understand why specific fences carry increased risk. The aim of epidemiological analysis is only to identify risk factors; understanding why these factors are associated with risk requires research of a different nature. In contrast with studies that have identified fence-level risk factors for horse falls, the current study has identified a number of risk factors that would be simple for the governing bodies to mitigate, without the necessity of further, arduous research or expertise from different fields. For example, the finding that an increased number of dressage penalties is associated with an increased risk of a horse fall could be alleviated simply by introducing a penalty cap for the dressage phase, whereby riders cannot progress to the show-jumping or cross-country if they surpass this cap in penalties. This is something that BE already have in place for show-jumping; horse/rider combinations that have exceeded 24 penalties in the show-jumping are not permitted to progress to the cross-country (BE, 2018). Additionally, the finding that increased number of previous horse falls in horses' careers are associated with increased risk of a horse fall could be mitigated by implementing a cap on how many horse falls a horse can have in their career before they are no longer permitted to compete in the sport. Alternatively, the governing bodies could use this information to 'flag' horses that have had a certain number of horse falls, to try and ascertain on a case-by-case basis why this is occurring.

The findings of the first study supported previous literature in identifying known risk factors for horse falls in the cross-country phase of eventing, in addition to discovering new, previously unidentified risk factors. This first study thus adds to prior knowledge; that there continues to be identifiable risk factors for horse falls in eventing cross-country and leads into the second study which evaluated the validity of a specific method for assessing stress in horses. Improving methods for assessing stress in horses can be used to inform a wide range of future research; for example, the assessment of stress in horses competing at eventing competitions. In future, this information could also be used to inform studies that aim to investigate how this stress might affect performance and thus risk.

The second study (Chapter Five) within this thesis aimed to review the literature on the use of HRM devices for collecting HR/HRV data for the assessment of stress in horses. A scoping review was conducted, following established methodology for conducting research of this type. After systematic literature searching and a process of study selection and quality assessment was completed, 24 research studies were included. The review critiqued the available validation studies that had tested HRM devices in comparison with the gold-standard ECG, evaluating the findings in depth which enabled consideration of the validity of HRM devices for use in horses. Additionally, to add strength to the study, the review considered research that had utilised HRM devices in combination with other validated measures of stress in horses. This enabled the review to consider not only whether HRM data was statistically significantly comparable to ECG data, but additionally, whether data collected with HRMs could enable researchers to successfully identify periods of stress in horses. It was considered that although HRM devices may not collect statistically significantly comparable data to ECG devices in all conditions (indicating a lack of precision), the devices did tend to enable researchers to identify periods of stress in horses in agreement with other measures of stress such as SC. The findings suggest that HRM devices are useful when attempting to identify changes in horse HR/HRV relevant with baseline measures, but perhaps are inappropriate for situations that require precise values, such as medical assessment/diagnoses. Further to the validity of HRMs, the review considered the variety in methodological approaches used by researchers that utilised the devices. This revealed that there is currently a lack of standardised methodology for using HRMs, however evaluation of the research available permitted some suggestions to be made to optimise the reliability of HRMs. The key findings of the review were that HR/HRV data obtained using HRMs in horses is statistically significantly correlated with ECG data when the horses are in stationary (non-exercising) settings, such as loose in a stable, or tethered. The review highlighted that further research is needed to provide more information on optimal data collection using HRM devices, such as any potential effects of the use of conductive gel, the thickness of the horses coat and the body composition of the horses used.

Previous reviews have been conducted that have evaluated the use of HR/HRV for assessment of stress in horses, in addition to methodological considerations (Stucke et al, 2015; von Borell et al, 2007). There is an absence of previous research however that considered the validity of HRMs for this purpose. Despite this, recent research published in scientific journals continues to utilise HRMs for assessment of HR/HRV in horses (e.g. Ijichi et al, 2019; Mott et al, 2021; Squibb et al, 2018) thus the review is valuable in offering guidance for future studies on optimal settings and analysis methods when using HRMs. It is possible that misinformation has been disseminated within equine research due to inappropriate methods (particularly for studies that utilised HRMs to assess stress of horses during exercise), thus it is imperative that future research focuses on achieving not only parity, to enable true comparisons, but also rigorous, evidence informed techniques to avoid spurious research results. The review conducted in this thesis cannot be conclusive, but certainly contributes to knowledge in this field of study. Furthermore, the findings of the review support the methodological approach adopted in the final study.

The final study (Chapter Six) within this thesis had three aims; the first was to investigate pre-competitive stress experienced by horses and riders at eventing competition and explore whether there is an association between physiological measures of stress in horse and rider combinations in these circumstances. The study involved data collection in-field at eventing competitions in the UK. HR/HRV data were collected at four time-periods for both horse and rider: resting at 'home', resting at competition, at the cross-country warm-up of competition and in the cross-country start box at competition. HRM devices were used to collect HR/HRV data, with data being collected for one-minute intervals whilst both horse and rider were standing still during the time-periods of interest. Results demonstrated that the cross-country start box induced the highest stress response in both horses and riders, with RMSSD during this time-period being significantly lower than all other time-periods for horses, and significantly lower than resting at home and the cross-country warm up in riders. Although the valence of the stress is not known, it is clear that both horse and rider experience high levels of stress at eventing competition. Due to this study being the first to assess the stress of horse/rider at eventing competition, the findings are preliminary but can be used to develop future study designs. It could be that increased levels of stress immediately prior to the cross-country are beneficial and may reduce the risk of a horse fall occurring. On the contrary, high levels of stress at this time-period could be detrimental, increasing the risk of a horse fall. Now that we know that horses and riders do experience high levels of stress prior to the cross-country phase, future research should aim to investigate whether this stress has a detrimental or beneficial effect on performance and therefore risk. No association was found between horse and rider stress, suggesting that they do not affect each other. The horse-human relationship has been previously reported to be a key factor in reducing risk of injury/incident in general horsemanship, as perceived by the rider. The findings of the current study may suggest that the horse-rider relationship is mechanical in nature, whereby movement, weight and posture of the horse and rider can affect one-another however physiological/psychological state does not.

The second aim of the study in Chapter Six was to investigate rider feeling-states before and after eventing competition and explore any association between the riders' feeling-states and horse/rider stress prior to the cross-country. The EIFI was used to collect data on the riders feeling-states prior to and following completion of the competition. Results revealed that riders had significantly higher tranquillity after the competition had finished than before the competition began, indicating that completing the activity increased tranquillity in riders. The findings could also suggest that riders had reduced tranquillity prior to the start of the competition, which could indicate pre-competitive anxiety or nervousness, however this can only be speculated upon as these emotions were not assessed. A correlation test for association between riders' feeling-states and the horse and riders' stress levels revealed that there was a positive correlation between rider positive engagement after the competition was complete and horse RMSSD at the cross-country warm up. Additionally, a positive correlation was found between rider tranquillity after the competition was complete and horse RMSSD at the cross-country start box. Understanding the biological significance of these findings is challenging, however it could be that lower stress levels in the horse are associated with better performance (contrary to what has been reported in previous literature, e.g. Peeters et al, 2013), and thus the rider reports higher tranquillity and positive engagement due to good performance in the cross-country phase (pre-empted by higher RMSSD, which indicates lower stress levels in the horse at the cross-country warm up and start box), which was the last phase to be completed prior to the riders completing the 'post-competition' EIFI. Further research is needed to aid in better understanding of the relationship between rider emotions and horse/rider performance/risk during the cross-country.

The third aim of the study in Chapter Six was to explore whether there was any difference in horse and rider speed of approach to cross-country fences depending on fence type/style. Unfortunately, due to loss of data this aim could not be assessed and this aspect was removed from the study. Research that investigates horse/rider speed of approach to fences would be beneficial considering previous research that reported fence-level risk factors for horse falls (Barnett, 2016; Murray, 2005, 2006b) and that speed of approach (too fast or too slow) also increased risk of horse falls (or rotational horse falls in comparison with non-rotational) (Barnett, 2016; Murray et al, 2005, 2006b).

The study in Chapter Six has provided information on the stress that is experienced by horse and rider at eventing competition. Due to this study being the first study to assess horse and rider stress at eventing competition, the scope of the study is limited and therefore the results should be considered as preliminary. Nonetheless, the study has identified that horses and riders do experience high levels of stress at eventing competition which provides important knowledge to be considered for future research. As discussed, these findings should be built upon by future studies to try and assess how stress affects the performance of horse and rider and thus potentially their risk of horse falls.

Taken together, this thesis provides an overview of the data available from the BE database regarding horse falls during the cross-country phase of one-day eventing competitions in the UK, provides recommendations for the use of HRM devices for assessing stress in horses; subsequently utilising these methods to assess the stress of horse and rider at eventing competition in combination with measuring the riders' feeling-states before and after competition, which providers preliminary findings on horse/rider stress at eventing competition.

The findings of this thesis highlight the importance of research such as this not only to reduce the risk of horse falls, but vitally, to improve the welfare of horses used for the sport. The welfare of horses used in eventing sport is not currently well described in the literature. Furthermore, the governing bodies for horse sport do not currently include horse injury/fatality statistics in their annual reports (BE, 2020, May/June; FEI, 2021a), thus the public (and researchers) have no way of retrieving this information. The audit by Barnett (2016) did include horse injury statistics thus it appears that the data is recorded by the FEI; it is therefore unclear why the governing body do not currently share yearly updates for these statistics. Barnett (2016) reported that the incidence of serious injury/fatality to the horse as a result of horse falls was one in every 42 horses for the period of 2010-2014, indicating that the risk of serious injury/fatality to horses is lower than in riders for the same period (one in every 19 falls) (FEI, 2016, February 26). Nonetheless, it is important to consider that the rider chooses to partake in the high-risk activity of eventing, whereas the horse has no such choice. Riders can make an informed decision regarding whether the risk of injury/fatality is ultimately acceptable to them, the horse cannot. Additional to the inherent risk of injury/fatality to the horse, previous research has investigated other welfare concerns of horses that are used in equestrian sport. For example, McGreevy et al (1995) reported that 30.8% of eventing horses displayed abnormal behaviours and indeed, previous research states that stereotypies in animals should be considered as a warning sign of suffering or poor welfare (Mason & Latham, 2004). Additionally, Hausberger et al (2009) observed 76 horses in their stables for a total of 20-minutes per horse and reported that licking/biting stereotypies were more prevalent in eventing horses than show-jumping, advanced school, dressage, high school or vaulting horses. The findings of Huasberger et al (2009) may indicate that eventing horses are predisposed to higher levels of stress or poor welfare which could cause increased prevalence of stereotypies. It is possible that the prevalence of stereotypies is high in eventing horses due to the stress that they are exposed to at eventing competitions, which is reflected in the findings of the study presented in Chapter Six. Although conclusions cannot be made as to the causal reason for the stress experienced at eventing competition in horse or rider, the findings have highlighted that high levels of stress are experienced by both horse and rider.

As previously discussed, (Chapter Two, Section 2.2.1), an acute stress response prior to or during exercise can be beneficial for performance (and thus may reduce the incidence of risk outcomes such as horse falls). It is vital to consider however that frequent or prolonged exposure to stress (regardless of the valence) can alter the physiological stress response of the body (i.e. excess release of cortisol; which is correlated with HRV) can produce long lasting deleterious effects in both horses and riders (Archer & Proudman, 2006; Bartolomé & Cockram, 2016; Dimsdale, 2008; Ebbesen et al, 2009; Lee et al, 2010; Pouwer et al, 2010). An acute bout of distress could affect the horse welfare in the context of their emotional state, however healthy horses should recover from this quickly, with their plasma cortisol concentrations returning to baseline shortly after competition (Bartolomé & Cockram, 2016). On the contrary, chronic stress in horses can result in poor health, which would be a more serious welfare concern. Further studies need to progress the research in this field, using the preliminary findings of the current study to inform study design. Research should aim to investigate whether the stress that the horse is experiencing is distress or eustress and subsequently, how this stress may affect their welfare, and performance. The stress levels experienced by the rider suggest that riders may benefit from sports psychology education, where they can learn to manage and cope with competition stress.

7.1 Limitations of the thesis

The study presented in Chapter Four is limited by poor data quality as a result of human error and data recording/storing procedures; all of which are the responsibility of the governing body where the data was obtained. Chapter Four is also limited by a lack of analysis for fence- and course-level factors, which would have been beneficial considering the findings of previous literature. The lack of fence- and course-level factors was again related to data quality and availability, as discussed in Section XXXX. The study in Chapter Four is also limited by not being geographically comprehensive (UK only) and only including competitions of a one-day format; this may mean that aspects of horse/rider competition history are absent from the data set. Furthermore, training activity is not recorded thus is also absent from the data set.

The study presented in Chapter Five is limited due to only two databases being utilised to conduct the literature search; use of a third or fourth database may have revealed further studies for inclusion. Additionally, the study in Chapter Five is limited by a lack of available research, necessitating the inclusion and appraisal of studies that utilised other measures of arousal (such as salivary cortisol) in combination with ECG/HRM validatory studies, which presented an element of subjectivity into the review.

The final study, presented in Chapter Six, is limited by the study-design being in-field which prevents control for an unknowable number of variables (i.e. weather/environmental surroundings). In addition, due to the study being conducted at live competition there were restrictive timeframes that had to be adhered to which meant that other, more widely used feeling-states scales could not be used due to their length (i.e. the time it would take to complete), thus appraising the results of the study in relation to previous literature was a challenge. The use of HRM's in-between exercise may also have affected the validity of results, as data collection in these conditions has not been previously validated. Finally, due to this being the first study of its kind, the study design was developed with a lack of previous literature to build on. The study design was therefore limited in that on reflection, further time-points of analysis may have been beneficial as well as utilising a larger number of horses/riders on a singular basis.

Regarding limitations of the thesis overall, the variety in study design between the three pieces of research presented in the thesis affect the overall narrative of the work. This may have been improved by adopting a more aligned, progressive thread of research into horse falls in eventing cross-country, such as focussing on either: epidemiological methods of data analysis to identify risk factors for horse falls, or investigating stress and its effect on horse/rider performance.

7.2 Recommendations and future directions

7.2.1 Recommendations

Individual recommendations arising from each study are available in the relevant study chapters (Chapter Four, Five and Six). General recommendations are provided here in consideration of the collective findings of the thesis:

1. The study has identified key risk factors for horse falls in the cross-country phase of eventing and recent data from the governing bodies confirms that horse falls continue to carry risk of injury and fatality to both horse and rider. Participants of the sport and the relevant authorities must therefore continue to strive to reduce the risk of horse falls in the cross-country.

2. The study findings have indicated that horses and riders experience high levels of stress at eventing competition, in comparison with baseline. This has implications beyond the scope of the study however participants of the sport and relative authorities should have an awareness of the stress placed upon the horse and the rider and should drive research into understanding the possible beneficial or detrimental implications of this.
3. Equestrian researchers should strive to produce rigorous and valid study findings by ensuring that the literature available is consulted in depth, prior to study design. This will ensure that research follows the appropriate recommendations for the intended methodological techniques; this is particularly recommended for the use of technology such as HRMs.
4. Researchers must work to communicate and establish good working relationships with the governing bodies to enable change (as a result of research findings).

7.2.2 Future directions

Individual recommendations for future directions arising from each study are available in the relevant study chapters (Chapter Four, Five and Six). General future directions are provided here in consideration of the collective findings of the thesis:

1. The national governing bodies (e.g. BE) should commit to improving the quality of their data capture and subsequent handling. The quality of research into risk factors for horse falls is highly dependent on the quality of the data. In particular, it is strongly recommended that the national governing bodies focus on improving the cross-referencing of multiple data sets that they have in their possession which would enable researchers to include further variables of interest relating to the course and fences. It is recommended that the world governing body for equestrian sport (FEI) advises the national governing bodies on how to appropriately capture and handle eventing data, this would ensure parity worldwide which would further facilitate progression in the research.
2. Researchers should continue to conduct validation studies on the use of technology such as HRMs for assessment of stress in horses with the aim of providing standardised protocols that will ensure the reliability of the data.
3. Further research is needed into the stress that horses and riders are exposed to as a result of being engaged in the sport. This should include training and competition which would offer a more comprehensive view of the demands placed upon horses and riders.

4. Research is needed to assess whether the stress that horses and riders are exposed to as a result of training/competing in the sport with a view to investigating how stress affects the risk of horse falls in eventing cross-country.

7.3 Contribution to knowledge and Implications of the research

Chapter Four revealed nine risk factors that significantly affect the risk of a horse fall during the cross-country phase of one-day eventing competition in the UK that have not been previously reported in the literature, demonstrating a significant and original contribution to knowledge. In addition to revealing previously unidentified risk factors for horse falls, the findings of the study in Chapter Four also support and expand upon the findings of previous research. These findings can be utilised to add weight to recommendations that can be made to the governing bodies of the sport to direct procedural/rule change in the pursuit of reducing the risk of horse falls and ultimately serious, and fatal injuries to horses and riders. Chapter Five included a review that critically analysed the use of HRMs for measuring equine HR/HRV. The review highlighted that many published studies have not adopted appropriate methods for HR/HRV calculations in horses and subsequently made clear recommendations for improving methodological techniques in this field. The recommendations offered in the review have the potential to improve the quality of research in this field whilst also making recommendations for developing future research. Chapter Six highlighted that horses and riders experience high levels of stress at the cross-country start box at eventing competition. This is the first time that a scientific study has assessed the physiological stress that horse and rider experience at eventing competition, thus making a significant and original contribution to knowledge. The valence of the stress experienced by horses and riders (eustress/distress) can only be speculated upon, however the levels of stress seen in both horse and rider within this study were extreme. The physiological cost (e.g. to health of horse/rider) of experiencing stress to this degree on a recurrent basis warrants further investigation. The study also investigated the association between horse and partnered rider stress, finding no association, indicating that horse and partnered rider stress is independent of one another. The study did reveal however that horse stress at the cross-country warm-up and start box is associated with rider feelings-states following the cross-country round; with further research needed to understand the implications of this association. The study findings pave the way for future studies to investigate the impact that horse/rider stress at competition can have on welfare, performance and safety.

The ideas for this thesis were built upon existing ideas within the literature in combination with the findings of previous, relevant research. The work within this thesis encompasses known approaches and applies them in an original way, such as utilising methods of racing risk factor analysis in the field of eventing. The work also includes the inclusion (and creation) of novel risk-factors for analysis of horse falls. Notably, this thesis also includes a study-design that had never been conducted previously within the literature, to assess the mental stress that horses and riders experience at eventing competition. Conducting research in an unchartered field such as this does not come without challenges, as is clear from reflection on the study design. However, the research has provided preliminary study findings which can be used by future studies to build upon. Furthermore, this thesis has critiqued existing theories by conducting a scoping review on the use of HRM devices for analysis of HR/HRV data in horses, which enabled recommendations for the use of such equipment to collect valid HR/HRV data in horses. This thesis has provided a significant and original contribution to knowledge by providing recommendations from the conducted studies that can be utilised to: (1) implement regulatory changes with the aim of reducing the risk of horse falls during eventing cross-country (Chapter Four), (2) improve the quality of published scientific research by establishing recommendations for appropriate methodology when using HRM devices in horses to collect HR/HRV data (Chapter Five), and (3) inform future research that aims to assess how stress can affect the risk of a horse fall in eventing cross-country by providing preliminary data on the stress that horses and riders are exposed to at eventing competition (Chapter Six).

7.4 Conclusion

The goal of the research presented in this thesis was to improve safety within equestrian sport, with a particular focus on the cross-country phase of one-day eventing competitions in the UK. More work is needed to fill the gaps in knowledge that have been highlighted here, for example to better understand rider psychology. Whilst it will be impossible to completely eliminate the risk of horse falls in eventing cross-country, a number of key conclusions can be drawn from this thesis. First, there are eleven risk factors that predict horse falls during the cross-country phase of eventing based on the statistical analysis of a unique, long-term database. The class of competition was a dominant factor (with more advanced competitions carrying a higher risk). Eventing regulators and those in charge of safety at events are faced with a challenging task of mitigating horse falls and improving rider safety, and the factors in Chapter Four should be considered a priority during safety planning. Although an analysis of a retrospective database such as that presented in Chapter Four can improve our understanding of horse fall risk factors, such an analysis can only provide limited understanding of the mechanisms that might predict a horse fall, such as horse or rider stress. In Chapter Five, I therefore explored the potential viability of using heart rate monitors for monitoring and quantifying stress levels in horses during the cross-country phase of eventing. I found that current methods were not appropriate for use when horses are moving, but they are appropriate when horses are stationary. Another potential mechanism underlying horse falls during the cross-country phase of eventing that is poorly understood, is both rider and horse mental state. In Chapter Six I sought to explore the stress experienced by horse and rider at eventing competition as well as the psychological/physiological relationship between horse and rider, using heart rate variability. I found that horses and riders experience significantly higher levels of stress at the start box than during the other time-periods that were investigated at eventing competition, and highlighted areas for future research. This may reveal an important stage of the competition where event safety can be improved by looking at methods to minimise (or optimise) horse and rider stress during this time. As can be expected from research of this scale, the work met with limitations and difficulties. Despite this, the thesis has set out distinct recommendations as a result of each study, along with recommendations for future research in the ongoing effort to reduce horse falls in eventing cross-country. Sir David Brailsford CBE utilised the concept of *'the aggregation of marginal gains'* to lead British Cycling teams to worldwide success; applying this approach from performance to risk reduction; where a wide range of research techniques are utilised to aggregate many small reductions to the risk of a horse-fall, could ultimately be the difference between life and death for a horse or rider.

8. References

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9. Appendices

Appendix I. Course details file: variables

Event name
Country
Event date
Course designer
CEN
C_ref
course status
Course Class
Course length
Optimum time
Number of starters
Efforts
if CIC was SJ before XC
Technical Advisor
Season

Appendix II. Fence details file: variables

C_Ref
Fence Number
Fence Element
Route
CF_Ref
CFE_Ref
CFER_Ref
FE number
Route Number
alt
Type of fence
Frangible
Portable?
Height
Top spread
Base spread
Jumpable Width
Dist to next fence
Take off out of water
Landing into water
Approach slope
Landing
Take-off rail
Off a bend?
Fence Description
Position in combination
STOP
FT1
FT2
FT3
Approach Ground-Conditions
Landing Ground-Conditions
Slope?
Bend?
Water Feature?
Water Depth
Course Defect?
Details of Course defect
FT1 - Previous fence
FT2 - Previous fence
FT3 - Previous fence

No elements
Id
Season
Same Fence type previously negotiated on this course?
Added Info
Decoy

Appendix III. Incident details file: variables

C_Ref	Weather	C12 Contribution - Horse jumping into Shadow?
Fence Number	Wind?	C13 Contribution - Horse Distracted?
Fence Element	Poor Visibility?	C14 Contribution - Horse Fatigued?
Route	Fall involved a Fence?	C15 Contribution - Horse Impaired (health / injury)?
CFER_Ref	did horse refuse?	C88 Other Contribution?
CF_Ref	way up?	Other Contribution – details
Fence descripton	way down?	Notes
CFE_ref	hit hard?	P01 Precipitated by Horse hitting fence hard?
Element number	break fence?	Fence Judge name
Route Number	tip portable?	Email or Phone no
Form	somersault?	P02 Precipitated by Horse tipping portable Fence?
Country	Rider Hit Fence?	P03 Precipitated by Horse breaking Fence?
Incident Number	Rider's Injury Severity	P04 Precipitated by Horse Somersaulting?
Date	Horse Injured?	P88 Precipitated by some Other Factor?
Time	Horse impacted Fence?	Other Precipitation – details
Event Name	Initial Point of Impact	C07 Contribution - Horse too close to Fence?
Course Class	Did vet attend?	Type of fence
Location	Initial Angle of Impact	Frangible break
Fall Type	C01 Contribution - Situation misjudged by rider?	Frangible
Horse fell / trod on Rider?	C02 Contribution - Rider Inexperience?	Season
Text Description of Incident	C06 Contribution - Uncontrolled Horse?	AirJacketWorn
Did Continue	C03 Contribution - Rider Distracted?	AirJacketActivated
C10 Contribution - Horse Slipped?	C04 Contribution - Rider Impaired (drink / drugs)?	Rider's Programme Number
Ground conditions	C05 Contribution - Rider Impaired (fatigue)?	Rider's Name
Bend	C08 Contribution - Horse going too Fast?	Rider's Gender
Slope	C09 Contribution - Horse going too Slow?	Other Object Struck?
Course defect?	C11 Contribution - Horse jumping into bright / low Sunlight?	Details of other Object Struck

Appendix IV. Competition details file: variables

Location
Date
RiderName
Members.sex
date_of_birth
colour
Horse_name
dam
sire
current_grade
TotalFoundationPoints
Total_points
Horses.sex
height
year_foaled
ClassCode
SectionNo
PenaltyDressage
PenaltySJ
PenaltySJTime
PenaltyXCTime
PenaltyXCJumping
CompletionCode
EliminationCode
TotalPenalty
Position
PrizeMoney

Appendix V. British eventing fall report form

Section 1. Rider and Horse Information

Fall reference number (office use only)

Program number	Rider's name		Male	Female	Membership No. (office use only)
	Horses name				Registration No. (office use only)

Severity of rider's injuries	No injury	Slight (Sprains, slight cuts and bruises)	Serious (Hospital treatment required)	Fatal

Was Air Jacket worn?	Yes	No	Did Air Jacket activate?	Yes	No	Not Known
Did horse and rider continue?	Yes	No				

Section 2. Attendant Circumstances (What Happened)

Date of accident		Time of accident				
Name of Event						
Event Type	1 day event	2 day event	3 day event			
Class	BE 80	BE 90	BE 100	Novice	Intermediate	Advanced
Accident location	Cross Country	Show Jumping	Dressage	Elsewhere		
Did the fall involve a fence?	Yes	No				
FENCE DETAILS	Number	Element (a, b, c etc.)	Route (If applicable)	Did Frangible Pin break? (yes, no, not frangible)		
Description of fence						
Fence associated with water?	No	Yes – Fence before water	Yes – Fence after water			
FALL TYPE	Horse and rider both fell	Rider unseated	No Fall			
Did horse fall on or tread on rider?	Yes	No				
Description of accident (what happened?)						
Did the horse slip?	Yes	No				
Ground Conditions	Deep	Heavy	Slippery	Good to Soft		
	Good	Good to Firm	Hard	Rough / Rutted		
Course defect	No	Yes	Specify			
Other object struck	No	Yes	Specify			
Bend	Yes	No				
Slope	Up	Down	Level Ground			
Weather	Fine	Raining	Snowing	Other (specify)		
Wind	Yes	No				
Poor visibility (fog, smoke, mist, etc)	Yes	No				

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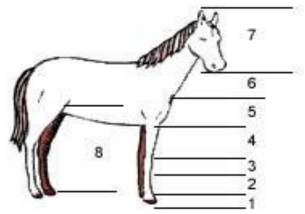
Section 3. Falls at fences (only complete if fall was at a fence)

Did horse refuse?	Yes	No	Did horse break the fence?	Yes	No
Did horse hit fence on the way up?	Yes	No	Did horse tip portable fence over?	Yes	No
Did horse hit fence on the way down?	Yes	No	Did horse somersault?	Yes	No
Did horse hit the fence hard?	Yes	No	Did the rider hit the fence?	Yes	No

Section 4. Details of Injuries Sustained by Horse

Severity of horses injuries	No injury	Slight	Serious	Fatal	Not known
Did vet attend?	Yes	No			
To be completed if accident involved a collision between a horse and a fence	Please indicate the initial point of impact between the horse and the fence				

Section 5. Contributory Factors (why something went wrong)

Situation misjudged by rider	Yes	No
Rider inexperience	Yes	No
Horse out of control	Yes	No
Rider distracted	Yes	No
Rider impaired by drink or drugs	Yes	No
Rider impaired by fatigue	Yes	No
Horse going too fast	Yes	No
Horse going too slow	Yes	No
Horse jumping into bright / sunlight or reflection	Yes	No
Horse jumping into shadow	Yes	No
Horse distracted	Yes	No
Horse fatigued	Yes	No
Horse impaired by health/injury	Yes	No
Other (specify)		

Fence Judge Name		E-Mail Address or Phone No.	

Explanatory notes:

It is important that this form is completed accurately and submitted promptly. Information about all falls and injury accidents will be collated, analysed and acted upon in order to improve the safety of our sport. A copy of this form must be completed in full following the occurrence of a fall. The form should be completed by a Fence Judge, BE Technical Adviser or other course official and should be submitted to the BE Technical Adviser on the day on which the fall occurs.

Appendix VI. Review framework for scoping review

Population	- Horse - Healthy - 3+ years of age - Not pregnant
Setting	- Competition - Travel - Training - Handling - Loose - Experimental (controlled setting)
Outcome	- Quantitative (derived from HRM IBI data) • HR • HRV - Quantitative (any of these in combination with the above) • Cortisol (salivary or blood) • IRT (core temperature - eye) • HR (from ECG) • HRV (from ECG)

Appendix VII. Inclusion criteria for scoping review

Inclusion criteria	✓
Studies published in scientific journal with peer review	
Studies using HR/HRV as a measure of stress/arousal (or using ECG in combination with HRM for validation purposes).	
Studies using HRM's to collect IBI derived HR/HRV data	
Studies related to equine subjects	
Equine subjects are healthy, ≥ 3 years of age and not pregnant	
Studies presented in the English language	
Short term HR/HRV is investigated (<1 hour)	
Studies published in the last 10 years (2010-2020)	
Studies recording IRT (core temperature - eye), Blood Cortisol, Salivary Cortisol or ECG derived HRV data with HRM derived HR/HRV data	
Exclusion criteria	
Review Paper	
Studies that involve administering a drug to subjects, or involve subjects recovering from anaesthesia	

Search terms using Boolean operators (Scopus & VetMed):

(“Heart Rate” OR “HR”) AND ("Heart Rate Variability" OR "HRV") AND ("Equine" OR "Horse") AND ("Welfare" OR "Stress").

Appendix VIII. Descriptive summary tables: scoping review

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
1	Lenoir, A., Trachsel, D. S., Younes, M., Barrey, E. & Robert, C	2017	Agreement between electrocardiogram and heart rate meter is low for the measurement of heart rate variability during exercise in young endurance horses.	Frontiers in Veterinary Science	4, 170	V	36 endurance horses (between 4 and 6 years old)	In-field Standardised Exercise Test	Cross-sectional (Validation)	The test consisted in three standardized phases including a 15-min warm-up at walk and trot (I), followed by a 20 km/h canter phase (II) of 15 min duration for the 4-year old, 30 min for the 5-year old, 45 min for the 6-year old, and (III) a 22–25 km/h gallop phase on 500 m.	S810 : RR , HR, LF, HF, SDNN, RMSSD (2x periods of 5 min, 1= warmup, 1= canter) were compared for ECG and HRM (TYPO IN DEVICE MODEL = CORRECTED TO S810i)	Electrode set - Polar, unknown model	Warm up = Heart rate and RR intervals showed agreement within the predefined ranges. For all the other measures of HRV, agreement was judged inadequate based on both the Bland–Altman analysis. Canter Phase = only HR and RR intervals showed acceptable agreement between the two measuring methods. For all the other measures of HRV, the obtained agreement parameters from the Bland–Altman analysis were higher. study shows that when comparing recordings obtained during exercise in horses using an ECG or a HRM, agreement is poor between measures of the HRV analysis, with the exception of HR and RR-interval.	78.6
2	Bohák, Z., Harnos, A., Joó, K., Szenci, O. & Kovács, L	2018	Anticipatory response before competition in Standardbred racehorses.	PLoS One	13, 1-8	E	8 standardbred stallions between 3 and 4 years of age	During training and during a race (trotting)	Cross-sectional	Measurements were performed in the same place under two different conditions: during training (mild exercise, n = 8) and during real trotting race (maximal effort, n = 8). All the exercises were performed between 10:00 AM and 11:45 AM and lasted approximately for 48–55 min. Blood samples were obtained: S0; pre-race, 5 min before warming up, S1; after warming up (17–20 min after S0), S2; immediately after the intensive stage of the exercise (15–20 min after S1 depending on the type ofwork) and S3; after a 30-min recovery (30 min after the exercise has finished). IBIs were recorded before the exercise for one hour between 07:00 and 08:00 AM at rest, and during the exercise. 5-min continuous IBI samples were used for HRV analysis.	Polar Equine RS800CX multi device and a Polar H2 sensor. (RMSSD LF/HF) Blood Cortisol.	Polar H2 sensor (belt)	Baseline LF/HF ratio was higher (12.0 ± 6.6 vs. 5.9 ± 4.5, P = 0.009), while baseline RMSSD did not show significant difference (34.8 ± 15.9 ms vs. 48.0 ± 30.5 ms, P = 0.96) when pre-race and pre-training values were compared. Pre-race cortisol levels on training and race days were 97.3 ± 16.4 nmol/L and 171.8 ± 18.7 nmol/L (means ± SD), respectively (P< 0.001). According to the linear mixed model, both the type of work and the time of sampling had a significant effect on the cortisol level (P < 0.001 and P = 0.012, respectively). Cortisol level was higher in the case of race at every sampling.	71.4

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
3	Villas-Boas, J.D., Dias, D.P.M., Trigo, P.I., Almeida, N.A., dos, S., de Almeida, F.Q. & de Medeiros, M.A.	2016	Behavioural, endocrine and cardiac autonomic responses to a model of startle in horses	Applied Animal Behaviour Science	174, 76-82	E	Six Brazilian Sport horses (3 males and 3 females; 6–8 years old; 450–550 kg in weight), with appropriate body condition scores (between 5.0 and 5.5)	Arena (startle test)	Cross-sectional	Each horse was taken individually to a covered arena (70 × 30 m) and subjected to the startle test, the abrupt opening of an umbrella. The horse was led by a known handler and positioned at a predetermined location, with its back to a low wall (70 cm high) that surrounds the arena and held loosely by its lead rope. The horse was left undisturbed until signs of quietness and inattention were seen. Then, a rainbow coloured umbrella (diameter of 70 cm) was suddenly opened and spun for 2 min by a person that was hidden behind the wall at a distance of approximately 1.5 m from the rump of the animal. Blood cortisol was taken 20 min before the test, 30 min after the test and 1 hour after the test. Cardiac intervals were continuously sampled using a heart monitor. HRV was analysed in 64s time periods.	Polar RS 800 G3 (strapped to the chest - HR, LF/HF, LF(n.u), HF (n.u), Power Spectral Density (PSD)). Blood Cortisol	Strapped to the chest' Polar - model not stated	Horses subjected to the startle test showed an increase in HR (F2,8 = 0.4017, P = 0.0101), in the power of the LF band of the cardiac interval spectrum (F2,8 = 0.8073, P = 0.0002) and in the LF/HF ratio (F2,8 = 0.9695, P = 0.0066), but a decrease in the power of the HF band of the cardiac interval spectrum (F2,8 = 0.8073, P = 0.0002). There was no significant difference in the cortisol levels (p = 0.521). No correlation was found among the cortisol levels 30 min after startle, the ratio LF/HF and the distance, latency and time of reaction in the behavioural analysis.	100
4	Janczarek, I., Wilk, I., Stachurska, A., Krakowski, L. & Liss, M	2019	Cardiac activity and salivary cortisol concentration of leisure horses in response to the presence of an audience in the arena	Journal of Veterinary Behaviour	29, 31-39	E	12 adult warmblood horses, riding-school geldings	Arena (presence of audience)	Cross-sectional	Five research variants that differed according to the presence and behaviour of an audience were performed: one control variant without the audience (RV0) and four variants with the audience present (RV1, RV2, RV3, and RV4). The audience consisted of 10 persons, each time the same, who were unfamiliar with the horses. The horses were randomly divided into two groups of six horses and riders. Within each research variant, the two 6-horse groups were tested one by one, so that each horse experienced each of the variants one time. Successive variants were conducted at 3-day intervals. Procedure: mount immediately after entering the	Data were collected at rest (while the stable was quiet in the morning; 20 minutes measurement), at work (from the beginning of the first walk after mounting till the end of the last trot; a continuous 35-minute measurement, later divided into 16 minutes of walking, 17 minutes of trotting, and 2 minutes of	"The electrode was dampened with an ultrasonography gel and then attached to an elastic belt around the horse's body" - Polar, model not stated	The considered factors and interaction between them were significant in the case of all parameters at the significance level P < 0.01, and only for LF/HF, the level was P < 0.05. During recovery, RMSSD in all research variants was lower than that in RV0. Salivary cortisol concentration was higher at work in RV4 than in the other cases. When the audience was present in the arena, many changes of HRV parameters appeared in the horses during a low-intensity exercise compared with when the audience was absent. The re- actions, usually RMSSD and HF decrease, showed lowered activity of the parasympathetic ANS branch. The changes were particularly apparent when the audience simultaneously	57.1

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
										arena,10 minutes of walking (5 minutes to the left and 5 minutes to the right), 7 minutes of trotting to the left, 3 minutes of walking, changing rein, 7 minutes of trotting to the right, 3 minutes of walking, changing rein, 1 minute of cantering to the left at 350 m/minute, 1 minute of trotting, changing rein, 1 minute of cantering to the right at 350 m/minute, 2 minutes of trotting, changing rein, 20 minutes of walking (10 minutes to the right and 10 minutes to the left). Saliva samples were collected three times during each research variant: at rest (while the stable was quiet in the morning), at work (after the last trot), and at recovery (20 minutes after the last walk).	cantering), and at recovery (during the last walk; 20-minute measurement). PolarRS800CX (RMSSD, HR, LF, HF, LF/HF) Salivary Cortisol (three times during each research variant: at rest (while the stable was quiet in the morning), at work (after the last trot), and at recovery (20 minutes after the last walk)).		walked and talked. The cortisol level in the saliva distinctly showed a negative influence of the audience simultaneously talking and walking. This result suggests that such behaviour of the audience is frustrating and stressful for the horses	
5	Schmidt, A., Biau. S., Möstl. E., Becker-Birck, M., Morillon, B., Aurich, J., Faure, J.M. & Aurich, C.	2010	Changes in cortisol release and heart rate variability in sport horses during long-distance road transport.	Domestic Animal Endocrinology	38, 179-189	E	7 horses. Age of the horses was 13.7±2.0 y (mean±standard error of the mean [SEM], range 11-18 y). One of the horses was a mare, and 6 were geldings.	Transport	Cross-sectional	Horses of the Cadre Noir de Saumur (classical dressage team of the French National School of Equitation) were studied before, during, and after road transport over 1370km from Saumur, France, to a presentation in Neustadt (Dosse), Germany. The study period included 2 d before transport,2dof transport from Saumur to Neustadt (Dosse),7dat Neustadt (Dosse),2dof return transport, and 3 d thereafter.	Salivary Cortisol Polar S810i (SDRR, RMSSD, SD1, SD2) 30 MIN PERIODS USED FOR ANALYSIS	"attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the middle of the left thorax. The electrodes were affixed with a second girth, which also contained a pocket for the recording watch. " Electrode set? model not stated	Transport on all days caused a marked increase in salivary cortisol concentrations, which lasted at least several hours. Transport also caused a clear increase in cortisol metabolite concentrations in faeces. In the present study, the heart rate and heart rate variability data are less clearly to interpret than the endocrine data on cortisol release. However, RR interval and heart rate variability were significantly affected by transport. During the first 90 min of outbound trans- port, RR interval decreased, and thus heart rate increased. An increase in heart rate indicates increased sympathetic activity and/or decreased parasympathetic (vagal) activity	78.6

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
6	Schmidt, A., Aurich, J., Möstl, E., Müller, J. & Aurich, C.	2010 b	Changes in cortisol release and heart rate and heart rate variability during the initial training of 3-year-old sport horses	Hormones and Behaviour	58, 628-636	E	16 three year-old Warmblood horses of the German Sport Horse breed were available. Animals were mares (n=7) and stallions (n=9)	Arena	Pre-test Post-test	Horses were followed for 12-week (mares) and 9-week (stallions) through a classical training program from lunging to first mounting of a rider and progressing to moderate work. Saliva sampling, recording of beat-to- beat (RR) intervals and HRV analysis were always performed on 2 days per week. In stallions, there was a one-week training break before week 6 (Christmas week) with daily free movement in the riding arena only and no saliva sampling and heart rate recording. Salivary samples for cortisol analysis were taken on Tuesday and Thursday of each weak. On these days, 2 samples were collected in the stable at 60 and 30 min before the training unit. Further samples were taken immediately after the training unit (time 0) and at 5, 15, 30, 60, 90, 120 and 180 min thereafter. Beat-to-beat (RR) intervals and HRV were recorded on Tuesdays and Thursdays continuously from 30 min before to 30 min after the training unit on these days.	Polar S810i (SDRR, RMSSD, SD1, SD2) 5 MIN PERIODS FOR ANALYSIS Salivary Cortisol	"attached to a girth around the thorax of the horse. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax." Polar - electrode set? Model not stated	Salivary cortisol IR concentration immediately after training (time0) was significantly correlated neither with the RR interval nor with HRV variables obtained during mounting of the horse by a rider. In contrast, salivary cortisol IR at time 0 was loosely but significantly correlated with the RR interval (r=-0.209, p<0.01) and the HRV variables RMSSD (r=-0.151, p<0.05), SD1 (r=-0.153, p<0.05) and SD2 (r=-0.344, p<0.001) but not SDRR obtained during the riding phase of the training unit, i.e. the phase directly preceding saliva collection immediately after riding.	86.7
7	Kędzierski, W., Janczarek, I., Stachurska, A. & Wilk, I.	2017	Comparison of Effects of Different Relaxing Massage Frequencies and Different Music Hours on Reducing Stress Level in Race Horses	Journal of Equine Veterinary Science	53, 100-107	E	60 3-year-old Purebred Arabian horses (The horses were randomly divided into five equal groups of 12 individuals. Only the sex was considered so that in	Loose in stable	Cross-sectional	Groups were treated with various relaxing methods: relaxing music for 1 hour a day (MC1), relaxing music for 3 hours a day (MC2), relaxing massage only on the day preceding an official race (MG1), and massage treated every day during the 6 months of the racing season (MG2). HRV data were recorded and analysed during the following stages: 10 minutes at rest in the stable, during the next 10 minutes while horses were being prepared for training sessions, including grooming and saddling, and during 10 minutes of walking	Polar RS800CX (HR, LF/HF, RMSSD) Salivary cortisol	This set was mounted around the horse's chest using an elastic belt. (RS800CX set). Polar????	HR and LF/HF decreased during the study in the experimental groups or were lower than in CN. HR, LF/HF, and salivary cortisol concentrations lowered, whereas RMSSD and racing performance increased. Decreased salivary cortisol concentrations were found in MG2 at rest and after 30 minutes of restitution in test 1 compared to test 0, as well as in MG1 after the training session in test 2 (Table 4). A lower value was also noted in MC1 after the training session in test 1. When comparing the groups, it was lower in MG2 at rest in test 1, higher in MG1 and	60

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
							each group, six stallions and six mares were present.)			with a rider from the stable to the training track. On each day of data collection, saliva samples were collected from the horses three times: at rest (after the 10 minutes of HR and HRV registration), immediately after returning from the training track, and 30 minutes after the end of a training session.			MG2 after the training session in test 1, and in MC2 after the restitution in test 0.	
8	Parker, M., Goodwin, D., Eager, R. A., Redhead, E. S. & Marlin, D. J.	2010	Comparison of PolarW heart rate interval data with simultaneously recorded ECG signals in horses	Comparative Exercise Physiology	6, 137-142	V	Six mature horses (four Thoroughbred geldings, one native pony mare and one Anglo-Arab mare).	Various	Cross-sectional (Validation)	Data were acquired simultaneously from the subjects using two different systems, a 24-h Polar Equine S810i with two electrodes, and a Telemetric ECG system with three electrodes. Each recording session was run continuously for 15 min in order to ensure that each horse provided a minimum of 512 beats. Each animal was tested once in each of the three conditions: loose in the field, at liberty in the stable and standing still in the stable. Differences between corrected Polar, uncorrected Polar and ECG were examined.	Polar S810i & ECG (VLF, LF, HF, Total, PNSI, SNSI, RMSSD, pNN50)	Electrode set - Polar, unknown model	During standing there were significant main effects of measurement type (i.e. corrected Polar, uncorrected Polar and ECG) in relation to RMSSD [P<0.05]. Pairwise comparisons suggested a closer agreement between the uncorrected than the corrected Polar data and the ECG. For stable RMSSD Pairwise comparisons suggested that the corrected Polar data were closer to the ECG recording than the uncorrected Polar data. For field RMSSD the corrected Polar data followed the ECG data more closely than the uncorrected Polar data. Corrected data show a better agreement than uncorrected data, but both show wide limits of agreement indicating that the Polar was regularly and significantly under- and overestimating IBIs. Simultaneous data collection using Polar S810i and ECG indicated that agreement between ECG and uncorrected Polar data, particularly with relation to time domain indices, reduced as the movement of the horses increased.	78.6
9	Ille, N., Aurich, J., Erber, R. & Aurich, C	2014 b	Comparison of heart rate and heart rate variability obtained by heart rate monitors and simultaneously recorded electrocardiogram	Journal of Veterinary Behaviour	9, 341-346	V	14 Haflinger mares. Age 8.4 ± 2.8 years (± standard deviation;	Loose in stable	Cross-sectional (Validation)	Data were recorded simultaneously from the horses with 2 different recording systems, namely a Polar HRM and a portable ECG device (Televet 100 version 4.2.3; Kruuse, Marslev, Denmark). Recordings started in the morning at 08:30	Polar (unknown) RR, HR, SDRR, RMSSD (Polar and Televet ECG)	"The positive electrode was located at the right shoulder and the negative electrode at the mid of the left	Correlations between RR interval, HR, and all HRV variables obtained with the Televet ECG and Polar HRMs were highly significant (P< 0.001) at all recording times, and Pearson's coefficient of correlations was higher than 0.9 at all times. Correlations increased with	85.7

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
			signals in nonexercising horses				range, 5-14 years).			hours and lasted for 60 minutes. Comparisons between the 2 recording systems were made for intervals of 1, 2, 5, and 30 minutes each.		thorax." Electrode set? Model not stated	increasing recording time and with recording intervals of 30 minutes exceeded 0.99 for all parameters determined. The simultaneous recordings of cardiac RR intervals with Polar HRMs and the Televet 100 ECG in stationary, non-restrained horses demonstrate a strong agreement between the 2 recording systems.	
10	Becker-Birck, M., Schmidt, A., Lasarzik, J., Aurich, J., Möstl, E. & Aurich, C.	2013	Cortisol release and heart rate variability in sport horses participating in equestrian competitions.	Journal of Veterinary Behaviour	8, 87-94	E	13 German sport horses owned. Mean age of the horses was 6.2 6 3.8 years, and the group consisted of 2 geldings, 4 mares, and 7 stallions.	Competition (DR & SJ)	Cross-sectional	Saliva samples for determination of basal cortisol concentrations were taken on 2 days before the first competition at 7:00, 7:30, 14:00, 14:30, 20:00, and 20:30 hours. Additional samples were collected on each competition day at 60 minutes and 30 minutes before riding. Further samples were taken immediately after each competition (time 0) and at 5, 15, 30, 60, 90, 120, and 180 minutes thereafter. The RR interval was recorded with a mobile recording system (S810i; Polar, Kempele, Finland). Recordings were made for 1 hour directly before riding, continuously during riding, and for 1 hour thereafter. The means for variables were determined for subsequent periods of 5 minutes	S810i HR, SDRR, RMSSD Salivary Cortisol	Not stated	Cortisol concentrations increased significantly in response to each of the competitions. Heart rate increased significantly in response to the competitions on all 3 days. The HRV variable SDRR only tended to decrease in response to competition, but this decrease at no time reached statistical significance. For RMSSD, a significant decrease was found during preparation of the horses for competition in the stable and during the actual competition on day 2. None of the HRV variables differed significantly between horses competing in dressage and show jumping.	73.3
11	Schmidt, A., Möstl, E., Wehnert, C., Aurich, J., Müller, J. & Aurich, C.	2010 c	Cortisol release and heart rate variability in horses during road transport	Hormones and Behaviour	57, 209-215	E	24 horses	During travel	Cross-sectional	Horses were transported in a van (6 horses of each group) and trailer (2 horses of each group) combination. Horses were loaded in individual stalls parallel to the axis of the vehicle and were facing the driving direction. No stops were made on the 1-h transport. The 3.5- and the 8-h transport were stopped every 60 min for collection of saliva samples. Immediately after the end of transport, horses were unloaded and returned to their stables. HRV were calculated for 30-min intervals. Heart rate was	F810i (RR, SDHR, SDRR, RMSSD, SD1 & SD2) Salivary Cortisol	"attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax. The electrodes were fixed with a second girth	With the onset of transport, salivary cortisol-IR concentrations increased. In horses transported for 1 h, highest cortisol-IR concentrations were measured at the end of transport, in horses transported for 3.5 and 8 h, highest values were reached at 3 h and 7 h, respectively. The mean RR interval decreased significantly ($p<0.05$) in horses of all groups and remained at a lower level throughout the transport period. Standard deviation of heart rate (SDHR) increased with the onset of transport and remained elevated	78.6

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
										recorded with a mobile recording system (f810i, POLAR, Kempele,) Saliva samples for cortisol determination were taken at 30-min intervals for 2 h before loading of the horses, every hour during transport, immediately after transport and at 30-min intervals for 6 h thereafter.		which also contained a pocket for the recording watch." Electrode set? model not stated	for at least the duration of transport. Mean RMSSD values in horses of group T1 at individual time points after transport were higher than the pre-transport baseline	
12	Becker-Birck, M., Schmidt, A., Wulf, M., Aurich, J., von der Wense, A., Möstl, E., Berz, R. & Aurich, C.	2013 b	Cortisol release, heart rate and heart rate variability, and superficial body temperature, in horses lunged either with hyperflexion of the neck or with an extended head and neck position.	Journal of Animal Physiology and Animal Nutrition	97, 322-330	E	A total of 16 adult German sport horses. The age of the horses was 7.7 ± 0.7 years (±SEM), and 14 animals were geldings and two mares.	Lunging (arena)	Cross-sectional	Horses were lunged on 2 days in an indoor riding arena (15 · 35 m). On each day, lunging was begun with an 11-min warm-up phase with loose side reins attached between a lunging-girth fixed above the saddle and the ring of the bridle allowing a totally free position of the head and neck. The horses were then stopped, and side reins were tightened. On 1 day (day A), side reins were shortened to reach a head position closely at the vertical. On the other day (day B), the side reins were shortened to bring the head of the horse into a position clearly behind the vertical (hyperflexion of the neck;). After fixation of the side reins, the horses were again lunged for 13 min. Beat-to-beat (RR) intervals were recorded on the day before the first experiment for 2 h to obtain baseline values. On both experimental days, RR intervals were recorded continuously from 60 min before to 60 min after lunging. Saliva for determination of cortisol concentrations was collected on 2 days before the first experiment at 6:00, 6:30; 14:00, 14:30, 22:00 and 22:30 to obtain baseline values. Saliva was then collected at 60 and 30 min before each experiment, during the break for fixing the side reins and at 0, 5, 15, 30, 60, 90, 120,	S810i (RR, SDRR, RMSSD) Salivary Cortisol	Reference to previous paper which describes "attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax. The electrodes were fixed with a second girth which also contained a pocket for the recording watch." Electrode set? model not stated	In response to lunging, cortisol concentrations increased during the warm-up phase and further when the horses were lunged with the head and neck brought into the respective experimental positions by use of side reins. The RR interval decreased in response to lunging during the warm-up phase and decreased further when horse were lunged with their head and neck fixed by side reins in a position either before the vertical or beyond the vertical. SDRR, RMSSD and RR intervals decreased during the warm-up phase and a further decreased during the experimental phase with the side reins fixing the head and neck either in a position before (day A) or beyond the vertical (day B; Fig. 3b,c, $p < 0.001$).	85.7

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
										150 and 180 min after the end of lunging. HRV variables were calculated for periods of 5 min each in the following phases: 60–55 and 30–25 min before lunging, warm-up phase (walk), trot phase of lunging with side reins, canter phase of lunging with side reins and 0–5 and 25–30 min after lunging.				
13	Schmidt, A., Hödl, S., Möstl, E., Aurich, J., Müller, J. & Aurich, C.	2010 d	Cortisol release, heart rate, and heart rate variability in transport-naive horses during repeated road transport.	Domestic Animal Endocrinology	39, 205-213	E	Eight 3-yr-old geldings	During travel	Cross-sectional	The group of horses was transported 4 times by road over the same 200-km route. Transport time was approximately 4 h. Recovery time between the first and second transport was 4 d and between all other transport was 2 d. Saliva samples for determination of basal, pre transport cortisol concentrations were taken 1 d before each transport in the morning (8:00–9:30 AM, 4 samples at 30-min intervals) and on each transport day at 60 and 30 min before loading, which corresponds to 7:00 and 7:30 AM. During transport, samples were taken at 60- min intervals. Further samples were taken immediately after transport (time 0) and at 5, 15, 30, 60, 90, 120, and 180 min thereafter. Beat-to-beat interval was recorded on the day before each transport (from 8:00–10:00 AM), for 1 h directly before transport, continuously during transport, and for 2 h thereafter. The horses were pre-pared for recordings by putting on a girth with a non- activated recording device for 2–3 h each day for 5 d before the actual experiment. The means for all HRV variables were determined for sub- sequent periods of 30 min each.	RR, SDRR, RMSSD, SD1, SD2 (S810i) Salivary Cortisol	"attached to a girth around the thorax of the horse. The positive electrode was located at the right shoulder and the negative electrode at the middle of the left thorax." Electrode set? Model not stated	marked increase in cortisol IR concentrations occurred during each transport. After transport, salivary cortisol concentrations decreased continuously and reached pre-transport baseline values between 90 and 180 min after unloading. The HRV variable SDRR changed in response to transport 2. In response to the last transport, a short but significant decrease in SDRR was found toward the end of transport time. Changes over time in RMSSD were similar to SDRR but reached statistical significance for transport 4 only.	64.3

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
14	von Lewinski, M., Biau, S., Erber, R., Ille, N., Aurich, J., Faure, J.M., Möstl, E. & Aurich, C.	2013	Cortisol release, heart rate and heart rate variability in the horse and its rider: Different responses to training and performance	Veterinary Journal	197, 229-232	E	sport horses (n = 6). The mean age of the horses was 9.7 ± 2.3 years (±SD, 8–11 years) and all were geldings and of the French Sport Horse breed.	Training Vs Performance	Cross-sectional	Horses and riders were studied during a riding performance of the schools (airs) above the ground at the ENE and during a rehearsal for such performances. Each performance lasted 7 min and consisted of being ridden in canter and included the airs above the ground (18 jumps). Saliva for determination of basal cortisol concentrations was taken from horses at 30 and 15 min and from riders at 30 min before the riders mounted their horses. Further samples from both horses and riders were taken immediately after each performance and rehearsal, respectively, at Time 0 and at 15, 30 and 60 min thereafter. HRV Recordings were made for 1 h directly before riding, continuously during riding and for 1 h thereafter in the horses, and for 30 min directly before riding and continuously during riding in the riders.	RR, SDRR, RMSSD (S810i) Salivary Cortisol	Reference to previous paper which describes "attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax. The electrodes were fixed with a second girth which also contained a pocket for the recording watch." Electrode set? model not stated	In response to both the public performance and an identical rehearsal of the airs above the ground, cortisol concentrations increased significantly in horses ($P < 0.001$) and their riders ($P < 0.01$) and were significantly higher than baseline values immediately (Time 0) and 15 min after the equestrian tasks. Cortisol release did not differ significantly in either horses or riders between rehearsal and performance. in horses SDRR did not change significantly during equestrian activities and did not differ between types of activity. RMSSD decreased significantly during equestrian activities in both horses and their riders ($P < 0.001$).	78.6
15	Christensen, J. W., Beekmans, M., van Dalum, M. & VanDierendonck, M.	2014	Effects of hyperflexion on acute stress responses in ridden dressage horses.	Physiology and Behaviour	128, 39-45	E	15 Danish dressage horses (7 mares, 7 geldings, 1 stallion; age 8.7 ± 1.0; range 5–18 years)	Ridden dressage	Cross-sectional	Each test was preceded by a 20 min standardised warm-up followed by a 10 min walking period, during which the rein tension device was attached. During the 10 min test, all riders rode the same programme (5 min trot, 4 min canter and 1 min walk). Exercises included extended trot and canter, leg-yield, shoulder-in, small (10 m) and large (20 m) circles on both reins. Saliva was collected at 0, 5, 15 and 30 min after the test (samples B–E). The riders walked with their horse during the cool-down phase (15 min) after which the horse was led to the stable and groomed. HR/HRV were analysed for the trot/canter period only (9 min)	Polar Equine RS800cx HR, RMSSD, LF/HF Salivary Cortisol	Polar Equine Wearlink - BELT	The average HR did not differ between treatments and neither did the HRV measures; RMSSD and LDR and LF/HF-ratio. There was no difference between the treatments in baseline cortisol concentrations. The sample directly after the test showed a strong trend towards significance with LDR resulting in the highest concentrations, whereas there were no significant treatment effects in the other samples.	85.7

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16	Ille, N., Von Lewinski, M., Erber, R., Wulf, M., Aurich, J., Möstl, E. & Aurich, C.	2013	Effects of the level of experience of horses and their riders on cortisol release, heart rate and heart-rate variability during a jumping course.	Animal Welfare	22, 457-465	E	16 sport horses, 6x stallions, 10x geldings. Mean (± SD) age of group 1 horses was 6.5 (± 0.9) years.	Jumping course (SET)	Double Latin Square	Horses and riders were studied before, during and after a standardised jumping course. horses and riders warmed up 'in walk' (5 min), followed by trot (3 min) and canter (3 min). After this warm-up phase, they jumped two individual obstacles (numbers 2 and 5) at reduced height. This was followed by the jumping course which consisted of eight obstacles and was identical for all participating horse-rider pairs. Saliva for determination of cortisol concentrations was taken at 30 and 15 min before riding and at 0, 15, 30 and 60 min thereafter. HRV Recordings were made for 1 h before riding, continuously during riding and for 1 h thereafter in the horses and the riders. For comparisons of heart rate and heart-rate variability, 1-min intervals were selected from the warm-up walk, trot and canter phase, the jumping course and the cool-down walk phase. Additional 1-min intervals were analysed at 30 and 15 min before the riders mounted their horses and 15, 30 and 60 min after finishing the course, i.e. when riders had dismounted their horses	S810i (SDRR, RMSSD) Salivary Cortisol	Reference to previous paper which describes "attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax. The electrodes were fixed with a second girth which also contained a pocket for the recording watch." Electrode set? model not stated	Salivary cortisol concentrations in horses and their riders increased significantly during riding and returned to baseline values about 30 min after the jumping course (changes over time: horses; P < 0.001, riders; P < 0.01;). The HRV variable SDRR decreased significantly during riding in horses and their riders (both P < 0.001). In horses, the most pronounced decrease was found when the animals were mounted by the riders. The SDRR decreased further during trot but remained at that constant level during canter and the jumping course. For RMSSD, a significant decrease during riding was found in horses and riders (both P < 0.001). RMSSD was higher in experienced horses (P < 0.05) and riders (P < 0.001) versus less-experienced horses and riders, respectively, and in the riders, significant interactions between time and group existed (P < 0.05;). RMSSD reached a nadir during walk, trot, canter and jumping course in horses and during the trot, canter and jumping phase in riders.	80
17	Pasing, S., von Lewinski, M., Wulf, M., Erber, R. & Aurich, C	2013	Influence of semen collection on salivary cortisol release, heart rate , and heart rate vari ability in stallions	Theriogenology	80, 256-261	E	16 breeding stallions of different breeds (13 Warmblood, 1 pony, 1 Arabian horse, and 1 Draught horse), aged 3–13 years (mean: 6.3	Semen Collection	Pre-test Post-test	During the breeding season that started on 6 February and ended on 1 August, semen collection was performed once daily between one and six times per week. Start of heart rate recordings and saliva sampling was adjusted to the time the animals were scheduled for semen collection. The RR interval was recorded continuously from 60 minutes before until 60 minutes after collection of	RMSSD (S810i) Salivary Cortisol	"attached to a girth around the thorax of the horse. The positive electrode was positioned onto the right side of the withers and the negative electrode onto the left side next to the	The HRV variable RMSSD and cortisol secretion did not differ between days or change over time.	**78.6**

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							± 0.7 years).			semen. 1-minute intervals were analysed starting at 30 minutes before the stallions were scheduled for semen collection at 15-minute intervals until 30 minutes after semen collection. Furthermore, the last 3 minutes before the stallion mounted the dummy, the minute when the stallion mounted the dummy and ejaculated (minute 0) and minutes 1, 2, and 3 thereafter were analysed. On the two semen collection days, collection of saliva started 60 minutes before the stallion was scheduled for semen collection in the AI centre. Further saliva samples were collected at 30-minute intervals until 120 minutes after semen collection. Additional samples were collected at the exit of the collection barn and 15 minutes after semen collection.		heart base. Water and exploratory gel were used to optimize the contact between electrode and skin" Electrode set? model not stated		
18	Ille, N., Aurich, C., Erber, R., Wulf, M., Palme, R., Aurich, J. & von Lewinski, M.	2014	Physiological stress responses and horse rider interactions in horses ridden by male and female riders	Comparative Exercise Physiology	10, 131-138	E	8 male horses (7 geldings and one stallion). Mean age of the horses was 11.0 ± 3.2 years.	Indoor arena (course of jumps)	Latin Square	All horses and riders had to manage a standardised jumping course of moderate difficulty. Each horse took part twice, one time with a male and one time with a female rider. For determination of cortisol concentration, saliva was taken at 60, 30 and 15 min before start of the jumping course and at 0, 15, 30 and 60 min thereafter. Recording started 60 min before the jumping course and lasted until 60 min thereafter. To compare heart rate and HRV between groups, 1 min intervals were selected starting at 30 and 15 min before the jumping course, during the warm-up walk, trot and canter, the jumping course and immediately and 15 and 30 min after finishing the course.	S810i (SDRR, RMSSD) Salivary Cortisol	Reference to previous paper which describes "attached to the thorax of the horse with an elastic girth. The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax." Electrode set? Model not stated	Cortisol in saliva of horses increased significantly (P<0.001) in conjunction with the equestrian tasks of the study but was not affected by the sex of the rider. HRV parameters SDRR and RMSSD decreased during walk and remained low during trot, canter and jumping and increased thereafter (P<0.001). The sex of its rider did not affect heart rate, SDRR and RMSSD of the horse during the equestrian tasks. Jumping a course of obstacles and the warm-up for jumping elicited a stress response in horses. This was clearly indicated by an increase in salivary cortisol concentrations and a decrease in the HRV variables SDRR and RMSSD.	**73.3**

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
19	Squibb, K., Griffin, K., Favier, R. & Ijichi, C.	2018	Poker Face: Discrepancies in behaviour and affective states in horses during stressful handling procedures	Applied Animal Behaviour Science	202, 34-38	E	46 horses (26 geldings and 20 mares). Age of subjects ranged between 3 and 20 years (mean=9.33 ± 4.20) and subjects were of mixed breeds.	Indoor arena (handling test)	Cross-sectional	Subjects completed two novel handling tests where they were asked to navigate two distinct obstacles. Task A consisted of a 2.5m x 3m blue tarpaulin secured to the surface of the indoor holding arena by 20 individual tent pegs. To complete this test, the subject walked over the tarpaulin. Test B consisted of two jump wings extended to a height of approximately 2.5 m with a 1.6 m long pole suspended over-head, from which hung 2m long plastic streamers. To complete this test, the subject walked under the overhead pole, causing the streamers to touch the face and body of the subject as they passed through. Once the 3 min threshold had been reached the test was ended. Eye temperature images (FLIR E4 thermal imaging camera (FLIR Systems, USA.)) of each subject's left and right eyes were taken on entering the arena prior to each test and immediately after testing. HR data was measured from the point of the pre-test IRT measurement to the post-test IRT measurement.	V800 (SDRR) (Written in different syntax by authors: STDRR, but it is the same HRV measurement). IRT	"Polar elasticated adjustable surcingle was attached to the girth area of the subject. This was moistened with water to aid conductivity and checked to ensure it was detecting HR." BELT - model not stated	Physiological indicators of stress were not associated with compliance, indicated by crossing time. Crossing time did not correlate with either pre-test or post-test eye temperatures or the discrepancy between eyes. Additionally, it did not correlate with heart rate variability. Proactivity during testing did not correlate with any physiological measures of stress. Physiological indicators of stress did not correlate with the time taken to complete two handling tests.	78.6
20	Wulf, M., Aurich, C., Von Lewinski, M., Möstl, E. & Aurich, J. E.	2013	Reduced-size microchips for identification of horses: response to implantation and readability during a six-month period.	Veterinary Record	173, 451	E	12 mares (4–8 years old, 5.5±1.5 years)	Microchip implantation	Pre-test Post-test	All mares were implanted with a reduced-size microchip. Microchips were implanted at the left side of the neck, half-way between the poll and the withers and halfway between the crest of the mane and the ventral line of the neck. All microchip implantations were performed by the same experienced person. Mares were held by another person and the microchip implantation site was disinfected but not clipped before implantation. Mares received a microchip and were submitted to	S810i (SDRR, RMSSD) Salivary Cortisol	Not stated	Heart rate showed a small increase (P<0.01) at disinfection for micro-chip implantations and control treatments, and on average was slightly lower already before control treatments compared to microchip implantations (P<0.01). The HRV variable SDRR increased slightly at microchip and at sham implantations (P<0.05). For RMSSD, significant differences were not found over time or between treatments. No significant differences in salivary cortisol concentrations of horses were found at any time after microchip	50

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										control treatment (pressure applied with a cannula at the implantation site without penetrating the skin), thus serving as their own controls. Microchip implantation and control treatment were performed on the left side of the horse's neck. Time between microchip implantations and control treatments was 14 days. The order of treatments was randomised with six mares receiving the control treatment first and implantation of a microchip thereafter, and the other six mares treated in opposite order Saliva for determination of basal cortisol concentrations was taken at 60 and 30 minutes before and immediately (time 0), and at 15, 30, 60, 90 and 120 minutes after microchip implantation and control treatment. HRV Recordings were made continuously from one hour before to one hour after microchip implantation. Further one-minute intervals were analysed starting at 1, 15, 30 and 60 minutes after microchip implantation and control treatments.			implantations and control treatments. Cortisol concentrations in saliva were initially higher in mares on the day of control treatments versus the day of microchip implantation and decreased in the former and increased slightly in the latter (changes over time P<0.01).	
21	Ijichi, C., Griffin, K., Squibb, K. & Favier, R.	2018	Stranger danger? An investigation into the influence of human-horse bond on stress and behaviour	Applied Animal Behaviour Science	206, 59-63	E	46 horses of mixed breeds and genders (26 geldings and 20 mares) took part. Age ranged from 3–20 years (mean=9.33 ± 4.20).	Indoor arena (handling test)	Cross-sectional	The familiar handler was the owner and daily care-giver of the subject. The unfamiliar handler was the same for all subjects. Subjects completed two novel handling tests where they were asked to navigate two distinct obstacles. Task A consisted of a 2.5m x 3m blue tarpaulin secured to the surface of the indoor holding arena by 20 individual tent pegs. To complete this test, the subject walked over the tarpaulin. Test B consisted of two	V800 (STD RR) IRT	"The elasticated surcingle was attached to the girth area, which had been moistened with water to aid conductivity." BELT - model not stated	There was no statistically significant difference in behaviour or any indicator of stress, depending on whether horses were handled by a familiar or unfamiliar person.	85.7

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										jump wings extended to a height of approximately 2.5 m with a 1.6 m long pole suspended over-head, from which hung 2m long plastic streamers. To complete this test, the subject walked under the overhead pole, causing the streamers to touch the face and body of the subject as they passed through. Once the 3 min threshold had been reached the test was ended. Eye temperature images (FLIR E4 thermal imaging camera (FLIR Systems, USA.)) of each subject's left and right eyes were taken on entering the arena prior to each test and immediately after testing. HR data was measured from the point of the pre-test IRT measurement to the post-test IRT measurement.				
22	Erber, R., Wulf, M., Aurich, J., Rose-Meierhöfer, S., Hoffmann, G., von Lewinski, M., Möstl, E. & Aurich, C.	2013	Stress Response of Three-year-old Horse Mares to Changes in Husbandry System During Initial Equestrian Training	Journal of Equine Veterinary Science	33, 1088-1094	E	8 three-year-old Warmblood sport horses	Change in husbandry (from group nousing to indicidual loose boxes)	Cross-sectional	mares were followed from 4 days before to 5 days after transfer from the group stable and paddock housing to individual loose boxes. Saliva samples were obtained daily at half-hour intervals in the morning (6:30-7:00 AM), at noon (12:00-12:30 PM), and in the evening (6:00-6:30 PM). On the day of transfer from group stable to individual boxes, saliva was collected at 6:30 and 7:00 AM. The mares were brought into indi- vidual boxes at 8:30 AM, and further saliva samples were collected at 0, 5, 15, 30, 60, 90, 120, 150, 180, 240, 300, and 360 minutes thereafter and at 6:00 and 6:30 PM. The RR intervals were recorded continuously from 7:00 AM to 6:00 PM. on all days, the first 5 minutes from each hour were taken. In addition, on the day of transfer to individual boxes, 5-minute intervals were	S810i (SDRR, RMSSD) Salivary Cortisol	"attached to a girth around the thorax of the horse. The positive electrode was positioned on the right side of the withers and the negative electrode on the left side next to the heart base." Electrode set? Model not stated	Cortisol release differed significantly between days (P < .001), and the most pronounced release occurred on the day of transfer to individual stalls (day 0) and no significant decrease on the days thereafter.The HRV variable SDRR tended to change more on the days horses were kept in a group stable with access to a paddock than when mares were stabled in individual boxes. Short-term decreases in SDRR and RMSSD were found immediately after individual stabling. SDRR also decreased in association with riding on days 3, 4, and 5. When SDRR and RMSSD, calculated as area under the curve for each day, were compared, no significant differences between days could be demonstrated.	85.7

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
										analyzed starting at 0, 5,10, and 30 minutes after mares were brought into individual boxes. On the days horses were exercised, in addition, the total time of exercise was analyzed, divided into 5 minute intervals.				
23	Flaköll, B., Ali, A. B. & Saab, C. Y.	2017	Twitching in veterinary procedures: How does this technique subdue horses?	Journal of Veterinary Behaviour: Clinical Applications and Research	18, 23-28	E	12 male horses were used in this study, all geldings. Breeds were 6 quarter horses, 4 thoroughbreds, and 2 draft horses. The age range of the horses was 7-20 years, with a median age of 13.	Twitching (ear/lip)	Cross-sectional	HR and cortisol levels were measured in 2 groups of horses: one receiving the lip twitch and the other the ear twitch. Subjects in both groups were then evaluated behaviorally to ascertainwhether they tolerated being touched in the area surrounding the body part where they would later be twitched (i.e., if the horse was in the lip twitch group, the experi- menter would attempt to touch the horse's lip). After the first behavioral assessment, HR was measured for 15 minutes, and at the end of this period, saliva was collected to measure cortisol levels. For the horses in the first group, the lip twitch was applied, HR was measured for 15 minutes, and saliva was once again collected at the end of the measurement period. The same procedure was carried out with the second group; the only difference was that an ear twitch was applied instead of a lip twitch. HRV = early phase: first 5 min of twitching, late phase: last 10 min of twitching.	RS800 G3 (SDRR, RMSSD, HF, LF, LF/HF) Salivary cortisol	"The monitor was placed around the heart girth of the horse. Ultrasound transmission gel was applied to the belly and withers of the horses near the location of electrode strip on the HR monitors" BELT? Model not stated	Early phase lip twitch group = HR and LF/HF ratios were significantly lower than baseline values, whereas experimental RMSSD and SDRR were higher than baseline (with RMSSD levels significantly higher than baseline). Results for the ear twitch group were opposite to those in the lip twitch group, showing experimental HR and LF/HF ratios significantly higher than baseline and experimental RMSSD and SDRR lower than baseline. Late phase = HR and LF/HF ratios augmented significantly in relation to baseline values, and experimental RMSSD and SDRR dropped significantly in comparison to baseline (behaving in a manner similar to the ear twitch group). Ear twitch results remained consistent over time. Salivary cortisol = no significant change attendant with intervention was noted for lip twitch, whereas in the ear twitch group, experimental levels were significantly higher than baseline and control.	86.7
24	Ijichi, C., Green, S., Squibb, K., Carroll, A. & Bannister, I.	2019	Zylkéne to load? The effects of alpha-casozepine on compliance and coping in horses during loading	Journal of Veterinary Behaviour	30, 80-87	E	10 healthy horses (6 geldings and 4 mares) of mixed breeds and ages. Ages ranged from 8 to	Loading	Cross-sectional	Each subject was loaded once with Zylkéne Equine (supplement) and once without. There were equal numbers of supplemented and control horses in each trial. Zylkène Equinewas fed once daily for 4 days before testing. IRT readings were taken in the stable before testing (S.G.), once loaded on to the lorry when	V800 (SDRR, RMSSD) (Written in different syntax by authors: STDRR, but it is the same HRV measurement). IRT Salivary Cortisol	"was paired to an elasticated adjustable surcingle." BELT? Model not stated	There were no significant differences in physiology between treatment and control. There were no significant differences between treatment and control in subjects tested with control before treatment, with the exception of core temperature post confinement.	85.7

#	Authors	Year	Title	Journal	Volume, Page	Exp.	Subjects	Setting	Study Design	Methods	Outcome Measures	Sensor type?	Results	Score
							25 years (mean ¼ 12.6; IQR ¼ 9.25-14.5). Mean subject weight was 492.9 kg (±70.34).			the ramp had been closed and before the ramp was opened and the horse was unloaded from the lorry. Two saliva samples were taken, per horse, for each condition. The first sample was taken in the stable to determine a baseline level of cortisol for each horse. The second saliva cortisol sample was taken after 5 minutes within the lorry. HRV recordings began at a marker 3.5 m from the ramp of the lorry and recorded continuously during loading, confinement, and unloading. Recording was stopped when the horse returned to the marker after unloading.				

Appendix IX. Quality scoring: scoping review

Paper #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Criterion 1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Criterion 2	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	1
Criterion 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Criterion 4	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Criterion 5	0	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0
Criterion 6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Criterion 7	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	1
Criterion 8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Criterion 9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Criterion 10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Criterion 11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Criterion 12	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Criterion 13	NA	NA	NA	NA	NA	1	0	NA	NA	1	NA	NA	NA	NA	NA	1	NA	0	NA	NA	NA	NA	1	NA
Criterion 14	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Criterion 15	1	0	1	0	1	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1
Criterion 16	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1	0	1	0	0	1	1	0	1	1
Sum	**11**	**10**	**14**	**8**	**11**	**13**	**9**	**11**	**12**	**11**	**11**	**12**	**9**	**11**	**12**	**12**	**11**	**11**	**11**	**7**	**12**	**12**	**13**	**13**
Count	**14**	**14**	**14**	**14**	**14**	**15**	**15**	**14**	**14**	**15**	**14**	**14**	**14**	**14**	**14**	**15**	**14**	**15**	**14**	**14**	**14**	**14**	**15**	**14**
Total	78.6	71.4	100	57.1	78.6	86.7	60.0	78.6	85.7	73.3	78.6	85.7	64.3	78.6	85.7	80.0	78.6	73.3	78.6	50.0	85.7	85.7	86.7	92.9

Papers: 1 = Lenoir et al, (2013), 2 = Bohák et al, (2018), 3 = Villas-Boas et al, (2016), 4 = Janczarek et al, (2019), 5 = Schmidt et al, (2010), 6 = Schmidt et al, (2010b), 7 = Kędzierski et al, (2017), 8 = Parker et al, (2010), 9 = Ille et al, (2014), 10 = Becker-Birck et al, (2013), 11 = Schmidt et al, (2010c), 12 = Becker-Birck et al, (2013b), 13 = Schmidt et al, (2010d), 14 = Von Lewinski et al, (2013), 15 =Christensen et al, (2014), 16 = Ille et al, (2013), 17 = Pasing et al, (2013), 18 = Ille et al, (2014b), 19 = Squibb et al, (2018), 20 = Wulf et al, (2013), 21 = Ijichi et al, (2018), 22 = Erber et al, (2013), 23 = Flaköll et al, (2017), 24 = Ijichi et al, (2019)

Appendix X. Participant: PARQ, information sheet, consent form, disclaimer

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1) Has your doctor ever said that you have a heart condition **OR** high blood pressure?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
6) Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer **NO** if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity. Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Canada's Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a Canadian Society for Exercise Physiology - Certified Exercise Physiologist® (CSEP-CEP) or a CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional (CSEP-CEP) before engaging in this intensity of activity.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever - wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the **ePARmed-X+ at www.eparmedx.com** before becoming more physically active
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity program.

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PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — YES ☐ NO ☐

1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? — YES ☐ NO ☐

1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months? — YES ☐ NO ☐

2. Do you have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck? — YES ☐ NO ☐

2b. Are you currently receiving cancer therapy (such as chemotheraphy or radiotheraphy)? — YES ☐ NO ☐

3. Do you have Heart Disease or Cardiovascular Disease? *This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3e — If **NO** ☐ go to question 4

3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — YES ☐ NO ☐

3b. Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) — YES ☐ NO ☐

3c. Do you have chronic heart failure? — YES ☐ NO ☐

3d. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) — YES ☐ NO ☐

3e. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? — YES ☐ NO ☐

4. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 4a-4c — If **NO** ☐ go to question 5

4a. Is your blood sugar often above 13.0 mmol/L? (Answer **YES** if you are not sure) — YES ☐ NO ☐

4b. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet? — YES ☐ NO ☐

4c. Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)? — YES ☐ NO ☐

5. Do you have any Mental Health Problems or Learning Difficulties? *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)*

If the above condition(s) is/are present, answer questions 5a-5b — If **NO** ☐ go to question 6

5a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — YES ☐ NO ☐

5b. Do you **ALSO** have back problems affecting nerves or muscles? — YES ☐ NO ☐

PAR-Q+

6.	**Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*	
	If the above condition(s) is/are present, answer questions 6a-6d	If **NO** ☐ go to question 7
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐
7.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*	
	If the above condition(s) is/are present, answer questions 7a-7c	If **NO** ☐ go to question 8
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐
8.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*	
	If the above condition(s) is/are present, answer questions 8a-8c	If **NO** ☐ go to question 9
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐
9.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?**	
	If you have other medical conditions, answer questions 9a-9c	If **NO** ☐ read the Page 4 recommendations
9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
9c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20-60 min of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional (CSEP-CEP) before engaging in this intensity of activity.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional (CSEP-CEP) to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever - wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the **ePARmed-X+ at www.eparmedx.com** before becoming more physically active
- Your health changes - talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The PAR-Q+ Collaboration, the Canadian Society for Exercise Physiology, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- Please read and sign the declaration below:
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
www.eparmedx.com or
Canadian Society for Exercise Physiology
www.csep.ca

Citation for PAR-Q+
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Key References
1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

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Participant Information Sheet

Participant Name ………………………………............. Date…………………………………

Dear Participant,

You have been recruited to participate in a research study that is investigating ***the effects that the rider has on performance of horse and rider during cross-country competition.*** This information sheet provides basic information regarding the testing procedure and attached is a consent form for you to fill in which asks for your agreement to take part in the testing. The information and agreement form are referred to as informed consent. The following information aims to address any questions you may have about the testing. Please feel free to ask any additional questions to enable you to feel happy to provide consent to take part.

Aim of Study: To investigate the effects that the rider has on performance of horse and rider during cross-country competition

What will I have to do?

Prior to this testing you will have filled in the participant application form and will have met all of the eligibility criteria to be selected to take part in the study.

The work of the main study will take place at a training location of your choice within the UK and at British Eventing competitions in the UK.

During the first part of the study we (the research team) will attend a training session with you where the following will be done:

- Your heart rate will be taken at rest
- We will ask that you wear a heart rate monitor while exercising your horse
- Your horses heart rate will be taken at rest
- We will ask that your horse wears a heart rate monitor during exercise
- A GPS device will be attached to your horses tack and will record the speed of travel during exercise

During the second part of the study we will attend competitions in which you are entered, to record various data. We will not request that you attend any specific event, but do request that you inform us of which events you plan to attend. Once you have informed us of your event schedule we will inform you which events we will be attending to carry out our research, we will attend a minimum of two events with you and a maximum of five.

If you or your horse withdraw from competition due to injury or any other reason, then we ask that you contact us to inform us.

At competition you are required to do the following:

- Wear a heart rate monitor during your cross-country round
- Have a heart rate monitor on the horse for the duration of the cross-country round
- Wear a GPS device during your cross-country round (normally attached to the horses tack)
- Answer some questions before and after your cross-country round, the questions are very quick and can be done on the move, we do not want to disrupt your day!

The final part of the study will be carried out at a centre in Lancashire where you will be required to:

- Answer two different personality test questionnaires
- Ride an equestrian simulator, following instructions given to you by researchers
- Wear the heart rate monitor while riding the equestrian simulator

During the equestrian simulator section of the study you will be asked to carry out tasks on the simulator which may provoke different emotional responses including stress and excitement. If you experience any emotional distress from participating in the study it is strongly recommended that you visit your local General Practitioner to discuss this.

What are the risks of taking part?

You are responsible for any risks during event riding. The research team will ensure that the equestrian simulator is safe and is used in a safe environment.

It should be noted that the demands of the testing you will experience on the equestrian simulator are NOT anything different to that of a basic jumping training session on the horse.

A full risk assessment has been carried out by Myerscough College and UCLan (University of Central Lancashire), which minimises any risks to you and the researchers.

Do you have to take part?

Participation in this study is entirely voluntary. You are free to withdraw from this study at any time during the testing. Your data will be stored using numerical file names during testing, so once testing is complete you will not be able to withdraw it from the study as it will not be distinguishable from other participants' data.

All participants of the study will be entered in to a prize draw for the chance to win a year's free registration with British Eventing for one rider and one horse, kindly offered by British Eventing.

What will happen to my data?

Any data collected during this research study will be stored numerically and anonymously therefore no data will be traceable back to participants. All data collected is recorded as anonymous and will not be distinguishable from other participants' data for data protection purposes. All information provided by you regarding health status and consent will be stored anonymously on a password protected computer and will not be shared with any third parties. The overall results found during this study may be published by the University to peer reviewed journals and/or conferences.

We can offer you the personal results from yours and your horses' recorded data (heart rate and GPS), we can only provide you with this data in a descriptive manor on request following completion of the study. Please state below if you would like this service.

If you wish to receive a preliminary write up of the results of the study once complete please state below and we will send this to your email (please note that this is in regards to the entire data which is anonymous, you will not be able to distinguish your own personal data).

I would like my own and my horses heart rate and GPS data ☐

I would like to receive an email with the preliminary results write up ☐

Ethical Consent

This study has been granted ethical approval by the University of Central Lancashire.

If you wish to participate in this study, please sign the attached consent form. This is a requirement of the study that you provide a signature which provides your written consent to take part and perform the research.

You have been entered in to a prize draw to win a year's free registration for one rider and one horse with British Eventing in return for your voluntary application to participate in the study.

I acknowledge I have read and understood the contents of this form, and have been given full opportunity to discuss any queries I have.

Signed……………..……………..………….………….……. Date……………………………….…

Print…………………………………………………………….

All communications please contact:
Heather Cameron - Whytock
PhD student with UCLan
Myerscough College
Bilsborrow
Preston
PR3 0RY

Tel: 01995 642222 (EXT. 2020)
Email: hcameron-whytock@myerscough.ac.uk

Consent Form

Participant Name………………………. ***Date……………………………….***

Study Title: The effects that the rider has on performance of horse and rider during cross-country competition

Principal Researcher: Heather Cameron - Whytock

Written Consent for Testing

Please initial if the following apply to you:

I am fully aware of what is required of me during the testing of this study and understand the risks associated. (Initial__________)

I understand the risks of equestrian activities and take full responsibility for any equestrian activities or eventing competitions that I partake in. (Initial__________)

I understand that all data collected will be treated with confidentiality, however I am aware that the results produced from this research may be used in future publications. If I wish, the results will be available to me. (Initial__________)

I willingly agree to participate in the study. (Initial__________)

I have read the attached information provided and understand that I can withdraw from the study at any point without reason. (Initial__________)

If you agree to take part in this study please give your written consent below:

Name of Participant

Print Name: …………………………………………………………………………………………………

Participants Signature: ……………………………………………………………………………….

Date: ………. /………. /……….

Researcher/Witness

Print Name: …………………………………………………………………………………………………

Participants Signature: ……………………………………………………………………………….

Date: ………. /………. /……….

Disclaimer

The Research Team shall not be responsible for any damages, loss, injury or death to horse or rider resulting from the participation of British Eventing competition, or any equestrian activity, at which we will perform our research. We will ask you to sign this disclaimer before participating in any of our research.

You acknowledge that all equestrian activity involves a risk of personal injury, including a risk of serious injury or death, and agree to take responsibility for your own and your horses' health and well-being in relation to this research.

You must inform us, as soon as possible, if, at any time:

- you no longer wish to participate in the study
- you have concerns regarding the study
- you are uncomfortable with any methods or equipment used during the study

We may in our sole discretion prohibit you from participating in the study at any time; and you must comply.

We will not be liable to you in respect of any personal injury (including without limitation serious injury or death) that you may suffer or sustain directly or indirectly as a result of any equestrian activity. Nor will we be liable to you in respect of any other losses arising as a result of any such personal injury.

We will not be liable to you in respect of any of your personal property that is lost, stolen or damaged before, during or after your research participation. We will not be liable to you in respect of any losses arising out of any event or events beyond our reasonable control.

We will not be liable to you in respect of any business losses, including (without limitation) loss of or damage to profits, income, revenue, use, production, anticipated savings, business, contracts, commercial opportunities or goodwill.

In this disclaimer, "we" means (and "us" and "our" and "The Research Team" refer to):
Heather Cameron – Whytock[1]
Sarah Jane Hobbs[2]
Charlotte Brigden[1]
Paul Taylor[2]
Jonathan Sinclair[2]

[1]Myerscough College, St Michael's Road, Bilsborrow, Preston, PR3 0RY
[2]University of Central Lancashire, Preston, PR12HE

I HAVE READ, UNDERSTOOD AND AGREE TO THE TERMS OF THIS DISCLAIMER

SIGNATURE:

PRINT NAME:

ADDRESS:

DATE:

Appendix XI. Rider questions before/after cross-country

RIDER: HORSE: DATE: COMPETITION:

XC WARM UP START:…………………… XC START:……………………

PRIOR XC ROUND	Not at all				Very
Your level of fatigue	1	2	3	4	5
Horses level of fatigue	1	2	3	4	5
Your level of anxiety	1	2	3	4	5
Eagerness to do well	1	2	3	4	5
Horses level of response to you today	1	2	3	4	5

Are you aware if any frangible pins have been used on course?	Yes	No
Which fence?	……………………………………………… / I don't know	
Is this horse for sale?	Yes	No

For Researcher:

Is rider wearing a watch?	Yes	No
Is rider wearing an air jacket?	Yes	No
Is this the first horse to be ridden round course by this rider?	Yes	No it is number ……………………………
Does rider know dressage score?	Yes	No
Has rider looked at scores in tent?	Yes	No

RIDER: HORSE: DATE: COMPETITION:

POST XC ROUND

Rider ID…………… Horse ID……………

	Not at all				Very
Difficulty of XC round	1	2	3	4	5
Level of anxiety during	1	2	3	4	5
Level of concentration during	1	2	3	4	5
Do you think you met the optimum time?	1	2	3	4	5
How well did the horse respond to you during XC	1	2	3	4	5

Were there any fences that the horse attempted to refuse?

Yes fence ……………… No

Did rider meet optimum time? Yes No

If no above: Too slow Too Fast

Optimum time ____________ (Rider time penalties ___________)

Appendix XII. Participant debrief

Study Debrief Information

Study Title: ***The effects that the rider has on performance of horse and rider during cross-country competition***

This research aims to improve safety in the sport of eventing by identifying factors that contribute to the occurrence of horse falls on the cross-country course. Discovery of these factors has the potential to educate governing bodies, riders and trainers on how to reduce the occurrence of horse falls, which could result in saving a person, or a horse's life. Research like this is also vital for the continuation of the sport of eventing, if we do not consistently strive to improve safety then we could see our sport come to an end over safety fears. Studies like this would not be possible without voluntary participants, so we thank you greatly for your participation.

Data will not be identifiable so it is now too late for you to withdraw your data, please be reassured that all data is completely anonymous and is kept in a safe and secure place with restricted access measures.

The results of the study will now be written up in to a PhD thesis, it is likely that the study will also be published in academic journals and potentially the media. You will be notified if the study is published in academia or the media, to enable you to read about the study if you wish.

During application of the study and consent, you were asked if you would like preliminary results of the study to be sent to you via email, if you did not opt for this service but would now like to, please contact the lead researcher using the contact details below.

Thank you again for your participation in the study, your contribution to safety research within your sport is invaluable.

If you have any questions of queries regarding the study, please feel free to contact me.

Your Sincerely,

Heather Cameron – Whytock BSc (Hons)

Contact:

Heather Cameron - Whytock
PhD student with UCLan
Myerscough College
Bilsborrow
Preston
PR3 0RY

Tel: 01995 642222 (EXT. 2020)
Email: hcameron-whytock@myerscough.ac.uk

Appendix XIII. Advert for participants

A study of physiological and psychological factors during eventing competition and their effect on performance

Do your bit for safety in your sport!

New research on eventing safety looking for event riders to voluntarily participate

- Would you be happy to allow researchers to observe you during training and at British Eventing competition?
- Would you be happy to wear a Heart Rate monitor during training and your cross-country round at British Eventing competition?
- Would you and the horses owner be happy for the horse to wear a Heart Rate monitor during training and your cross-country round at British Eventing competition?

If you have answered yes to all of the above questions then you could volunteer to participate in the study and have the chance of winning a years free registration with British Eventing for you and your horse.

Interested? Contact hcameron-whytock@myerscough.ac.uk and you will be sent further information and an application form.

N.B. Applicants must be 18 or over and regularly compete at British Eventing competition. All applicants will be entered in to a prize draw to win a year's free registration for themselves and their horse with British Eventing.

Research Team

Heather Cameron—Whytock (Lead Researcher. PhD student. Myerscough College in Association with University of Central Lancashire)

Dr Sarah Jane Hobbs

Charlotte Brigden

Dr Paul Taylor

uclan University of Central Lancashire | Myerscough Associate School

BRITISH EVENTING Providing the ultimate equestrian challenge

Appendix XIV. Survey Monkey: Participant recruitment form

Participant Recruitment Form

1. Age

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45+

2. Gender

- ◯ Male
- ◯ Female

3. How often do you compete at British Eventing during the eventing season (approximately)?

- ◯ I compete once a month
- ◯ I compete twice a month
- ◯ I compete more than twice a month

4. How many horses do you regularly compete at British Eventing?

- ◯ 1
- ◯ 2
- ◯ More than 2

5. What level of British Eventing competition do you compete at? Please select all that apply

- ☐ BE80 (T)
- ☐ BE90
- ☐ BE100
- ☐ Novice
- ☐ Intermediate
- ☐ Advanced

6. Are you a professional event rider? Please select 'yes' if you do this as a full time job, are paid to event or if you have represented Great Britain in Eventing competition. If you are unsure please explain your circumstances in the 'other' box.

- Yes
- No

Other (please specify)

7. Do you plan to continue eventing in these same circumstances in 2017?

- Yes
- No

8. Would you be happy to wear a heart rate monitor during eventing competition?

- Yes
- No
- Other (please specify)

9. Would you be happy for your horse to wear a heart rate monitor during eventing competition?

- Yes
- No
- Other (please specify)

10. Please give your location within the UK and your email address here

Appendix XV. Recruitment sample frame

Recruitment Sample Frame

Proposed sample size: n=16

	Rider Age				Gender		Level of Competition				Rider level		Horses Competing		
	18-24	25-34	35-44	45+	Male	Female	Be 80(T) – BE100	Novice	Intermediate	Advanced	Amateur	Professional	1	2	3+
Desired	4	4	4	4	8	8	5	5	4	2	8	8	4	8	4
Actual															

Essential Criteria

	Yes	No
<TBC% of all starts result in HF		
Rider is over the age of 18		

Appendix XVI. British Eventing consent letter for participants (example)

BRITISH EVENTING
Providing the ultimate equestrian challenge

Abbey Park, Stareton, Kenilworth, Warwickshire, CV8 2RN
T: +44 (0)2476 698856 • F: + 44(0)2476 697235
E: info@britisheventing.com
www.britisheventing.com

RE:

RE: Eventing Safety Research Project

This letter confirms that permission has been granted for and her horse to take part in research titled "A combined data and field analysis of risk factors for horse falls in the cross-country phase of British Eventing" at British Eventing affiliated events throughout the UK. The research is conducted by Heather Cameron – Whytock (lead researcher) and her research team from Myerscough College and The University of Central Lancashire.

Heather has recruited a number of horse and rider combinations who will have data collected during the competition. British Eventing are happy for and her horse to participate in this study and contribute to this important research.

This research will include the use of the following items of electronic equipment:

- Polar Heart Rate Monitor for horse and rider
- RidersMate device

If you have any queries or questions please contact Chris Farr, British Eventing Sport Operations Manager at chris.farr@britisheventing.com or on 07702 901006.

Yours sincerely,

Chris Farr

British Eventing Sport Operations Manager

Appendix XVII. Results of normality testing (Shapiro-Wilks)

Rider HR/HRV at different time-periods

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
R T1 Mean HR	.199	13	.200*	.849	11	.042
R T1 Min HR	.173	13	.200*	.853	11	.046
R T1 Max HR	.174	13	.200*	.911	11	.248
R T1 RMSSD	.157	13	.200*	.939	11	.512
R T2 Mean HR	.158	13	.200*	.969	11	.873
R T2 Min HR	.159	13	.200*	.964	11	.815
R T2 Max HR	.150	13	.200*	.971	11	.893
R T2 RMSSD	.211	13	.185	.893	11	.154
R T3 Mean HR	.169	13	.200*	.955	11	.714
R T3 Min HR	.230	13	.109	.873	11	.085
R T3 Max HR	.210	13	.189	.894	11	.155
R T3 RMSSD	.192	13	.200*	.941	11	.532
R T4 Mean HR	.257	13	.041	.855	11	.050
R T4 Min HR	.136	13	.200*	.923	11	.346
R T4 Max HR	.236	13	.088	.879	11	.101
R T4 RMSSD	.182	13	.200*	.955	11	.706

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Horse HR/HRV at different time-periods

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
H T1 Mean HR	.123	13	.200*	.906	13	.161
H T1 Min HR	.130	13	.200*	.914	13	.206
H T1 Max HR	.174	13	.200*	.877	13	.064
H T1 RMSSD	.306	13	.002	.613	13	.000
H T2 Mean HR	.402	13	.000	.606	13	.000
H T2 Min HR	.325	13	.001	.712	13	.001
H T2 Max HR	.463	13	.000	.539	13	.000
H T2 RMSSD	.250	13	.026	.851	13	.029
H T3 Mean HR	.251	13	.025	.829	13	.015
H T3 Min HR	.193	13	.198	.789	13	.005
H T3 Max HR	.246	13	.031	.860	13	.039
H T3 RMSSD	.394	13	.000	.621	13	.000
H T4 Mean HR	.163	13	.200*	.947	13	.550
H T4 Min HR	.125	13	.200*	.959	13	.738
H T4 Max HR	.199	13	.169	.937	13	.415
H T4 RMSSD	.275	13	.008	.762	13	.003

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Horse: Mean HR (C1 & 2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HT1 MeanHR	.203	8	.200*	.882	8	.197
HT2 C1 MeanHR	.444	8	.000	.513	8	.000
HT3 C1 MeanHR	.375	8	.002	.690	8	.002
HT4 C1 MeanHR	.169	8	.200*	.971	8	.909
HT2 C2 MeanHR	.176	8	.200*	.977	8	.947
HT3 C2 MeanHR	.160	8	.200*	.929	8	.505
HT4 C2 MeanHR	.133	8	.200*	.991	8	.996

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Horse: Min HR (C1 & 2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HT2 C1 Min HR	.381	8	.001	.570	8	.000
HT3 C1 Min HR	.350	8	.005	.694	8	.002
HT4 C1 Min HR	.163	8	.200*	.947	8	.677
HT2 C2 Min HR	.148	8	.200*	.982	8	.971
HT3 C2 Min HR	.240	8	.194	.895	8	.262
HT4 C2 Min HR	.151	8	.200*	.976	8	.938

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Horse: Max HR (C1 & C2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HT2 C1 Max HR	.462	8	.000	.506	8	.000
HT3 C1 Max HR	.208	8	.200*	.888	8	.222
HT4 C1 Max HR	.203	8	.200*	.917	8	.407
HT2 C2 Max HR	.246	8	.167	.900	8	.288
HT4 C2 Max HR	.312	8	.021	.879	8	.185
HT3 C2 Max HR	.147	8	.200*	.965	8	.853

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Horse: RMSSD (C1 & C2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HT2 C1 RMSSD	.237	8	.200*	.846	7	.113
HT3 C1 RMSSD	.442	8	.000	.587	7	.000
HT4 C1 RMSSD	.300	8	.057	.792	7	.034
HT2 C2 RMSSD	.242	8	.200*	.856	7	.139
HT3 C2 RMSSD	.395	8	.001	.693	7	.003
HT4 C2 RMSSD	.285	8	.089	.760	7	.016

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Rider: Mean HR (C1 & 2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RT2 C1 MeanHR	.159	7	.200*	.962	7	.835
RT3 C1 MeanHR	.198	7	.200*	.959	7	.811
RT4 C1 MeanHR	.192	7	.200*	.942	7	.656
RT2 C2 MeanHR	.158	7	.200*	.956	7	.780
RT3 C2 MeanHR	.289	7	.080	.881	7	.229
RT4 C2 MeanHR	.168	7	.200*	.938	7	.617

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Rider: Min HR (C1 & 2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RT2 C1 Min HR	.197	7	.200*	.949	7	.717
RT3 C1 Min HR	.245	7	.200*	.890	7	.275
RT4 C1 Min HR	.169	7	.200*	.945	7	.688
RT2 C2 Min HR	.187	7	.200*	.941	7	.648
RT3 C2 Min HR	.215	7	.200*	.912	7	.412
RT4 C2 Min HR	.199	7	.200*	.939	7	.633

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Rider: Max HR (C1 & C2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RT2 C1 Max HR	.165	7	.200*	.971	7	.905
RT3 C1 Max HR	.259	7	.172	.865	7	.167
RT4 C1 Max HR	.190	7	.200*	.946	7	.698
RT2 C2 Max HR	.198	7	.200*	.921	7	.479
RT3 C2 Max HR	.161	7	.200*	.945	7	.687
RT4 C2 Max HR	.170	7	.200*	.971	7	.904

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Rider: RMSSD (C1 & C2) Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RT2 C1 RMSSD	.218	7	.200*	.919	7	.459
RT3 C1 RMSSD	.159	7	.200*	.942	7	.658
RT4 C1 RMSSD	.206	7	.200*	.926	7	.521
RT2 C2 RMSSD	.186	7	.200*	.962	7	.832
RT3 C2 RMSSD	.306	7	.046	.763	7	.017
RT4 C2 RMSSD	.296	7	.063	.863	7	.161

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Association between horse/rider RMSSD

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HT3 RMSSD	.390	11	.000	.676	11	.000
RT3 RMSSD	.192	11	.200*	.941	11	.532
HT4 RMSSD	.264	11	.031	.735	11	.001
RT4 RMSSD	.182	11	.200*	.955	11	.706

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction