Equine gait-related eliminations in British endurance: Identifying risk factors to improve horse welfare

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Abstract

Introduction: Endurance is an equestrian sport where horse and rider combinations compete up to 160km in one day. In order to be successful within competition, horses must pass a metabolic and gait assessment by licenced veterinarians, not only at the start, but during and at the end of the competition. If they fail this inspection they are eliminated from competition. Lameness has been identified as the leading cause of elimination in studies of international-level competition but had not been evaluated in British Endurance.

Aim: To identify risk factors for lameness eliminations in British national competition, including details such as which limb(s) are most frequently identified as lame.

Methods: A retrospective epidemiological study followed by two prospective studies were conducted. First, competition data recorded by Endurance GB were analysed. Univariable analysis was used to inform two multivariable binary logistic regression models with the dichotomous variables pass/did not pass and lame/ not lame. These results informed the design of the prospective studies. The first determined whether there were significant differences between forelimb and hindlimb eliminations. The second prospective study investigated thoracolumbar back pain on palpation and tested inter-rater reliability of veterinary inspections for limb identification, lameness grade and epaxial muscle palpation.

Results: Retrospective study: Risk factors identified as significant ($P<0.05$) in the final multivariable models included historic cumulative distances attempted, historical number of starts, eliminations and specifically lameness eliminations.

Prospective studies: Technicality of the course in terms of steepness was an additional risk factor for single loop rides, whereas it was not for multi- loop rides. Increased average speed was a risk factor in multi-loop rides. Hindlimb lameness was identified more frequently than forelimb lameness. Asymmetrical back palpation was a significant risk factor for elimination and lameness across all distances. Inter-rater reliability of limb identification was excellent with 100% agreement between the assessors when two veterinarians were used ($K=1$, $p<0.001$, C.I.0.86-1.14) and remained excellent when three veterinarians identified the lame limb ($K=0.83$, $p<0.001$, C.I.0.75-0.9).

Conclusions: The results of this thesis considering British national level, agree with previous findings at international level, identifying lameness as the most common reason for elimination from competition. High cumulative distances, an increased number of starts and repeated eliminations are significant risk factors for gait-related elimination. Differences in risk factors exist between lower level competitions and higher distance competitions at National level. Palpation of the horse's back during the veterinary inspection should be considered as an important component of the examination across all levels of competition.

While Further work is required to better understand the cause and effect relationship between back pain and lameness at competition. The High levels of inter-rater reliability in lame limb identification and thoracolumbar epaxial palpation reported should give confidence in the veterinary panel. Competitors in endurance should heed the veterinarians' expert opinion to safeguard their horses' welfare and the social licence to operate of the sport. Understanding and recognising risk factors for lameness in competition, by all stakeholders within the sport will protect the welfare of the horse as well as improve competitive performance, as ultimately, lame horses cannot win.

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Abbreviations

AAEP	American Association of Equine Practitioners
ACPAT	Association of Chartered Physiotherapists in Animal Therapy
CER(s)	Competitive Endurance Ride(s)
CI	95% Confidence Interval
DSQ	Disqualified
EGB	Endurance GB
FEI	Fédération Equestre Internationale
GER(s)	Graded Endurance Ride(s)
IRR	Inter-rater reliability
MET	Metabolic Elimination
MOOCP	Mandatory Out of Competition Period
OOT	Out of Time
OR	Adjusted Odds Ratio
OV	Official Veterinarian
PR(s)	Pleasure Rides
PET	Permitted Equine Therapist
PTV	Permitted Treatment Veterinarian
RCVS	Royal College of Veterinary Surgeons
RET	Retired
ROC	Receiver Operating Characteristic curve analysis
SLO	Social Licence to Operate
VP	Veterinary Panel
WBGTI	Wet Bulb Globe Temperature Index
WDN	Withdrawn

Abbreviations may differ in appendices where they are written as per publication, but are explained fully within the specific appendix

Chapter 1

1.0 Introduction

Endurance riding is an internationally recognised equestrian sport. Internationally, the Fédération Equestre Internationale (FEI) govern the sport, whereas in Great Britain, the sport is governed by Endurance GB (EGB) (EGB, 2022c; FEI, 2022b). Horse and rider dyads compete in long distance rides of up to 160km across varied terrain.

In order to safeguard the welfare of the horses, they must pass a series of veterinary inspections, comprising of a metabolic assessment (heart rate, hydration status, muscular tone, respiration status and presence of gut sounds) and a gait assessment, where the horse is trotted in hand, 30 meters away from and back towards the examining veterinarian (EGB, 2022c; FEI, 2022b). If the horse does not fall within the accepted parameters of the metabolic assessment or is considered to be lame by the licensed veterinarians, the horse is eliminated from the competition. Accepted parameters and details of the veterinary inspection are detailed in Appendix 1. Veterinary inspections take place prior to the start of the competition, every 20-40 km during the competition, and again at the end of the competition (EGB, 2022c; FEI, 2022b). The horse must pass all veterinary inspections to avoid being eliminated from the competition.

Safeguarding the welfare of the horse is the key priority for both the FEI and EGB, which is the rationale for the multiple veterinary inspections (EGB, 2022c; FEI, 2022b). Statistics from the FEI identified >30% of horses are eliminated from competitions (FEI, 2020). Concerns surrounding the welfare of the horses competing in endurance are regularly voiced across social media platforms and as a result the social licence to operate (SLO) of the sport, as with other horse sports, could be at risk (Douglas, Owers and Campbell, 2022; Hampton, Jones and McGreevy, 2020; Heleski *et al.*, 2020; Williams and Marlin, 2020; Fiedler and McGreevy, 2016; McLean and McGreevy, 2010). In attempts to safeguard both the horses competing and the sport as a whole, several studies have looked at the risk factors for elimination from endurance competitions. These studies identify lameness as the most common reason for elimination (Bennet and Parkin, 2020, 2018a, 2018b; Marlin and Williams, 2018b; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2014a, 2014b; Nagy, Dyson and Murray, 2012; Fielding *et al.*, 2011; Nagy, Murray and Dyson, 2010). The majority of studies considering risk factors in Endurance to date have considered FEI level, or, in the case of Fielding *et al.,* 2011, American Endurance rides. American Endurance and the FEI both have independent rules and regulations as well as possible differences in climate and terrain compared to British national level competitions and therefore it is possible that there may be some differences between risk factors.

Proactive steps to promote horse welfare have been taken by the FEI by initially commissioning research into the risk factors for elimination and subsequently implementing regulatory changes, such as enforcing time away from competition to allow any microtrauma a chance to heal (FEI, 2022b; Bennet and Parkin, 2020, 2018b, 2018a). It is perhaps considered inevitable that the physical demands of an endurance competition would result in repetitive strain on the musculoskeletal system of the horse, due to the repetitive cyclic loading over long distances and varied terrain. This repetitive strain is likely to result in small amounts of damage in soft tissues and the skeletal system, which over time, if not allowed to heal, may accumulate to cause visible lameness and/or significant injuries such as fractures to the limb (Samol *et al.*, 2021; Loughridge *et al.*, 2017; Clansey *et al.*, 2012). There is, however, an anecdotal belief among British national competitors that the issues within the sport only exist at international level and not at national level. The rationale for this is not completely clear, it could be postulated that images that have circulated on social media of catastrophic injuries, have not arisen from competitions run under EGB rules. Perhaps, the severity of injuries is lower at British national level (although this has not been formally identified) and this adds to the perception that lameness is less of an issue. Despite this, a study identifying that out of nine countries, British horses had the highest percentage of lameness eliminations, albeit at FEI level (Nagy, Murray and Dyson, 2010).

The only study specific to British national level endurance thus far, was a survey issued to EGB members (Nagy, Dyson and Murray, 2017). The response rate was equivalent to 21.3% (n=258) of all horses registered. This survey identified that 80% of riders that responded acknowledged that their horse had been identified as lame at least once during their competitive career (Nagy, Dyson and Murray, 2017). The results suggest that lameness eliminations are worth considering at a more local, national level and that anecdotal assumptions, should be questioned. Perhaps, if risk factors for lameness are identified at the early stages of the horses' careers, and stakeholders are educated on risk mitigation, there would be fewer issues progressing to the international level. In turn, this would improve the welfare of the horses competing across all levels of competition.

It was therefore the overarching aim of this thesis to identify risk factors for veterinary eliminations at British national level of endurance competitions and discuss more specific information surrounding eliminations related to lameness than has previously been identified within competition.

Chapter 2

2.0 Aims and objectives

The overarching aim of this thesis was to identify risk factors for eliminations, specifically lameness eliminations from British national endurance competitions.

It was hoped that findings would provide riders, trainers and veterinarians within the sport a greater evidence base which can be used to, where possible, make recommendations to mitigate risk and promote of horses competing within the sport of endurance.

The objectives of this thesis were:

1. To identify risk factors associated with elimination and specifically lameness eliminations of horses registered with the governing body of British endurance, Endurance GB from information recorded and identify gaps within the data;
2. To establish which limb(s) are most frequently identified as lame at the point of elimination from competition.
3. To identify whether risk factors change depending on the level of competition;
4. To consider whether an additional component of the veterinary inspection, thoracolumbar epaxial muscular palpation, could identify an additional risk factor for eliminations and specifically lameness eliminations; and;
5. To assess the inter-rater reliability of lameness evaluations and thoracolumbar epaxial muscular palpation during the veterinary inspections at competitions.

Chapter 3

3.0 Literature Review

3.1 The sport of endurance

Endurance is an international equestrian sport in which horse and rider combinations compete up to 160km in one day. Depending on the distance of the competition, a series of loops of usually 20-40km are completed over varied terrain, to make up the total distance of the ride.

The FEI Endurance rules (2022) state:

> *'Endurance is a test of the athlete's ability to manage the horse safely over an Endurance course. It is designed to test the stamina and fitness of the athlete and horse against the track, distance, terrain, climate and clock, without compromising the welfare of the horse.'*

In order to compete at international level, horses and riders must qualify through a series of national level competitions, the qualifications required to compete through national to international level are provided in Appendix 1.

At National level, there are a range of competitive levels and ride categories that are available for horses and riders. In British endurance three types of rides exist: Pleasure Rides (PRs), Graded Endurance Rides (GERs) and Competitive Endurance Rides (CERs). Pleasure rides are non-competitive rides of up to 36km, which must be completed at 8-12km h^{-1}. Graded Endurance Rides (GERs) range from 20-160km in length and have a maximum and minimum speed allowed (EGB, 2022). Grades are calculated for successful completions based on the horses finishing heart rate and overall speed. At advanced level, horses and riders may take part in Competitive Endurance Rides (CERs) which are race rides; the first horse and rider combination to pass the finishing line and then successfully pass a veterinary inspection wins the competition. The competitors must fulfill the minimum speed limit, which is set out in the pre-ride details, (usually 10-14km h^{-1}) minimum) but there is no maximum speed limit. The minimum distance for a CER in EGB rides is 80km (EGB, 2022).

Research into the sport of endurance has predominantly focussed on FEI competitions and several studies have confirmed that the leading cause for elimination from endurance competition is lameness (Bennet and Parkin, 2020, 2018a, 2018b; Marlin and Williams, 2018b; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2014a, 2014b; Nagy, Dyson and Murray, 2012; Fielding *et al.*, 2011; Nagy, Murray and Dyson, 2010). A study looking at British national level competition, issued a survey to all EGB members (258 responded out of 1209 horses registered) concluded that 80% of the horses which had taken part in an EGB event had had a lameness episode, with 40% having been lame on two or three occasions (Nagy, Dyson and Murray, 2017). In 57.8% of cases, the most recent episode of lameness had resulted in the elimination from an endurance competition. Just over half of the lameness episodes (51.8%) were investigated by a veterinarian. This indicates lameness within the sport must be a key priority, not just at international level, and lameness eliminations at British national level should be considered in greater detail.

3.2 Social Licence to Operate in relation to using horses in sport

The term Social Licence to Operate (SLO) refers to the public acceptance, approval or consent of the activities of an organisation and whilst it originated from industry, it has been applied across sport and specifically in sports involving animals (Douglas, Owers and Campbell, 2022; Hampton, Jones and McGreevy, 2020; Heleski *et al.*, 2020; Williams and Marlin, 2020; Fiedler and McGreevy, 2016; McLean and McGreevy, 2010). A SLO requires positive public perception of the sport and where welfare is compromised or is questionable, the SLO may be at risk of removal (Douglas, Owers and Campbell, 2022;

Hampton, Jones and McGreevy, 2020; Heleski *et al.*, 2020; Williams and Marlin, 2020; Fiedler and McGreevy, 2016; McLean and McGreevy, 2010). Concerns have been increasing across equestrian disciplines about the risk of the SLO being removed, but there has also been a shift in research and regulations from performance optimisation to equine welfare, with the anticipation that improved welfare leads to improved performance and public perception (Douglas, Owers and Campbell, 2022).

There was public outrage at the Tokyo 2020 Olympic games over the ridden component of the Modern Pentathlon, which has been in every Olympic event since 1912, due to the treatment of the horses whilst competing. This public perception has resulted in the decision to remove and replace the ridden aspect of the event after the next Olympic games. Concerns over the future of all equestrian events at the Olympics have been voiced and as a result the French Parliament, hosting the 2024 Olympics have discussed an overhaul of horse welfare, currently listing 34 recommendations for improvement. It is not just the Olympics which has concerns over the use of horses in sports being accepted by the public, but across all horse sports, with horse racing having been under the spot light for some time (Douglas, Owers and Campbell, 2022; Hampton, Jones and McGreevy, 2020; Heleski *et al.*, 2020; Duncan, Graham and McManus, 2018). The Chief Executive of World Horse Welfare presented the concept of a social licence in equestrian sport to the FEI General assembly (Roly Owers, 2017). In the presentation the President of the European Equestrian Federation, Hanfried Haring, is quoted as saying

> *"It is no longer just us, the horse people, who decide what is right and wrong. The pressure from society on the treatment of horses is increasing."*

A SLO requires four key components: legitimacy, trust, transparency and communication (Douglas, Owers and Campbell, 2022; Williams and Marlin, 2020; Duncan, Graham and McManus, 2018). The first component, legitimacy, is the concept of following the rules and regulations, or to be able to defend a step away from the rules with an acceptable justification (Williams and Marlin, 2020). However, legitimacy can only be widely accepted if the rules and regulations are evidence-based to be in the best interest and protect the welfare of those taking part in the sport. In equestrian sport, this is more complex than sport which does not involve animals as both horse and rider welfare must be protected.

The FEI has taken proactive steps in improving the legitimacy in endurance by commissioning the Global Endurance Injuries Study (GEIS). The GEIS, commissioned in 2015, had the intention of providing an evidence base to changes to the rules and regulations, with the main focus being to protect equine welfare and reduce injury. A global review of FEI results and competitions identified a series of risk factors for horse injury which could be minimised by stakeholders with regulatory changes or changes that could be implemented by riders and trainers (Bennet and Parkin, 2018b, 2018a, 2020). Risk factors identified which could be reduced by stakeholders within the sport include; the size of the competitive field, previous eliminations of both the horse and rider, mandatory out of competition periods and speed (Bennet and Parkin, 2018b, 2018a, 2020). A further study, modelling successful outcomes in FEI endurance has since been completed (Zuffa, Bennet and Parkin, 2022). This identified high competition speed, increase in speed and competition level between successive competitions and a high competition frequency were associated with a decrease in odds of completion of the competition. The study frames successful outcomes which may alter the negative perception of the sport to a more positive framework of competitive success and horse welfare, imperative for a SLO in equestrian sports (Douglas, Owers and Campbell, 2022; Zuffa, Bennet and Parkin, 2022; Williams and Marlin, 2020). As a result of the evidence provided, the FEI has made regulatory changes, including increasing the MOOCP for those with metabolic and lameness eliminations and for those that are ridden at speeds exceeding 20km.h^{-1} (FEI, 2022b). Whilst this rule exists at British national level, it only applies to horses who are registered with the FEI, and in practice speeds above 20km.h^{-1} are rare at EGB competitions (EGB, 2022c; FEI, 2022b).

These regulation changes should improve the SLO components of procedural trust and transparency in the sport of endurance. The FEI acknowledged a concern, took proactive steps to identify the issues and implemented regulatory changes, underpinned by evidence and therefore demonstrated transparency (FEI, 2022b). Outcomes have clearly influenced regulatory changes at FEI level, however there is not a direct translation to national level competition rules, as the evidence to underpin these changes is not yet present at the lower levels of competitions. Therefore, the legitimacy in national level endurance has the potential to be questioned.

Completing research to underpin the regulatory changes is a promising start in terms of equine welfare and SLO, however it is not enough. The final component of the SLO is communication (Douglas, Owers and Campbell, 2022; Williams and Marlin, 2020). The communication must be clear and widespread in order to protect the welfare and enable the use of horses in sport to continue. It is however, a slightly uphill battle, with management of horses often based on anecdotal advice strategies, lacking scientific evidence. Combined with the increase use of social media, where anecdotal advice is often publicised and frequently followed, this presents a challenge to the evidence-based strategies being seen and accepted.

Emotive headlines, frequently seen on social media, often intentionally sensationalised grab the reader's attention and encourage readers to form an instant opinion, perhaps without reading the full facts, or acknowledging journalistic licencing and bias of the writer (Montejo and Adriano, 2018; Grabe, Zhou and Barnett, 2001). A few examples of negative media headlines about endurance are documented below:

> *"Guns, riots and death threats at the World Equestrian Games in Tryon"* (Dressage Hub, 2018)

> *"UAE2020 Endurance: Business as Usual in the Killing Fields"* (Cuckson, 2020)

> *"Record FEI ban for rider of nerve-blocked horse who suffered horrific fracture"* (Jones, 2020)

> *"This is NOT endurance: calls for world to unite in condemnation after at least two horses die"* (Jones, 2022).

Communication must be improved by stakeholders within the sport, the aforementioned steps taken by the FEI and the researchers must be clearly articulated to the participants of the sport, not just outlining rule changes but providing evidence underpinning them (Douglas, Owers and Campbell, 2022; Williams and Marlin, 2020). Until the evidence is understood by the participants, and adaptive strategies implemented into their own practice of horse management and welfare, the SLO remains at risk. The onus is not just on the researchers, but the governing bodies of the sport to proactively communicate and educate their members, and not just assume knowledge and understanding.

However, in terms of British national endurance competitions, the evidence is lacking and therefore communication can only be opinion based or experience based, which limits the legitimacy component of the SLO.

Research at national level competition is lacking as there is a fundamental anecdotal issue that exists currently in endurance, and perhaps across all horse sports: issues surrounding horse welfare in competition are perceived to exist only at the elite level. Evidence has focussed on elite competition, as this is the most visible to the public, but if those within the sport cannot understand there may be an issue at lower levels, then management strategies will not change and may follow the horse and rider as they progress through the competitive levels. To date, there have been no studies specifically evaluating risk factors for lameness or elimination at British national level within endurance, despite riders acknowledging that 80% of their horses had been lame at least once within their competitive career (Nagy, Dyson and Murray, 2017). Participating in ridden sport is a high -risk activity for both horse and rider and as such risk elimination is not possible, however stakeholders within the sport should aim to mitigate or at least reduce known risks. Proactive strategies are required to understand the risk factors for lameness at British national level and communicate them to those participating in competitions. If this is understood at entry level, then there is the possibility of management strategies to protect the welfare of the horses at the start of their career filtering up the levels, as well as filtering down from the changes made by the FEI and the top-level competitors. Failure to act, risks the SLO of the sport being removed and compromises equine welfare.

3.3 Evaluation of Lameness

There has been a variety of definitions of lameness in literature, most of which describe lameness as a clinical representation of structural, mechanical or functional disorders of the locomotor system, characterising within a visible alteration on gait pattern, rather than a diagnosis (AAEP, 2019; Davidson, 2018). It is standard practice to determine lameness by visual identification, with forelimb lameness confirmed when the horse consistently raises its head as the affected limb lands on the ground, in turn this means as the non- affected forelimb lands on the ground, the head is slightly lower, hence the common phrase 'sound to the ground'. Hindlimb lameness is often more difficult to identify but is apparent with increased vertical displacement of the tuber coxae of the affected limb in comparison to the non-affected limb. The subjective evaluation of lameness, as in the case of a vetting within an endurance competition, relies on the ability and experience of the observer. De Mira *et al.* (2019) reported that among FEI veterinarians, most (98.2%) had been questioned and/or confronted by competitors who disagreed that their horse was lame. Whether this is because the competitors had a 'win at all costs' attitude, or genuinely were unable to visualise the lameness due to their lack of clinical experience remains unknown. Other studies have confirmed that horses perceived as 'sound' or 'without lameness', by their owners, were identified as lame by veterinarians or objective gait analysis (Müller-Quirin et al., 2020; Rhodin et al., 2017; Dyson and Greve, 2016). It is, perhaps, not surprising that competitors in the sport may struggle with identifying a lameness when inter-rater reliability (IRR) of subjective evaluations of lameness between veterinarians has been shown to be poor (Hammarberg *et al.*, 2016; McCracken *et al.,* 2012; Keegan *et al.*, 1998, 2010; Fuller *et al.*, 2006; Hewetson *et al.*, 2006).

Lameness identification within an endurance competition relies on the subjective assessment of the veterinarians, observing an in-hand straight-line trot. Competitors may well be aware of the limitations of a subjective assessment, but the rules of the competition ensure that as the experts the veterinarians decision is final, in order to safeguard the welfare of the horse (EGB, 2022c; FEI, 2022b). Perhaps, having a more transparent veterinary examination with limb identification and/or severity of lameness identified may improve competitors trust in the veterinarians assessment, which in turn may lead to their advice being followed more closely. The practicality of veterinarians identifying a limb and/or severity of lameness within an endurance competition has not previously been considered.

To help classify the severity of lameness, several scales have been described. The American Association of Equine Practitioners (AAEP) describe a lameness scale of 0-5, with very explicit definitions for each grade (Table 1).

Table 1: American Association of Equine Practitioners Lameness Scale

The American Association of Equine Practitioners (AAEP) Lameness scale (AAEP, 2019).

Grade	**Description**
0	Lameness not perceptible under any circumstances.
1	Lameness is difficult to observe and is not consistently apparent, regardless of circumstances (e.g. under saddle, circling, inclines, hard surface, etc).
2	Lameness is difficult to observe at a walk or when trotting in a straight line, but consistently apparent under certain circumstances (e.g. weight carrying, circling, inclines, hard surface, etc.)
3	Lameness is consistently observable at a trot under all circumstances.
4	Lameness is obvious at a walk.
5	Lameness produces minimal weight bearing in motion and/ or at rest or a complete inability to move.

In Britain, it is commonplace to use the 0 (no lameness evident) – 10 (non-weight bearing lameness scale described by Wyn-Jones (1988). Dyson (2011) reports using a 0-8 lameness scale to quantify the severity of the lameness, this scale, like the Wyn-Jones scale, is a numerical scale, without clear definitions for each grade other than no lameness (0), mild lameness (2), moderate lameness (4), severe lameness (6) or non-weightbearing (8). As veterinarians are independent practitioners, they are likely to utilise a scale which they consider is repeatable for themselves and has, in their opinion higher intra-rater reliability. However, it has been documented that even selecting the same limb has had poor intra-rater reliability, which would likely impose a further challenge for reliability of accurate grading (Hammarberg *et al.*, 2016).

Subtle lameness, such as grades 1-2 on both the AAEP and Wyn-Jones scale are more difficult to observe than severe, non- weight bearing lameness. Studies have sought to recognise factors which may impact on the experienced clinicians' ability to identify these subtler presentations. Starke *et al.* (2013), confirmed that in a straight line, lameness was more difficult to visually detect at faster trotting speeds. In endurance specifically, experienced veterinarians listed poor handling by the person trotting the horse for the gait assessment, poor behaviour of the horse, poor trot up lane/ surface, lighting, rainfall and their own fatigue as challenges that impact gait evaluation (de Mira *et al.*, 2019).

There has been an increase in development and use of inertial sensors to objectively analyse gait patterns to identify lameness in horses (Rungsri *et al.*, 2014; Marshall, Lund and Voute, 2012; McCracken *et al.*, 2012; Keegan *et al.*, 2004). Keegan *et al.* (2011), confirmed that the repeatability of inertial based systems for identifying lameness is high and therefore a valid tool for assessment. Perhaps of concern with the objective analysis of lameness is the high level of sensitivity of the inertial sensors. Inertial based systems have identified lameness at a much lower level than visual observation by veterinary surgeons (Lopes, Eleuterio and Mira, 2018; McCracken *et al.*, 2012). If thresholds are set too high, then almost every horse would demonstrate an asymmetry. Low level of asymmetry may be of little or no clinical relevance, but at some point, asymmetrical movement patterns translate to lameness and then there is a risk to equine welfare (Weeren *et al.*, 2018). McCracken *et al.* (2012) sought to clarify threshold levels for identifying lameness using inertial sensors and accepted that accepted parameters of >6mm of vertical movement asymmetry of the head and >3mm of the sacrum were indicative of lameness. However, using the thresholds accepted by McCracken *et al.* (2012) 72.5% of 222 horses in work and believed to be without lameness, exceeded the lameness threshold for at least one parameter (Rhodin *et al.*, 2017). Accepted thresholds have also been questioned in horse racing where movement asymmetries have been identified at 16mm for the head and 11mm for the sacral measurement (Sepulveda Caviedes, Forbes and Pfau, 2018). In the horse racing industry, experts were asked to grade lameness observed and this was compared against gait asymmetries identified with objective measurements from inertial sensors. They concluded that movement asymmetries of >14.5mm of the head and >7.5mm of movement asymmetry at the pelvis equated to a lameness diagnosis (Pfau, 2019). In endurance specifically, objective gait analysis using inertial sensors (Equinois Lameness Locator) identified irregular gait patterns in 21 out of 22 horses (Lopes, Eleuterio and Mira, 2018). This study used the parameters of >6mm of vertical movement asymmetry of the head and >3mm of the pelvis to determine an irregular gait. However, only three horses assessed with the inertial sensors were eliminated for irregular gait/ lameness by the attending veterinarians. Only 14.3% of the horses assessed with the sensors, were identified as having irregular gait only at the end of the competition, whereas 54.5% were deemed to have an irregular gait at the start of the competition (Lopes, Eleuterio and Mira, 2018). This would suggest the accepted level of asymmetry is potentially higher in endurance, but this has not been specified. Perhaps, having experts grade the severity of lameness within endurance competitions, may allow for a more transparent acceptable threshold level to be set and where the line must be drawn between functional and dysfunctional asymmetry equating to a lameness diagnosis. Establishing this may be more challenging in endurance as it is logical that the gait pattern of the horse may change from the start of the competition to the end of the competition when fatigue is present. This creates an ethical debate as to what level of asymmetry and/or fatigue is acceptable for comfortable functionality, particularly during competitive horse sports, where horses are being pushed beyond basic physiological function. Although, if physiological fatigue is developing and impacting on gait function, metabolic parameters may also be impacted and the horse should not be continuing in the competition. In racehorses, it has been identified that there is an increased risk of musculoskeletal injury significantly associated with a decreased speed and a decrease in stride length across multiple starts (Wong *et al.,* 2023). Perhaps future research into endurance could consider changes in speed and stride length, not just between competitions but at the start/ finish of an endurance competition. This may help to guide the acceptable parameters and whether any/ how much change from the baseline (start) should be tolerated before the horse is eliminated. Changes to baseline data for individual horses may occur through the course of an endurance ride due to a variety of reasons, including the increase of the physiological demand on the horse as it progresses through the competition, to the trot up itself, with issues such as the speed of trot up or position of the handler being mentioned as influencing factors (de Mira *et al.,* 2019; Starke *et al.,* 2013). In a study of 15 Thoroughbreds in race training, gait assessments were carried out daily for five consecutive days and then once every week for five days. The gait patterns were evaluated using inertial sensors. Differences occurred between the individual horse asymmetries on a daily and weekly basis, including differences of 14-16mm head movement and 9-15mm for sacral movement (Sepulveda Caviedes *et al.,* 2018). This would suggest there are changes in horses' baseline levels of asymmetry which still enable them to continue with their training and competing, but acceptable levels of change are currently difficult to quantify. As the demands of the horses' physiological systems differ between disciplines, the acceptable thresholds may also differ and expert opinion sought from veterinary surgeons are required to safeguard the acceptable limits and advocate for the welfare of horses competing.

3.4 Lameness in Endurance

Endurance GB specifically uses the word lameness as a reason for elimination from competition, whereas the FEI uses the phrase 'irregular gait' (EGB, 2022c; FEI, 2022b). Discussions with FEI officials report that they use this terminology because the vetting within an endurance ride is not diagnostic but to ensure the welfare of the horse (Personal correspondence in conversation with veterinarians at competitions across 2019). Terminology is an interesting debate, with clear distinctions needing to be made between lameness and asymmetry. Wierman *et al.* (2018) suggested that the term lameness be used when the gait pattern of the horse has been assessed by a veterinary surgeon to be performance-limiting. Using this definition, an elimination from an endurance competition following the veterinary decision on the trot up, would indicate that 'lame' or 'lameness' would be the correct wording. The two governing bodies (The FEI and EGB) differ again in cases where a panel of veterinarians cannot conclude on whether the horse should pass or be eliminated after three consecutive trot ups. The FEI conclude that if no decision can be made after the three trot ups, the horse is eliminated with an irregular gait, whereas EGB give the benefit of the doubt and the horse is passed at that veterinary inspection (EGB, 2022c; FEI, 2022b). Perhaps, this aligns to the differing terminology of irregular gait versus lameness. If FEI veterinarians are concluding that there is an irregular gait pattern which may impact on the horses' welfare, then their ruling dictates that the horse should be eliminated, whereas if under EGB rules the veterinarians must conclude the horse is lame and the lameness is performance limiting, then perhaps the threshold for lameness is currently higher at British national level competition. Currently, the comparison between FEI and British national statistics has not been investigated to conclude whether this may or may not be the case. To be a veterinarian at EGB competitions, the requirement is the veterinarian must be recognised by the Royal College of Veterinary Surgeons (RCVS) as qualified and insured to work as a veterinary surgeon. At FEI level, the veterinarians must first acquire the status of a Permitted Treatment Veterinarian (PTV). In order to do this, they must apply through their national federation and supply details of their qualifications, experience and provide two references, one of which must be a recognised FEI official veterinarian (OV) (FEI, 2022a). Applicants for PTV status must also complete an online examination before they are eligible for registration. Having gained experience as a PTV, veterinarians are eligible to progress through to FEI official veterinarians, mentored and signed off as competent by an OV of higher rating than themselves (FEI, 2022a). All OVs must continue to pass online examinations every four years and attend courses to keep their knowledge up to date (FEI, 2022a). Whilst EGB rides often have experienced endurance veterinarians in attendance, it is clear the requirements are less than at international level, which may again impact on the acceptable threshold to allow a horse to pass or fail on a subjective lameness assessment. Key differences between FEI level endurance and British national level endurance are summarised in Appendix 2.

Epidemiological studies and qualitative studies have confirmed that lameness is the most common veterinary issue and cause for elimination in endurance (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2020; Di Battista *et al.*, 2019; Bennet and Parkin, 2018a, 2018b; Marlin and Williams, 2018b; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2014a, 2014b; Nagy, Dyson and Murray, 2012; Fielding *et al.*, 2011; Nagy, Murray and Dyson, 2010). Table 2 summarises elimination and lameness elimination statistics presented in previous endurance studies. In each case, lameness accounted for >40% of all eliminations.

Table 2: Summary of eliminations and lameness eliminations in previous endurance studies
Previous endurance studies and the number of eliminations and specifically lameness eliminations documented within them

Authors	Competition level	Number of Horse Starts	Successful completions	Eliminations	Lameness Eliminations
Nagy, Murray and Dyson, 2010	FEI	4326	1990 (46.0%)	2336 (54.0%)	1617 (31.8% of starts; 69.2% of eliminations)
Fielding *et al*, 2011	USA National	3493	2833 (81.1%)	660 (18.9%)	312 (8.9% of starts; 47.3% of eliminations)
Nagy, Murray and Dyson 2014	FEI	30741	15576 (50.7%)	15165 (49.3%)	9241 (30.1% of starts; 60.9% of eliminations)
Younes *et al*, 2016	FEI	7032	4294 (61.0%)	2738 (38.9%)	1765 (25.1% of starts, 61.0% of eliminations)
Bennet and Parkin, 2018a	FEI	82917	47897 (57.8%)	35020 (42.2%)	19960 (24% of starts; 41.6% of eliminations)
Marlin and Williams, 2018	FEI	389	219 (56%)	170 (44%)	125 (32% of starts; 74% of eliminations)
Di Battista *et al*, 2019	FEI	6326	3495 (55.2%)	2831 (44.8%)	1745 (27.6% of starts; 81.0% of eliminations)
Zuffa, Bennet and Parkin, 2022	FEI	108157	62682 (57.9%)	34849 (32.2%)	

A meta-analysis was conducted using the above studies in order to compare the studies and is displayed in Figure 1 below.

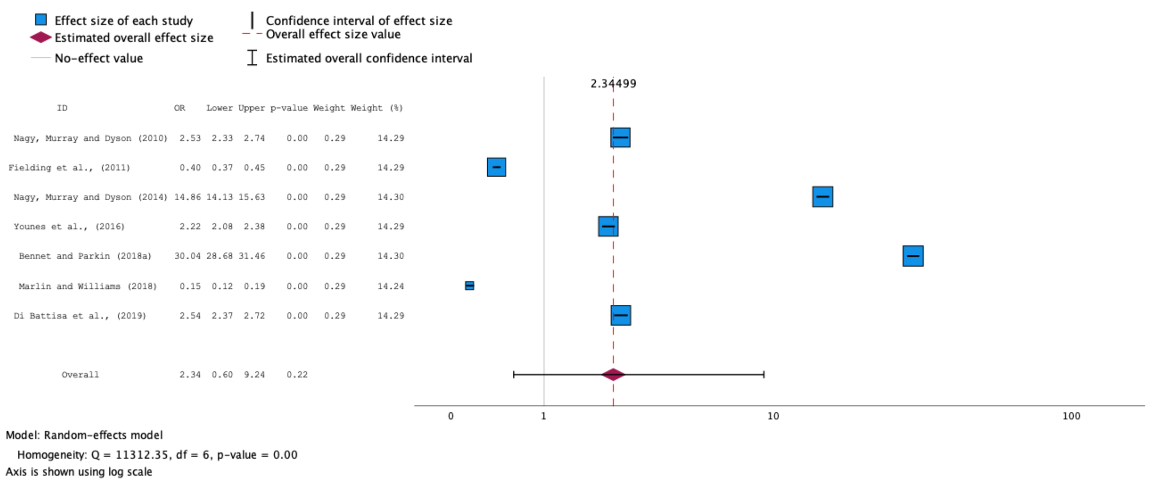

Figure 1: Forest plot displaying comparison of elimination rates and lameness rates across endurance studies

3.5 Sport specific injuries

Whilst diagnostic lameness examinations are impractical at the point of elimination in an endurance competition, identifying sport specific injuries can give insights into preventative strategies, or appropriate rehabilitation programmes (Dyson, 2000). In order to consider sport specific injuries, clinical records of 1096 horses competing in different disciplines, were examined at a specialist equine orthopaedic clinic in the UK (Murray *et al.*, 2006). They identified the tarsus to be the most common injury site in a small population of endurance horses (n=17) that presented with a clinical lameness to be evaluated.

Concerns regarding limb fractures have also been identified in Endurance horses, with notable mentions of increased speeds likely to have been contributing factors (Coombs and Fisher, 2012; Misheff, Alexander and Hirst, 2010). Misheff, Alexander and Hirst (2010) identified that forelimbs were statistically more likely to fracture than hindlimbs. The majority of fractures were of the fetlock with almost 75% of cases involving the proximal phalanx or the third metacarpal/ metatarsal. Fractures, as a result of repeated cyclic loading, with insufficient recovery time for bony remodelling are common in human marathon runners and are more likely in higher speed horse sports, such as racing (Samol *et al.*, 2021; Loughridge *et al.*, 2017; Clansey *et al.*, 2012). It would seem logical therefore that a combination of repetitive cyclic loading during an endurance competition, combined with high speed would result in an increased risk of fractures. Fractures in national Endurance are rare, which may be due to the lower speeds and also may be a reason that lameness is considered less of an issue at national level, as the most serious of injuries are not seen on the competition field.

A larger, more recent study reviewed medical records of 235 endurance horses and reported high- suspensory disease as the most identified condition, followed by joint disease of the metacarpal phalangeal and metatarsophalangeal joints (Paris, Beccati and Pepe, 2021). In this study, the majority of injuries (77%) were documented in the forelimbs. Notably, the two studies that looked at endurance horses outside of the United Kingdom, identified that injuries were more common in the forelimbs, whereas the clinical records from the study of UK horses identifies more injuries in the hindlimb (Paris, Beccati and Pepe, 2021; Misheff, Alexander and Hirst, 2010; Murray *et al.*, 2006). Rationalising the differences between British endurance horses specifically and those in the international studies, is challenging without the details as to whether the risk factors for injury remain the same at national and international level. Whilst anecdotally speeds are much slower in Britain than at FEI competition, speeds are not recorded for eliminated horses in British competition and consequently comparisons cannot currently be made. The second study within this thesis (Chapter 6), identifies CER's of three loops and above (distances 80-174km), having a median completion speed of 12.5± 2.9 kmh^{-1} , these were the fastest group of horses within the study. Marlin and Williams (2018b) reported the speed for finishers over 120km to be 18.8± kmh^{-1} and Nagy, Murray and Dyson (2014) reported the fastest finishing speed in the UAE to be 29.5 kmh^{-1} demonstrating this anecdotal assumption is seemingly accurate. However, EGB should improve their data recording quality in order to further explore this in the future.

At the point of elimination from competition, there is no diagnosis to attribute the lameness to, and it is up to the owner as to whether they seek further veterinary advice post elimination (unless the horse's welfare is urgently compromised, in such cases the horses will be treated by the veterinarians in attendance at the ride, or arrangements will be made for the transfer to the nearest equine hospital). Worryingly, in a survey sent to

EGB members only 52% of all horses that were identified as lame, either at a competition or at home were followed up by a veterinarian (Nagy, Dyson and Murray, 2017). This suggests that owners/ riders may not consider a lameness at a competition to be of great concern, or perhaps lack sufficient knowledge and understanding to identify lameness. Interestingly, for horses (n=60), assumed to be without lameness by their owners, 73% of horses were graded 2/8 by veterinarians, suggesting horse owners, without training, would require a horse to be 'moderately lame' before being able to identify it (Dyson and Pollard, 2020).

Anecdotally, competitors in endurance either do not consider the horse to be lame, despite the expert opinion of the veterinary panel, or they justify it as a 'something and nothing injury' such as a slip, trip or stone bruise and consider it will resolve over the coming days independently. However, the presentation of the lameness' and risk factors reported across endurance studies do not suggest that the lameness is acute in its presentation and is more likely to represent chronic musculoskeletal issues, which manifest at the point of competition when the performance demands on the horses physiological and musculoskeletal systems are higher than in training. The chronicity of the musculoskeletal issues is clearly highlighted by the findings of Bennet and Parkin (2020), that increasing mandatory out of competition periods (MOOCP), reduces deleterious outcomes such as lameness. When considering the demands of the endurance horse, not just during competition, but in the fitness preparation and training, the likelihood of musculoskeletal issues is clearly high.

Perhaps, given the poor follow up post lameness described by Nagy, Dyson and Murray (2019), return to competition should be more tightly controlled, in order to protect the welfare of the horses competing. One suggestion could be to ensure a veterinary certificate is issued, following an examination by an independent veterinarian prior to the horse returning to competition. Whilst this would ensure that the horse had been seen by a veterinarian following elimination, it would not necessarily confirm the owner or trainer had followed any instructions on return to training or competition post elimination. A challenge with issuing a veterinary certificate by an independent veterinarian on a day outside of competition could occur, if on the day of the ride the veterinarian examining at the competition considers the horse to be lame, but the rider has a certificate declaring it 'not lame'. This may reduce the confidence in the veterinary panel and cause confrontation, or challenges to the veterinary panel which is reported to be common (de Mira *et al.,* 2019). The FEI have now implemented an examination protocol that must take place if a horse that is registered with the FEI has a third elimination for lameness within a rolling year before that horse is allowed to compete at any other competition, be it at national or FEI level. This examination takes place prior to the pre-ride inspection. A panel of three veterinarians, including the President of the Veterinary Commission, the Foreign Veterinary Delegate and an additional member of the Veterinary Commission inspects the horse. The examination must consist of, but is not limited to, walk and trot in a straight line, walk and trot in a circle in both directions and palpation of relevant soft tissues. If the horse does not pass this, it is not allowed to compete (FEI,2022a). This is a proactive step and may be of benefit to all horses competing, whatever level that may be at.

3.6 Injury Pathways

There are three main pathways to orthopaedic injuries that are well documented within the study of racehorses, but which can be considered as the likely mechanisms of injury in endurance horses. The first is traumatic injury whereas, the second and third relate to the adaptation of the horse to the work load demanded; either the work load is increased too quickly to unadapted soft tissue and/or bone or, consistent, repeated loading accumulates damage which exceeds the capabilities of the adapted soft tissue and/or bone (Whitton *et al.,* 2018; Martig *et al.,* 2014; Whitton *et al.,* 2010; Riggs, Whitehouse and Boyde, 1999).

Traumatic injuries have been identified across the general population of horses, not just during competitive or training activities (Owen *et al.,* 2011). These injuries may be the result of an external force, such as a bite or a kick from another horse, or an injury sustained on fencing. During competition, these may occur due to collision with another horse, or an accidental trip/ slip or fall. In some cases, these traumatic injuries have modifiable risk factors such as the course design in the cross-country phase of three-day eventing or the competitive field size in racing or endurance (Di Batissa *et al.,* 2019; Bennet and Parkin 2018a & b; Nagy, Murray and Dyson, 2014; Williams *et al.,* 2013; Nagy, Murray and Dyson, 2010; Murray *et al.,* 2006; Murray *et al.,* 2005).

Traumatic injuries can be further divided into a penetrative injury (i.e. an incident with a fence in the field) or a blunt trauma, such as a kick or collision with another horse. Depending on the severity of injury, a major concern with a traumatic injury would be blood loss and potential hypovolemic shock. Acute blood loss results in less availability of blood to perfuse vital organs and therefore it is imperative to stem the blood loss (Hurcombe *et al.,* 2022). Apart from bleeding, physiological signs may include an increase in heart rate as the circulatory system attempts to keep up with the demand for blood that is being lost at the injury site, and increased respiratory rate and cold skin as the tissue perfusion decreases (Hurcombe *et al.,* 2022). Whilst a penetrative trauma is usually visible, a blunt trauma such as a kick occurring within the field, may not be obvious and signs of internal bleeding such as swellings or changes to surface temperature may be apparent (Hurcombe *et al.,* 2022).

The other injury pathways are shown in Figure 2. Loading of the soft tissue structures and skeletal system is beneficial in order for immature and undeveloped structures to adapt to the demands placed upon them. In young horses the process of bony modelling is activated by loading (Whitton *et al.,* 2018; Martig *et al.,* 2014; Whitton *et al.,* 2010; Riggs, Whitehouse and Boyde, 1999).

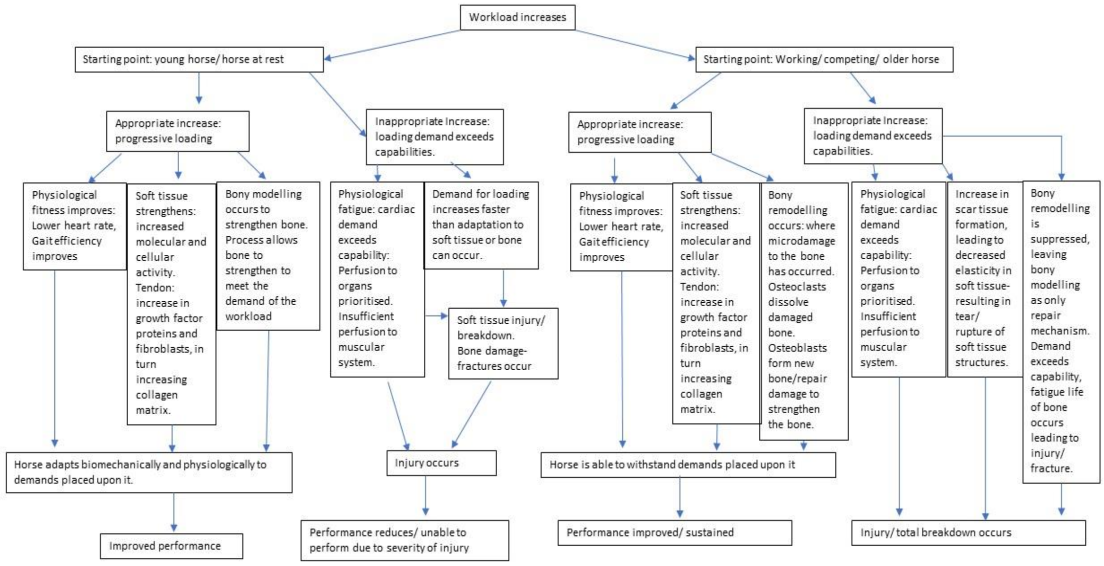

Figure 2: Injury pathways: unadapted tissue and fatigue
(Ortved, 2018; Whitton *et al.,* 2018; Martig *et al.,* 2014; Whitton *et al.,* 2010; Dowling and Dart, 2005; Smith *et al.,* 1999; Riggs, Whitehouse and Boyde, 1999).

Wolff's Law, developed by a German anatomist and surgeon Joseph Wollf in 1892, described a mathematical equation to surmise the process of bones adapting to the mechanical loading placed upon them, initially strengthening the internal matrix (trabecular bone) and then the outer cortical layer of bone (Teichtahl *et al.,* 2015). This has since been more specifically considered in race horses, where the third metacarpal bone, the main load bearing structure in the forelimb has been identified as having decreased porosity, higher bone density and increased cross-sectional area in young thoroughbreds in training, compared to horses who were not trained (Whitton *et al.,* 2010; Rubio-Martinez *et al.,* 2008; Boyde and Firth, 2005; Firth *et al.,* 2005; Riggs and Boyd, 1999; Riggs, Whitehouse and Boyde, 1999). These adaptations to the bone are considered to increase the load bearing strength of the bone (Whitton *et al.,* 2010; Rubio-Martinez *et al.,* 2008; Boyde and Firth, 2005; Firth *et al.,* 2005; Riggs and Boyde, 1999;

Riggs, Whitehouse and Boyde, 1999). This would suggest that if young horses are not trained appropriately their bone structure would not be sufficiently adapted to meet the demands placed upon them and therefore injury occurs.

However, it is also noted that in horses with fatigue fractures at the third metacarpal or metacarpophalangeal joint that horses have marked bony modelling within these areas and this may contribute to the fatigue fracture by concentrating stress in these areas due to the increased density gradient (Whitton *et al.,* 2010; Rubio-Martinez *et al.,* 2008; Boyde and Firth, 2005; Firth *et al.,* 2005; Riggs and Boyde, 1999; Riggs, Whitehouse and Boyde, 1999).

As a horse continues through training, the multiple repetitive, cyclic loading increases the stress on the load bearing structures within the limb and microcracks develop within the bone (Whitton *et al.* 2018; Whitton *et al.,* 2010). The bone homeostasis attempts to minimise the damage of these microcracks by a process of remodelling (Whitton *et al.,* 2010; Rubio-Martinez *et al.,* 2008; Boyde and Firth, 2005; Firth *et al.,* 2005; Riggs and Boyde, 1999; Riggs, Whitehouse and Boyde, 1999). During remodelling, osteoclasts reabsorb old or damaged bone and osteoblasts deposit cells for new bone in order to maintain or strengthen the bone. However, during intense exercise this remodelling process cannot keep up with demand and can also become supressed. Subsequently, microcracks continue to develop and elongate, until fatigue life of the bone is reached and a fracture occurs (Martig *et al.,* 2020; Martig *et al.,* 2014; Martig *et al.,* 2013; Romani *et al.*, 2002; Teitelbaum, 2000). Fatigue life refers to the number of cycles the limb can withstand before failure, which is an important factor in endurance horses, who by the nature of the sport, have many repeated loading cycles, not just in competition but in the training process in order to have them physiologically fit enough to withstand the demands of competition. Studies relating to the injuries sustained in endurance horses have discussed fractures of the metacarpal/ metatarsal phalangeal joint, which suggests the mechanism of injury is likely to be related to the fatigue life of the bone (Paris, Beccati and Pepe, 2021; Misheff, Alexander and Hirst, 2010). Whilst speed is known to decrease fatigue life of bone and is comparatively slower in endurance compared to the well-researched Thoroughbred sprint racing, the loading cycles during competition will be greater in an endurance horse and this mechanism of injury requires careful attention within the sport of endurance.

Soft tissue is impacted in a similar way to bone. Davis law, described by American orthopaedic surgeon in 1867, states that soft tissue will adapt and heal according to the manner in which they are stressed (Mueller and Maluf, 2002).

Due to its anatomical location the superficial digital flexor tendon (SDFT) and the suspensory ligament are the most commonly injured in racehorses (Thorpe, Clegg and Birch, 2010; Birch *et al,* 1999). The SDFT and the suspensory ligament are the main energy store for elastic recoil of the limb during gallop and therefore the most susceptible to injury (Rich and Patterson-Kane, 2014; Thorpe, Clegg and Birch, 2010; Birch *et al,* 1999).

Similar to bone, the soft tissue structures adapt in young horses in a positive manner to loading and exercise, with the cross-sectional area increasing (Dowling and Dart, 2005; Smith *et al.,* 1999). Foals have been identified as doubling the cross-sectional area of the SDFT between 50 days to one year of birth (Patterson-Kane and Firth, 2014). However, the SDFT is considered to have limited adaptability after a study by Dowling and Dart (2005) found that after a high intensity training period on a treadmill horses of 19 months no longer increased the cross-sectional area of the SDFT. This is thought to be because tenocyte activity and collagen turnover slows with age (Patterson-Kane and Firth, 2014). A study by Cherdchutham *et al.* (2010) demonstrated the complexity of appropriate loading by box resting foals, one group were confined completely and the other were sprinted 40m up to 32 times per day. The foals on complete box rest had reduced collagen cross links compared to exercised foals, demonstrating that loading is of benefit to develop the collagen matrix, however the sprinted foals had reduced tenocyte functionality, which suggests they were over loaded. When overloaded, the elasticity of the tendon is stressed beyond its capability and injury occurs.

Following adaptation, the soft tissue structures rely on the repair system of the body to maintain function. In mature animals, training increases the tensile strength of tendons (Buchannan and Marsh, 2002; Smith *et al.,* 1999). However, when continuously loaded, micro damage of the fibres will occur and the natural regeneration and repair process of the body over takes with the first stages being bleeding and inflammation of the tissue (Watson, 2022). In the regeneration of tissue, proliferation, which follows the inflammatory stage, results in tissue similar to the previous cells being developed. However, more likely in mature tissue, the repair process results in granulation of tissue which develops into scar tissue, with reduced elasticity, or potentially poor fibre alignment (Ortved, 2018). Whilst the scar tissue is developed to repair the injury, the loss of elasticity can increase the risk of breakdown as the tissue is no longer able to cope with demand (Ortved, 2018). Additionally, continuous loading during the slow repair process can result in further damage or indeed total rupture (Ortved, 2018).

In human literature, the acronym for recovery from sports skeletal injuries such as stress fractures is R.E.S.T. a) Removal of the abnormal stress; b) Exercise to maintain cardiovascular fitness and prevent muscular atrophy which could cause compensatory movement patterning and abnormal loading patterns; c) Safe, pain-free return to activity; and d) Time for bone healing to catch up with remodelling (Romani *et al,* 2022*).* Given that increased MOOCP have been successful in reducing lameness eliminations, perhaps the simple acronym of REST could be adopted in the sport of endurance (Bennet and Parkin, 2020; Romani *et al.*, 2002) . In order to use the acronym, understanding of the signs and symptoms of horses in musculoskeletal/ orthopaedic pain is imperative, otherwise the risk of moving through the stages prior to injury recovering fully is likely to be high. It has already been discussed that horse owners find it difficult to notice low grade lameness and therefore other signs of pain should be considered (Müller-Quirin et al., 2020; Rhodin et al., 2017; Dyson and Greve, 2016).These may include changes to physiological factors such as higher heart rates or respiratory rates at rest and/or during work, of course this may also be due to a decrease in fitness because of a reduction in work level and therefore is unlikely to be considered in isolation (Gleerup and Lindegaard, 2016; Pritchett *et al.,* 2003*;* Foreman and Lawrence, 1991*)*. However, endurance riders do often monitor heart rates and therefore this may be a useful objective measure to consider (Nedkova- Ivanova and Yalev, 2020; Bolwell *et al.,* 2015). In race horses, it has been identified that there is a significant association with musculoskeletal injury when stride length and stride duration decreased, whilst this is difficult for individual riders to measure, they may notice a slower pace or a decreased quality of movement during gait (Wong *et al.,* 2023). Outside of biomechanical and physiological factors, there may be changes in the horses' behaviour or attitude to work. Riders may notice this as a reluctance to work or avoidance behaviour such as reduced performance, refusing to move forward or rearing (Gleerup and Lindegaard, 2016). Additionally Dyson and Pollard (2020) developed an ethogram to identify pain responses in horses and concluded that horses who displayed eight or more behaviours from the twenty-four listed were likely to be suffering from musculoskeletal pain, these include position of the head, position of the ears, eyes/mouth/ tongue movement, tail clamping or excessive movement, a rushed/ slow or altered gait, poor canter pattern, tripping or stumbling and avoidance behaviours such as rearing or not going forward. Riders should be aware of their horse's behaviours and any changes should be taken into consideration as to whether the horse is in pain and appropriate professional advice should be considered.

The endemic of chronic musculoskeletal issues within Endurance must be addressed, not only for the welfare of the horse but for the SLO. Communication of this to competitors within the sport is key and respecting opinion of the experts entrusted with making the call on acceptable movement asymmetries is imperative. Establishing IRR of veterinary gait assessments within competition would be of benefit for ecological validity of the gait assessments. If IRR is poor, changes should be implemented to the assessments. If IRR is high then competitors can be assured the veterinary panel are fundamentally ensuring the welfare of the horses competing, without bias and their advice and their opinion should be respected and acted upon.

3.7 Not just limbs…

The second most commonly reported concern that riders in British endurance had relating to their horses was the presence of thoracolumbar back pain (Nagy, Dyson and Murray, 2017). Horses with back pain, commonly present in thoracolumbar extension due to hyper contraction and muscular spasm on palpation of the *longissimus dorsi* and other thoracolumbar epaxial musculature (Mayaki et al., 2020). Landman *et al.* (2004) concluded there was a close relationship between lameness and back pain in horses. They evaluated 805 horses with orthopaedic issues and identified that 74.3% of horses that had back pain were also lame (Landman *et al.,* 2004).

The link between back pain and lameness was explored in a small study of six horses. The horses had a low level of hindlimb pain temporarily induced to the extent of a lameness grade of 2 on the AAEP lameness scale and had their gait assessed in walk and trot on a treadmill using reflective markers to allow kinematic analysis. The induction of lameness significantly altered the kinematics of the horses back. An increase in thoracolumbar range of movement and hyperextension was identified. The authors of this study concluded that even low-level lameness has an impact on back kinematics and when chronic, low grade lameness is present it may induce back dysfunction and pain (Alvarez *et al.,* 2008).

When discussing the relationship between back pain and lameness, the muscular function of the back and hind limb should be considered. Whilst the *longissimus dorsi* is an important stabiliser of the equine spine, hyper contraction may limit the dynamicity, important for economical gait patterning, which is a key requirement for an endurance horse travelling long distances. The close anatomical interaction of the *medial gluteal* muscle, considered as an epaxial muscle, responsible for hip extension and medial rotation originates from the lumbar portion of the *Longissimus dorsi* and therefore the association between spinal movement and hind limb movement must be considered. Although back pain is frequently considered secondary to lameness, as the horse tends to increase the range of motion of the thoracolumbar spine and hyperextends through the back to compensate for the reduced comfortable movement of the affected hindlimb (Greve and Dyson, 2013; Alvarez *et al.*, 2008; Landman *et al.*, 2004). Whilst it has not been identified as such, it would not seem unreasonable to consider that if back pain, was the primary issue, and the horse was in thoracolumbar hyperextension then the *gluteus medius* which has a muscular origin on the spinal musculature of *longissimus lumborum,* would be adversely affected. The *gluteus medius* acts during extension of the coxofemerol joint, if this is impacted due to the interaction with the spinal musculature, stride length would consequently be reduced and stride frequency subsequently increased to achieve the task (Gunnarsson *et al.*, 2017). In turn the increase in stress on the musculoskeletal structures within the hindlimbs and may manifest as a lameness. This would seem plausible in the case of an endurance horse, where the rider is on the horse's back for a long period of time.

Extended durations of ridden work for up to twelve hours in competition and longer in training occur in Endurance. The resultant continuous loading of the horse's back by the rider is enough to postulate that back pain may be an issue in endurance horses (Williams *et al,* 2020). Throughout the competition, riders may also fatigue and alter their position, in turn altering the load on the horses back, which may result in the horse compensating or adapting movement patterns (Williams *et al.,* 2020; Viry *et al.,* 2015). Additionally, saddles are taken off for veterinary inspections and then put back on for the next stage of the competition. If saddles are placed in just a slightly different location, the rider is likely to change their load position on the horse, which may alter their biomechanics between stages of the competition, potentially resulting in adaptive movement or compensatory movement patterning and impacting on the gait pattern of the horse (Bondi *et al.*, 2020; Greve and Dyson, 2015; Greve, Murray and Dyson, 2015). Saddle fit is notoriously poor in endurance horses, with the belief that a light-weight saddle, for the aforementioned reasons of reducing the load is beneficial. However, frequently the saddles are changed between horses, rather than fitted to the individual horse and an ill-fitting saddle has been associated with lameness and especially hindlimb lameness (Greve and Dyson, 2013, 2015). Saddle fit has not currently been evaluated in endurance horses, with a wide variety of personal preference of manufacturers and models available on the market, making comparison complex, but it may be reasonable to assume that poor fit is an issue that may lead to back pain in endurance horses. Currently, there is a paucity of evidence surrounding equine back pain in endurance and whether there is an association with lameness during endurance competitions, despite anecdotal awareness that back pain in endurance horses does exist.

3.8.1 Identification of risk factors

Identification of risk factors for lameness and injury have been considered across equestrian sports (Bennet, Cameron-Whytock and Parkin, 2022; Pinchbeck *et al.*, 2013; Hitchens *et al.*, 2012; Murray *et al.*, 2010; Parkin *et al.*, 2010b; Murray *et al.*, 2005) Specifically, in endurance, several studies have considered risk factors for deleterious outcomes such as lameness or metabolic elimination. Table 3 summarises the significant risk factors identified for eliminations in endurance competitions identified in previous studies.

Table 3: Summary of risk factors for elimination(s) identified in previous endurance studies
A summary of risk factors identified from previous literature in endurance.

Authors	**Level of competition(s)**	**Location of competition(s)**	**Significant Risk factors identified for lameness eliminations**	**Significant Risk factors identified for metabolic eliminations**
Nagy, Murray and Dyson, 2010	FEI Rides >100km	Australia, France, Italy, South Africa, United Arab Emirates, UK, Uruguay, USA	-Ride location -Competitive field size (> 80)	-Ride location -Competitive field size (>100)
Fielding *et al,* 2011	USA National 25-100 miles	USA	-Length of ride -Breed of horse -Attitude of horse	-Length of ride -Age of horse (>6years old) -Breed of horse -Overall impression of horse -Gastrointestinal sounds
Nagy, Murray and Dyson, 2014	FEI Rides 100-160km	United Arab Emirates France Spain Italy Uruguay USA South Africa Bahrain UK New Zealand	-Country in which the ride was held -Year of competition -Distance of the ride -Competitive field size	Country in which the ride was held -Year of competition -Competitive field size
Younes *et al,* 2016	FEI and national rides 80-160km	France Portugal Spain United Arab Emirates	-Age of horse -Distance -Country in which the ride was held	-Distance -Country in which the ride was held

Bennet and Parkin, 2018a	FEI 80-160km	All FEI regional groups I Western/ Southern Europe II Northern Eastern Europe III Russia/ Western Asia IV North America V Central America VI South America VII North Africa/ Middle East VIII Oceania/ Asia IX Sub-Saharan Africa	-Age of horse (> 9 years) -Male horse -Male rider -Competitive field size (>61) -Regional group -Year of competition -Race distance	-Regional group -Ride distance -Male rider -Year of competition
Bennet and Parkin, 2018b	FEI 80-160km	All FEI regional groups I Western/ Southern Europe II Northern Eastern Europe III Russia/ Western Asia IV North America V Central America VI South America VII North Africa/ Middle East VIII Oceania/ Asia IX Sub-Saharan Africa	-Regional group -Ride distance -Competitive field size -Age of horse -Previous ride distance -Result of last competition -Days over mandatory rest period since last ride -Rider number of previous lameness eliminations -Rider number of previous metabolic eliminations -Number of competitions in last 120 days -Number of competitions in last 365 days -Average speed on second loop -Average speed on third loop -Change in speed loops 1-3	-Regional group -Ride distance -Age of horse -Male rider -Days over mandatory rest period since last ride -Rider number of previous metabolic eliminations -Number of rides in previous 240 days -Average speed loop 1 -Change in speed loops 1-3
Di Battista *et al*, 2019	FEI Rides 80-160km	Italy	-Competitive field size -Class entered (*/**/***) -Age of horse -Minimum temperature -Presence of rain	-Competitive field size -Class entered (*/**/***) -Breed of horse -Minimum temperature

As shown in Table 3, the majority of research in endurance has focussed on FEI competition and have identified several common risk factors. Some risk factors such as competitive field size, the number of competitive starts, speed and rest periods can and have been modified. In some cases, entries to the competition are limited. Horse speeds for novices are capped and rest periods are extended for FEI registered horses, they are extended further if horses compete at speeds over 20kmh^{-1} (FEI, 2022b; EGB, 2022c). Other risk factors such as breed of the horse and weather/ temperature cannot be modified. Stakeholders within the sport should be aware of all risks in order to mitigate and minimise those that they can and plan strategically around those risk factors that cannot be modified. Risk factors identified in table 3 are discussed in more detail below.

3.8.2 Race Location:

The challenges surrounding the environmental, climatic and topographical impacts on endurance horses have been briefly discussed but are often continuously changing throughout the course of the day, which can make the impact of them difficult to ascertain. Di Battista *et al.* (2019) identified that rain was associated with increased lameness eliminations. The presence of rain would increase the chances of a 'slip' related injury, and if the rain is sustained for a prolonged period of time, with multiple horses going over the same tracks, the ground may become deeper, resulting in heavier going for the horses and may contribute to fatigue induced injuries due to the increased effort required to navigate the terrain. Fatigue can decrease speed and the stride length, which leads to inefficient movement patterning and a greater risk of injury (Takahashi *et al.*, 2021; Wickler *et al.*, 2006). This has been identified in racing Thoroughbreds by changes in EMG values of propulsive hip extensor muscles and in the measurement of stride

length and duration across multiple starts, which has been associated with musculoskeletal injury (Wong *et al.,* 2023; Takahashi *et al.*, 2021; Wickler *et al.*, 2006). Fatigue based injuries are usually insidious in onset to the rider, but are often due to the result of subclinical adaptations to injury prior to the overt injury being noticed and therefore small changes in horses behaviour, physiological and biomechanical parameters should be noted and heeded as a warning sign, with appropriate professional guidance sought to minimise the risk of further injury (Wong *et al.,* 2023; Takahashi *et al.*, 2021; Dyson and Pollard, 2020; Gleerup and Lindegaard, 2016; Wickler *et al.*, 2006). Increased effort across terrain can also result in changes in metabolic homeostasis (Bollinger *et al.*, 2021; Trigo *et al.*, 2010). Whilst metabolic issues are not the focus of this thesis, derangements in homeostasis can impact of the biomechanical and physiological capabilities of the horse and this rationale is explored later.
Firm turf surfaces have also been associated with injury in race horses due to faster speeds and increased loading (Gibson *et al.,* 2023; Morrice-West *et al*., 2023). This is likely a rationale for increased injury in the competitions where the speeds are faster and the ground conditions likely to be drier, such as those in group XII locations (Bennet and Parkin, 2018a &b; Younes *et al.,* 2016; Nagy, Murray and Dyson, 2014, 2010).

In 2018, the World Equestrian Games were held at Tryon, in the United States of America. The endurance competition was cancelled halfway through the race due to the additional physiological exertion of the horses due to heavy rainfall, a high number of horses displaying metabolic compromise and a very high Wet Bulb Globe Temperature Index (WBGTI),

> *'The cancellation of the race was to protect the welfare of the horses competing'* (FEI, 2018)

Implications of a high WBGTI and the necessity of monitoring the climate at competition, both in terms of human and horse have been documented (Knechtle *et al.*, 2019; Schroter and Marlin, 2010). Whilst in the UK, extremes of temperature are not commonplace, they are perhaps increasing during the competitive season (March-October) with temperatures reaching above 40^{o} Celsius in 2022 (Met Office, 2022). Thermoregulation and appropriate cooling methods are imperative to prevent such issues as 'exhausted horse syndrome', more common in endurance related equestrian sports (Foreman, 1998). Whilst EGB recommends all competitors have a back-up crew, specifically to assist with cooling the horses, (or putting rugs on the horses in extremely cold temperatures whilst waiting in a vet hold) it is not compulsory that riders have a back-up crew unless they are competing in CER classes (EGB, 2022c). The impact of this ruling lacks evidence as risks for elimination have not been considered at GER level previously.

Anecdotally, social media would suggest British endurance riders do not consider that the UK has a lameness issue within the sport, compared to that of other countries. However, a study evaluating FEI endurance competitions across nine countries and five continents concluded that the country in which the ride was held was a key risk factor for elimination for both lameness and metabolic compromise (Nagy, Murray and Dyson, 2010).They identified that horses in the United Kingdom had the highest percentage of lameness eliminations and the highest odds of lameness elimination. Bennet and Parkin (2018a) completed the largest, global study in endurance and identified that the region in which the competition was held was associated with an increased odds of lameness elimination. The greatest odds of lameness elimination occurred in Northern and Eastern Europe (Bennet and Parkin, 2018a). Perhaps, the change and variability in terrain and temperature would be a consideration for the higher odds of lameness in European countries. Di Battisa *et al.* (2019*)* identified minimum temperature was associated with a higher rate of elimination in FEI rides across Italy, with the minimum temperature considered being -3^{0}C, which is a temperature that has never been recorded in the United Arab Emirates.

There is little information surrounding the risk associated with the terrain of endurance tracks and elimination, and specifically lameness elimination. Perhaps, this is due to the variety of terrain that occurs not just from location to location, but often within a single loop or ride. For example, within the UK, whilst some of the major rides take part across large estates, it is more common place for a network of bridle paths to be used, some may be across open fields or arable farm land, and others may be across forestry tracks, often linked by short (sometimes long!) stretches of roadwork. Depending on the time of year and weather, the bridle tracks could be dry and hard, or deep mud. Equally British weather can turn from dry and sunny to heavy rain even during the course of the competition. Whereas in the United Arab Emirates, the climate, although much warmer than in Britain, is relatively consistent and only three competitive venues are used. The competitive venues are purpose built for Endurance and therefore the ground conditions remain relatively stable from competition to competition. Nagy, Murray and Dyson (2014b) did consider the terrain and ground conditions, by asking the technical delegate at the ride to provide information as to whether the terrain was flat, hilly or undulating, had sections of asphalt, stones, slippery surfaces, deep mud/sand or soil or whether there were rabbit holes or sharp turns within each loop, but did not find an association with lameness. However, they did identify that deep sand/ soil increased the likelihood of a metabolic elimination. This would agree with the findings of an earlier study of endurance horses which found that muddy terrain was a significant factor in sweat fluid and electrolyte losses in endurance horses, which could be a consideration for metabolic compromise and fatigue-based injuries (Lindinger and Ecker, 2010).

The terrain may also have an impact on the biomechanics of foot surface and interaction with the ground. Whilst anecdotally the vast majority of endurance horses competing at FEI level are shod (+/- pads), ultimately it is the decision of the rider/ trainer in conjunction with their own farrier as to how the horse's feet are presented for competition. It is not unheard of, although certainly not common place, to have horses competing barefoot, more so in the lower levels of competition. The statistics for this have not been collected and cannot therefore be taken into account. Research into foot balance and shoeing within endurance specifically cannot be found and therefore lies outside the scope of this thesis.

Across other equestrian sports, ground conditions are identified to impact lameness or negative performance outcomes. In event horses, an increased risk of falling during the cross-country phase was associated when taking off from good-soft, soft or heavy ground (Murray *et al.*, 2006). A greater risk of lameness in Dressage is associated with working in indoor arenas, sand arenas or arenas that have a tendency to become deeper in wet weather conditions (Murray *et al.*, 2010). On the racetrack, Flat, National Hunt and Steeple chases have all identified that track surface/ going increases the risk of falls/injury and lameness, however there has been mixed findings as to which surfaces predispose the horses to the most risk (MacKinnon *et al.*, 2015; Parkin *et al.*, 2010a). Whilst terrain is difficult to quantify over the entirety of an endurance ride, it would not be unreasonable, given the varied terrain across Britain, that it may have an impact on risk of lameness or injury and attempts should be made to identify this to allow ride organisers and competitors to make evidence-based decisions and strategize around this.

3.8.3 Size of competitive field:

The size of the competitive field has been identified as a significant risk factor for a deleterious outcome in endurance rides (Di Battista *et al.*, 2019; Bennet and Parkin, 2018a; Nagy, Murray and Dyson, 2010). Perhaps, this could be explained by the competitive mind set of the rider, who may push the horse that bit harder, or faster in order to gain a higher position in a larger field of play. This could potentially be the same explanation of the findings that horses and riders are more likely to fall on the cross country phase of an eventing competition if the rider was aware that they were in the lead of the competition prior to the cross country course (Murray *et al.*, 2005, 2006). The same theory could be applied to horse racing, particularly in races such as the Grand National, where larger fields of play have resulted in faster speeds, which have been linked to an increased risk of falling (Williams *et al.*, 2013).

Larger competitive field sizes have also been found to have higher risks of injury in Thoroughbred flat racing and point to point perhaps due to the increased likelihood of accidental collisions with more horses in the same amount of space, or the impact on the ground conditions with multiple horses on the same ground (Mizobe, Takahashi and Kusano, 2021; Smith, Tabor and Williams, 2018; Parkin *et al.*, 2004; 2005). Whilst during an endurance competition, the proximity of horses to one another does tend to spread out as the race progresses, during CER competitions, endurance riders start in a mass start, which would expose them to similar risks of collision, especially on the first loop. Evidence has identified that the first loop of the endurance competition is key to competitive success (Bennet and Parkin, 2018b; Marlin and Williams, 2018b, 2018a), however currently EGB data does not identify at what stage of the competition a horse has been eliminated, nor do they record individual loop speed and therefore this cannot be assumed at British national level. This data would be beneficial for future research and it is recommended that EGB improve their data recording.

3.8.4 Distance of race:

Evidence in race horses has identified that the risk of musculoskeletal injuries and fractures increases when distance is increased, likely due to the repetitive cyclic loading at high speeds (Crawford *et al.*, 2021; Martig *et al.*, 2014; Boden *et al.*, 2007; Perkins, Reid and Morris, 2005; Parkin *et al.*, 2004). Parkin *et al.* (2004) suggested that an increased distance would result in a longer time spent exposed to additional risk. Distance has also been identified as a risk factor for elimination in endurance rides. Fielding *et al.* (2011) found an increased risk of lameness elimination was associated with an increasing distance in competition. A study of endurance competitions in New Zealand found an increased risk of lameness in rides of 100km and above (Legg *et al.*, 2019). Other studies have identified and increased odds of lameness at FEI 3* level (160km) compared with lower distances (Di Battista *et al.*, 2019; Younes *et al.*, 2016). The largest study by Bennet and Parkin (2018a), found an increased odd of lameness at 120 km, but did not find an increased odd of lameness at 160km (FEI 3*), but only an increased risk of metabolic eliminations, perhaps indicating the presence of physiological fatigue which may or may not present in the gait patterning.

3.8.5 Speed:

Whilst endurance horses do not compete at the same speeds as racehorses, speed has risen dramatically, with speeds at international level frequently reaching over 25km.h^{-1} and in cases over 30km h^{-1} on the final loop. Coombs and Fisher (2012), two very experienced FEI veterinarians documented their concerns over the increasing speeds, particularly referencing the increase in fractures sustained being similar in nature to racehorses (Misheff, Alexander and Hirst, 2010). Nagy, Murray and Dyson (2014b), did not find a significant association with speed and lameness. However, other endurance studies have identified speed as a significant risk factor for elimination (Bennet and Parkin, 2018b; Younes *et al.*, 2016).

Marlin and Williams (2018b; 2018a) found that higher first loop speeds, changes in speed and a negative pacing strategy were associated with deleterious outcomes and combinations who remained at a more consistent pace, or who completed their first loop at a slower pace and subsequently increased their speeds were more likely to have a successful outcome. Adamu *et al.* (2014) also concluded that horses with a negative pacing strategy were more likely to be eliminated. Details surrounding individual loop speed are not available in EGB data, so the impact of pacing strategies on EGB horses cannot currently be identified. These data would be of benefit to assess the risk and assist in education of competitors to strategize their competitive race plans appropriately, not only to reduce the risk to the horse, but to improve their chances of competitive success.

Whilst an increase in speed increases the impact force of the foot of the horse hitting the ground and travelling up the limb is a risk for injury, an increase on speed is also more likely to lead to error which may impact on the likelihood of musculoskeletal injury that presents as lameness (Nylund *et al.*, 2021; Murray *et al.*, 2006). It is worth noting that these studies all considered FEI data, speed for horses who are eliminated in EGB competitions are not available in current datasets and therefore comparisons cannot currently be directly extrapolated. Anecdotally, speeds at EGB competitions are much lower than FEI levels, particularly as there is a maximum speed cap on all GER competitions and therefore the risk at British national level may not be as significant as at FEI level, but evidence is needed to ensure that this is assumption is accurate and legitimate.

3.8.6 Rest Periods:

Higher speed and distance increase the likelihood of injury in endurance. It would seem logical that even horses who have not been eliminated during competition may have sustained some sub clinical micro-trauma and should be allowed time to recover in order to return to their next competition(s) successfully. Without appropriate rest and recovery, a cumulative effect of micro trauma may result in more significant lameness (Georgopoulos and Parkin, 2016). Fewer days between endurance competitions have been associated with a decreased likelihood of successful completion (Zuffa, Bennet and Parkin, 2022). Nagy, Murray and Dyson (2014b) identified that there was a significant reduction in risk of lameness if the period between FEI competitions was more than 90 days. In human sports, the principle of over training where continuous training and competition does not allow for adequate rest and repair from micro damage, has been well documented and even investigated by the International Olympic Committee to safeguard the welfare of athletes (Montalvo *et al.*, 2017; Soligard *et al.*, 2016; Kellmann, 2010). The same principle of over-training has also been identified in racehorses, the result of which can manifest in loss of training days or catastrophic injuries. This occurs due to the accumulation of microdamage within the bone occurring faster than the remodelling and repair of bone can be completed (Martig *et al.,* 2014). Remodelling is faster during periods of rest and reduced during training and racing, as more microdamage is continuing to occur during this time (Martig *et al.,* 2014). Governing bodies for equine sports must ensure they too are safeguarding the welfare of horses competing by allowing adequate recovery times between competitions, although it is hard to quantify what recovery and training protocols horses have outside of competition and it likely varies between individual stables/ owners / trainers.

Acute increases in training and competition have been strongly correlated to injury in other equestrian disciplines (Munsters *et al.*, 2020; Rogers, Bolwell and Gee, 2012; Ely *et al.*, 2010; Lam *et al.*, 2007; Murray *et al.*, 2005). Over training would seem to apply to endurance at FEI level due to the identification of multiple competitive starts being a risk factor for elimination and extended rest periods out of competition resulting in less deleterious outcomes (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2018a, 2020; Nagy, Murray and Dyson, 2014b). It would be reasonable to assume that these risk factors would also be present in national level British endurance, however as yet this has not been recorded or identified. As documented, these risk factors are readily modifiable by change in practice, reducing the number of starts and increasing the rest period between competition (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2018a, 2020; Nagy, Murray and Dyson, 2014b).

Due to risk factors within the sport of endurance being identified, some positive rule changes have been implemented, such as increasing the MOOCP for horses competing at

FEI level. This rule change was introduced following the predictive modelling of increasing the MOOCP, which identified a hypothetical reduction of deleterious outcomes by 2.3% (Bennet and Parkin, 2020). By further increasing MOOCP for horses competing at faster speeds of 20km.h^{-1} and above, by an additional week, over and above horses ridden below 20 km.h^{-1}, a hypothetical reduction in eliminations by 11.5% was calculated (Bennet and Parkin, 2020). Whilst British national horses who are registered with the FEI, must follow FEI regulations, those that are not registered with FEI, do not and will have shorter MOOCP, particularly in the event of repeated eliminations (Appendix 2) (EGB, 2022c; FEI, 2022b). Until risk factors are identified at national level, the impact on reduced MOOCP or the effect of not increasing it, cannot be directly extrapolated and so regulatory changes are unlikely, which has potential to negatively impact on horse welfare.

3.8.7 Metabolic compromise:

Metabolic compromise of an endurance horse is a reason for elimination from competition. This thesis does not focus on metabolic compromise but does acknowledge the impact of metabolic factors on the presentation of gait and therefore lameness. Endurance specific studies have found the risk of metabolic elimination was highest in the Middle East and North Africa (Bennet and Parkin, 2018a). Nagy, Murray and Dyson (2010) identified that the highest risk of metabolic elimination was in the United Arab Emirates. This may be due to the climatic conditions with higher average temperatures or increased racing speeds due to the more consistent terrain.

Whilst metabolic eliminations are not a main focus of this study, metabolic issues can impact on the presentation of lameness and therefore must be a consideration for endurance horses. The metabolic demands of an endurance horse are significant, requiring them to sustain high intensity workloads and energy production for long periods of time (Trigo *et al.*, 2010; Treiber *et al.*, 2006). Whilst for the majority of the competition, horses are likely to be working within their aerobic capacity, particularly over the longer distances and higher speeds there may be a demand over and above the oxidative capacity of the skeletal musculature. In such instances, the horses will turn to anaerobic respiration sustainable for short periods, but over long-time frames within, for example the last loop of an endurance ride, will not only lead to metabolic derangement but muscle fibre damage. A horse could therefore be eliminated due to metabolic compromise but may also present as lame. Blood biochemistry has been considered during endurance rides to understand metabolic derangements and perhaps 'metabolic lameness' (Bollinger *et al.*, 2021; Adamu *et al.*, 2013; Lawan, A. *et al.*, 2012; Al-Qudah and Al-Majali, 2008). Changes in creatine kinase and increased lactate in the blood, whether from fatigue induced anaerobic respiration or increased speeds, can result in tissue remodelling or even rhabdomyolysis where skeletal muscle tissue rapidly breaks down, not only causing severe pain and gait abnormalities but severe metabolic compromise which can be fatal (Wilberger *et al.*, 2015; Adamu *et al.*, 2013). The difference between 'fatigue' and 'lameness' is often difficult to establish (Ii *et al.*, 2006). If skeletal musculature is compromised, the biomechanical efficiency of the horse will decrease which could decrease postural stability and increase limb loading, which may result in a heightened risk of musculoskeletal and orthopaedic injuries alongside metabolic compromise. Li *et al*. (2006), found that 2 out of 12 horses eliminated for lameness in their study had the highest creatine kinase activity levels out of any of the horses studied, demonstrating rhabdomyolysis without visual muscle cramping. The horses were deemed to be lame, rather than metabolically compromised. The veterinary inspection in endurance competitions consists of a metabolic and gait assessment for reasons aforementioned it is possible for a horse to be eliminated for both gait related issues and metabolic compromise.

Additionally, ‘exhausted horse syndrome’ not only presents with clinical signs of metabolic derangement such as elevated pulse, high respiratory rate, dehydration, general depression and poor gut sounds/ colic, all of which are considered in the endurance veterinary inspections, but can also present with weakness, stiffness and even laminitis, which be evident on a gait assessment (Muñoz *et al.*, 2010; Foreman, 1998). Changes in homeostasis, including altered pH balances, which occurs as a result of increased exercise can impact on metabolic function and has been linked to painful gastrointestinal ulcers (Bell *et al.*, 2007). A high prevalence of gastric ulcers have been identified in higher level endurance horses during the competitive season, in comparison to the ‘out of competition’ season (Banse and Andrews, 2019; Tamzali *et al.*, 2011). At the point of fatigue induced metabolic compromise, and ulceration, the horses’ physiological status has already declined, for the welfare of the horse, spotting these signs prior to reaching ‘exhausted horse status’ is imperative. Whilst the veterinary inspections are in place to monitor horses, riders and trainers must take responsibility and heed the veterinary advice and where necessary adapt their own competitive strategies and goals to preserve the welfare and longevity of their horses. Education of riders, trainers and all stakeholders within the sport is key to understanding this and rationalises the need for veterinary parameters and regulations to be underpinned by scientific evidence.

3.9 Training the Endurance Horse

There is a lack of evidence surrounding specific training across horse sports. Training programmes, should be sport specific but in essence require cardiovascular fitness to allow the metabolic pathways to produce the required energy for the demands, strength training of sport specific muscle groups and neuromuscular co-ordination, in order to prepare appropriately to the demands of the sport and to reduce the likelihood of injury (Clayton, 1991). If the horse is trained appropriately, it will be better adapted to the demands of the sport and this should increase the longevity of soundness and ability to compete (Clayton, 1991). Most training programmes are based on previous experience, advice from other individuals with experience or intuition (Castejon-Riber *et al.*, 2017; McLean and McGreevy, 2010). The demands of the endurance horse are complex not only requiring a healthy musculoskeletal system to withstand the training and competition, but additionally, must be metabolically fit, in order to pass the veterinary inspections.

With a lack of evidence related to training endurance horses specifically, the principles of training of the ultra- endurance human athletes could be considered and adapted appropriately (Williams *et al.*, 2021; Zaryski and Smith, 2005). Ultimately, the goal of the endurance horse and rider dyad is the same as an ultra-endurance runner- to sustain a higher speed over a given distance, without injury, compared to any other competitors. Theoretically this should be achieved by following a periodized training plan of macro, meso and micro cycles, targeted specifically for important competitions (DeWeese *et al.*, 2015). It is suggested that training a horse for a championship, considering base line fitness and recovery can take a year, with the increase of activity developing over the competitive season (Castejon-Riber *et al.,* 2017). Figure 3 gives an example of periodization in endurance horses. This periodization should be combined with basic principles of training including overload, where training is increased sufficiently to ensure that adaptations to the cardiovascular and musculoskeletal system are made, to enable the horse to meet the demands of competition (Castejon-Riber *et al.,* 2017; Smith, 2003). Frequency, duration, intensity and rest and recovery are the important training principles for maximum success and to reduce the impact of over training and minimise the risk of injury (Williams *et al.*, 2021; Zaryski and Smith, 2005; Smith, 2003). The training programme should also be specific to the sport of endurance, excessive hypertrophic strength work would be of little benefit and possibly detrimental, compared to progressive cardiovascular fitness, but the explosive power from strength training may be required in a final sprint finish. Not all endurance competitors will compete in CER's and therefore may not need the sprint finish power, as such training programmes must be individualised. The often neglected principle of rest and recovery would seem to be the key in endurance horses for successful performance and career longevity (Montalvo *et al.*, 2017; Soligard *et al.*, 2016; Kellmann, 2010). The findings of Bennet and Parkin (2020) that horses were more successful if MOOCP were increased, suggests that rest and recovery is poorly understood by endurance riders. Rest and recovery, is key to repair micro-trauma sustained during training and competition, particularly following an injury or a lameness elimination. However, as competitors have been known to disagree with the veterinary decision on lameness appropriate recovery is likely to be currently lacking (de Mira *et al.*, 2019).

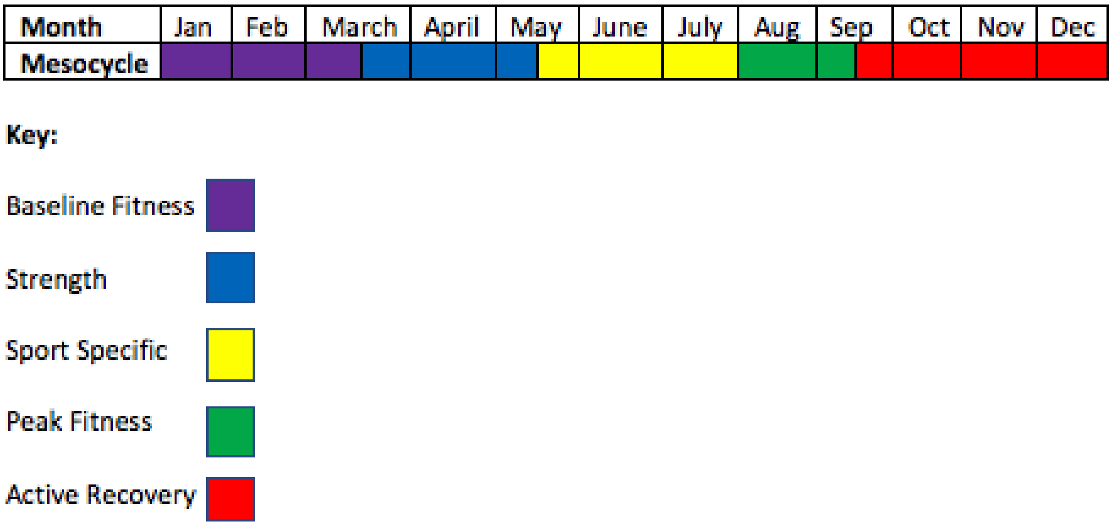

Figure 3: Example of periodisation in training endurance horses in Britain aiming for peak fitness at a championship hypothetically held in August/ September (Adapted from Williams *et al., 2021)*

In New Zealand, FEI riders were surveyed as to how they manage and train their competitive endurance horses (Bolwell *et al.*, 2015). This study demonstrated that riders had a basic understanding of the training principles, although perhaps were not specific enough with their periodisation, whether this is because plans change throughout the year and therefore programmes have to adapt, or whether the specificity was just lacking in this case is unclear (Bolwell *et al.*, 2015). Before the first competitive ride, the median amount of time horses were in training was 8 weeks, with the median frequency of training sessions being five times each week. The majority of respondents (70%) reported that they changed their training programme for their horse between competitive rides, although some reported increasing intensity (51%), others (30%) reported they decreased the intensity (Bolwell *et al.,* 2015). This study was qualitative in nature and therefore did not analyse any heart rate/ speed/ distance data but acknowledged the fact that as riders were proactively collecting this information, there was scope for further research into current training practices and parameters. It was also reported that when training sessions incorporated higher speeds, the distance covered during the training sessions reduced whilst the number of training sessions remained the same, which shows adaptation of the principles of intensity and duration impacting on the frequency (Bolwell *et al.,* 2015). This suggests that the riders in New Zealand at FEI level have an understanding of the principles of training, however, the variability between increasing or decreasing the intensity between competitive rides, suggests that greater sport-specific evidence is needed. Decreasing the intensity may be appropriate if at the time of competition, the horse is at the peak fitness level and is then undergoing a period of active recovery. However, it is suggested that riders use competitions for improving fitness, in which case, at the time of competition the horse may be in the period of sport specific training, which could account for the variability in responses in this case (Bolwell *et al.*, 2015; Smith, 2003).

A further study, surveying 21 FEI riders in New Zealand identified that the majority of respondents alongside aerobic fattening work, utilised schooling work to encourage flexibility and control (Webb *et al.*, 2019). This also suggests an understanding of the benefits of appropriate training, by adding schooling for variability and to add elements of control required for negotiating challenging terrain, or to position the horse appropriately in a mass start situation (Webb *et al.*, 2019; Clayton, 1991). However, Webb et al. (2019) also acknowledge that training such as schooling the horse can be convenience based, due to endurance being an amateur sport and fitting around full-time employment, which is also the case in Britain.

A study looking at a short-term training programme of 10 weeks in preparation for the competitive endurance season was conducted on six Bulgarian endurance horses, who were already successful at international level and were preparing for the World Championships 160km competition (Nedkova-Ivanova and Yalev, 2020). The training programme they followed consisted of a ‘basic training day’ where the horse was trained at a level without stress, a day of schooling, a conditioning day, cross-country basic training, which is assumed to equate to the British term of hacking rather than cross-country including jumps as in three-day eventing, a day of canter and conditioning training. There was a rest day prior to the cross-country training and post the canter and conditioning training. The horses were monitored during their training with a polar heart monitor and were instructed not to increase the heart rate above 200bpm for more than twenty minutes in any training session. The average heartrate was 103bpm with speeds ranging from 5.2-22.5kmh^{-1}. The study concluded that as the horse's heartrate remained within acceptable limits that the horses coped well with the training programme (Nedkova-Ivanova and Yalev, 2020). The true impact of the training programme in terms of competition performance was not able to be concluded due to the COVID-19 pandemic. The descriptors of the training programme could be considered vague as it mentions specific exercises were done during the schooling training, but does not mention what these are. Whether the horses had undergone any pre-training specifically for this study was unclear, however they had all been successful over 120km distances and were being prepared for the World Championships. The study suggests that the researchers were comfortable that the horses were prepared well within the ten weeks (Nedkova-Ivanova and Yalev, 2020).

Specifics of training in terms or duration and intensity are going to vary between trainers of endurance horses and are thus far poorly reported. This has been identified in racehorses, where speeds, frequencies and intensities of training and duration of rest periods were found to differ between trainers (Morrice-West *et al.,* 2020). Further research is needed to understand the impact of training in endurance horses and the relationship between the required fitness in order to be able to complete the ride without overloading and stressing the musculoskeletal system to the point of injury.

Inadequate levels of fitness have been linked to fatigue-based injuries in human sports (Gabbett, 2016; Holtzhausen *et al.*, 2007) Key determinants of performance and fitness are related to body mass (Lakoski *et al.*, 2011). Horses who lack fitness may be more at risk of being overweight, which has been identified as a risk factor for suspensory ligament injuries in sports horses (Gruyaert, Pollard and Dyson, 2020). With more British native breeds, which are known to be prone to obesity competing within endurance in the UK, training and fitness preparation is likely to be key in successful results. Currently training the endurance horse is predominantly steeped in anecdotal, historical and personal experience, rather than scientific evidence-based rationale. Whilst there has been a rise in monitoring heart rates, distance, speeds and time within training sessions by amateur riders, it is unlikely that the data are analysed and interpreted appropriately to give rise to meaningful results and progressive training plans (Williams and Tabor, 2017). Perhaps, not only for the benefit of horse welfare but the SLO of the sport, researchers must identify and proactively communicate evidence-based training strategies to endurance riders, to promote skills and prevent injury.

3.10 Horse demographics: Age, Breed, Sex, Competition History

3.10.1 Age

Endurance competitions have minimum ages at which horses can compete at certain levels, in order to prevent musculoskeletally immature horses competing (EGB, 2022c; FEI, 2022b). In the 2016 World Championships, held in Slovakia, six horses started the race aged eight years old, the youngest age that they were allowed to, none of them finished (Bollinger *et al.*, 2021). It is unclear whether this is down to the impact of overtraining as to be eligible for a championship at eight years old, the horses will have to have progressed rapidly through their qualifications (Munsters *et al.*, 2020; Rogers, Bolwell and Gee, 2012; Ely *et al.*, 2010; Murray *et al.*, 2005). Conversely, other studies looking at risk factors for elimination have actually found the younger horses have been less likely to be eliminated from competition (Legg *et al.*, 2019; Bennet and Parkin, 2018a; Younes *et al.*, 2016; Adamu *et al.*, 2014; Fielding *et al.*, 2011). In some cases, this may be due to younger horses competing at the lower distances and at lower speeds during qualification rides and are therefore less exposed to the additional risks of increased distance and faster speeds. Older horses may have a longer competitive history, exposing them to greater risk of accumulative microtrauma of the musculoskeletal system and potentially more degenerative changes, as suggested by Martig *et al.* (2014), when looking at older Thoroughbreds in racing. Several studies have identified in other equestrian disciplines that older horses are at a higher risk of lameness and injury (Murray *et al.*, 2010; Henley *et al.*, 2006; Parkin *et al.*, 2005). However, experience in competition has been demonstrated as reducing risk in racing and three-day eventing (Cameron-Whytock *et al.,*2023; Williams *et al.,* 2013; Pinchbeck *et al.,* 2002). These factors suggest that the relationship between age of the horse and the risk factor for injury may not be linear but may be dependent on other factors such as the competitive and training history of the horse. In EGB data, unless looking at specific results of an individual horse, the ages of the horses are not clearly identified. Clearer recording of this data would be of benefit to develop a more robust understanding of the impact of age a horse in relation to lameness eliminations in national level endurance. Currently, further evidence is required to establish if age is a risk factor for lameness at national level.

3.10.2 Breed

Studies within endurance have identified that most of the horses taking part in competition were Arabian or Arabian cross breeds (Castejon *et al.,* 1994). This is not necessarily the case across all levels of EGB competitions and frequently British native bred horses/ ponies have been on the front cover of the societies magazine. In the first five months of the 2022 EGB season 1105 horses had breeds listed, 57.4% (n=634) of these were Arabians, Anglo Arabians or Part bred Arabians and 27.3% (n=302) were British native, part bred or sports horses. The rest of the horses did not have breeds specified.

Attempts at establishing if breed superiority exists has been considered in endurance. Castejon *et al*. (1994) identified that at 20km h^{-1} both Anglo Arabians and Pure-bred Arabians had lower blood lactate levels and heart rates than that of the third breed tested (Andalusian), in effect this would mean that the Anglo Arabians and the Pure-bred Arabians would fatigue at a slower rate than the Andalusian. This is a broad assumption however, as it is not possible to ascertain whether the horses were of the same level of fitness or had undergone the same training prior to testing and therefore breed may not have been the only factor influencing the results.

When gait characteristics were considered in Anglo Arabians, Pure bred Arabians and Andalusians, it was shown that Andalusians showed greater forelimb flexion, which may result in a greater ground reaction force that that of the Arabians or Anglo Arabians (Cano *et al.*, 2001). A higher ground reaction force would put greater force through the limbs which may predispose the horse to more concussive joint injuries over longer distances (Dutto *et al.*, 2004). Fielding *et al.* (2011) concluded that heavier breeds were at increased odds of elimination perhaps again due to their biomechanics of gait. Identification of whether the British native breeds are at higher risk of lameness or elimination has not been completed previously in endurance, perhaps due to the focus being on higher level international competition, where the field is dominated by the Arabians. With almost 30% of the horses starting the 2022 competitive season being of native breed, this is a risk factor that should be investigated.

3.10.3 Sex

Nagy, Murray and Dyson (2017) identified in England and Wales, that geldings remain the gender of choice in competitive endurance. The behaviour of geldings has been described as more consistent than mares who may exhibit undesirable behaviour when in oestrus and can be more difficult to train than geldings (Pryor and Tibary, 2005). Previous evidence has suggested that male horses hold a performance advantage over females, with a higher aerobic capacity and greater speed being identified in male racehorses compared with females (Entin, 2007; Mukai *et al.*, 2003). However, it has been suggested in human sport that as distance increases, the male superiority within sport decreases, which may be a reason as to why at the elite level of endurance there appears to be no significant difference between the sex of the horses (Bennet and Parkin, 2018a; Ricard and Touvais, 2007; Coast, Blevins and Wilson, 2004). Ricard and Touvais (2007), demonstrated there were no significant difference between the sexes in terms of finishing place in endurance races. In other equestrian disciplines, such as three day eventing no performance differences have been found between sexes (Whitaker, Olusola and Redwin, 2008). More recent epidemiological studies within endurance specifically only found a difference between stallions and non-stallions, with stallions being at an increased odds (OR 1.12) of a lameness elimination, compared to non-stallions (Bennet and Parkin, 2018a). The rationale as to why stallions are at higher risk of lameness within endurance has not been explored, it may be that external factors, such as being expected to cover mares as well as compete or that they become mores distracted being in close proximity to mares within the race and particularly within the vetting area. If the stallions are distracted during the ride, or the trot up, they may be at greater risk of trauma injuries by tripping or overreaching. It may also be that stallions exhibit a more extravagant movement, which potentially puts them at higher risk of musculoskeletal strain or injury. A large-scale meta-analysis of race horses, identified that male entire horses were identified as a risk factor for catastrophic musculoskeletal injuries (Hitchens *et al.,* 2019). An increased body mass and hormonal differences have been suggested as a rationale for the greater risk of lameness and injuries among stallions in racing, which could be extrapolated across to stallions competing in other disciplines, such as endurance. Anecdotally, there are few stallions competing within EGB, whether this is because they are more frequently lame, or because they are more challenging to handle by a largely amateur competitor base is unclear.

3.11 Influence of the rider

The role of the rider within the sport of endurance is to safely and without sustaining injury manage their horse around the marked route, within the given time frame. By having an awareness of the risk factors, such as speed, pacing strategies and awareness of ground conditions, the rider can proactively adapt their race strategy to optimise their chances of a successful competitive outcome and protect the welfare of their horse (Marlin and Williams, 2018b; 2018a).

A review of the physiological and psychological demands of the endurance rider for successful performance in the sport highlighted the complexity of endurance riding (Williams *et al.*, 2021). In order to achieve the optimal performance outcome during competition, it is not only the horse that should be considered the athlete, but the rider as well (Williams *et al.*, 2021). Rider physiological and psychological fitness have been described as imperative for endurance. Rider hydration and nutritional status has been discussed as having an important role in being able to meet the demands of endurance riding and therefore appropriately manage the horses welfare (Williams *et al.*, 2021). However, EGB does not require riders to have a back-up crew who could provide fluids and nutrition to the rider during the course of competition until they reach CER level (EGB, 2022c). This requires the riders to carry drinks themselves, or go without at the lower levels, neither of which are perfect options. Carrying a drinks bottle will alter the symmetry of the rider or saddle, depending on how it is carried and going without fluids could lead to dehydration and lapses in concentration (Williams *et al.*, 2021). A lack of concentration may result in a bad decision in negotiating the terrain, perhaps travelling unnecessarily through deep mud, rather than directing the horse around the deep going which may conclude in equine lameness.

Having discussed the possibility of a fatigued horse presenting with a more asymmetrical gait pattern, it would not be unreasonable to consider a fatigued rider may become more asymmetrical within the saddle. Viry *et al.* (2015) identified that the level of expertise of the rider within an endurance ride influenced their ability to adapt and respond to the horses' movement pattern. However, it is unclear from the results whether improved riding strategy and race awareness of the more experienced rider, or rider fatigue of the less experienced competitor were the key influencers (Viry *et al.*, 2015). Anatomical asymmetry such as leg length discrepancy and functional asymmetry whereby riders adopt specific movement patterns relative to the task required have been documented in horse riders (Hobbs *et al.*, 2014; Symes and Ellis, 2009). MacKechnie-Guire *et al.* (2020) specifically induced rider asymmetry by altering stirrup lengths and identified an impact on the thoracolumbar spine movement of the horse, additionally there was an increase in maximal fetlock extension of both the forelimb and hindlimb on the side where the riders stirrup was longer. Whilst this study used a 5cm discrepancy between left and right stirrups, which may be more than commonly seen in asymmetries, the accumulative impact of any rider asymmetry on the gait patterning of the horse over a long period of time such as an endurance ride has yet to be clearly identified. It has been demonstrated that a horse will adapt to a riders positioning which will in turn have an impact on gait pattern (MacKechnie-Guire *et al.*, 2020; Williams and Tabor, 2017; Hobbs *et al.*, 2014; Viry *et al.*, 2013; Symes and Ellis, 2009; Peham *et al.*, 2004). Riders adopt their positioning to the movement of the horse, but riders adopt individual postural strategies and are unlikely to respond identically to other riders (MacKechnie-Guire *et al.*, 2020; Wilkins *et al.*, 2020; Viry *et al.*, 2013, 2015). Therefore, if a horse is usually trained and ridden by one individual and competed by another, the horse may adapt to the different movement patterns of the new rider which could result in altered or compensatory movement patterning. In turn this could may alter the biomechanics of the horses' gait pattern and potentially manifest in a gait abnormality or lameness elimination (MacKechnie-Guire *et al.*, 2020; Foreman, 1998). It is anecdotally common place at British national level that horses are ridden by the rider that trains them at home and therefore it is postulated that this is less of an issue at national level competitions, compared to FEI level, where it has been identified that riders who had not previously competed the horse were at a higher risk of a deleterious outcome (Bennet and Parkin, 2018a). However, this has not been investigated at national level and therefore true extrapolations cannot be made.

3.12 Gaps in the literature

The majority of endurance sport specific literature, identification of risk factors and indeed negative media headlines focus on international competition. The lack of evidence at British national level endurance could leave British riders to adopt an 'it is not our problem' attitude and fail to recognise risks of elimination, lameness and risks to horse welfare. Factors identified in previous studies such as higher speeds, are not necessarily applicable to British endurance and therefore the sport needs research at a more local level in order to provide evidence informed practice. As owners of EGB horses reported a high percentage of lameness (Nagy, Dyson and Murray, 2017), further information surrounding risk factors for elimination and specifically lameness is warranted at national level.

Whilst some information is available surrounding sport specific injuries in endurance and can perhaps be hypothesised from other sports, the evidence surrounding these injuries and rationale for lameness presentation relies on those who have sought follow up veterinary advice, which has not been found to be common place in British Endurance (Paris, Beccati and Pepe, 2021; Nagy, Dyson and Murray, 2017; Misheff, Alexander and Hirst, 2010; Murray *et al.*, 2006). Full clinical and diagnostic examinations for lameness are not feasible at a competition, but it would be of benefit to understand which limb(s) are most commonly identified as lame at the point of elimination from competition and understand the severity of the lameness presenting at British national level endurance competitions. Not only would this give a greater understanding of potential anatomical structures to be further investigated, but it may add weight to encourage riders to proactively seek veterinary follow up.

Lameness eliminations clearly occur in British national endurance (Nagy, Dyson and Murray, 2017), but without the evidence to quantify what these are and the risks that predispose the horses to risk of lameness, the governing body is unable to be proactive in implementing evidence-based risk mitigation strategies in terms of rules and regulations. There is a lack of evidence to underpin appropriate education for competitors on management strategies which would minimise the risk to their horses and the SLO of the sport.

Chapter 4

4.0 Research design

This chapter outlines the methodology and common methods used across the subsequent chapters and studies. Methods specific to individual studies are detailed within the relevant specific study chapter. Figure 4 demonstrates the connection and progression between the chapters of the thesis.

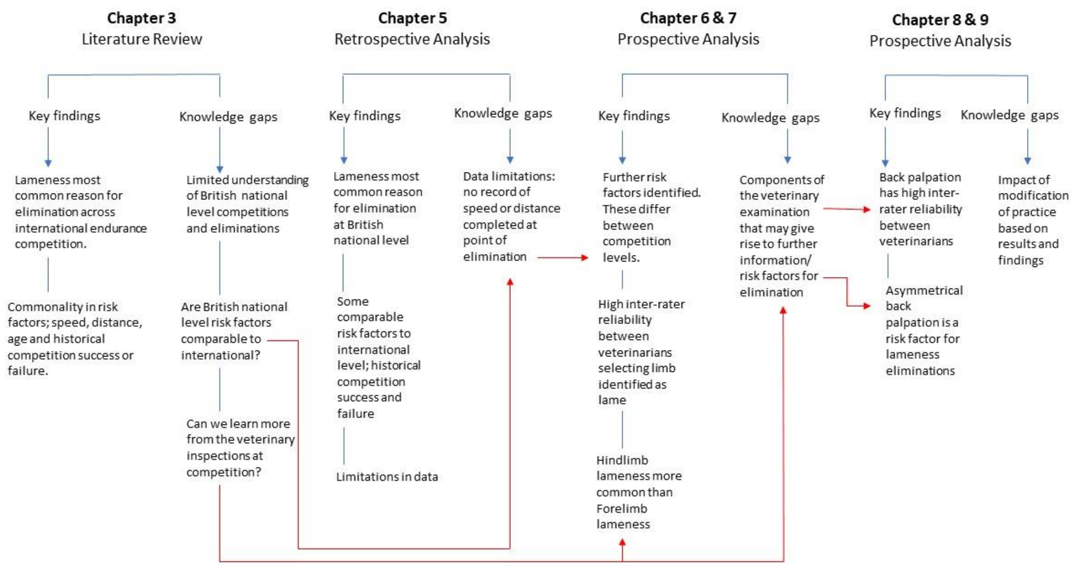

Figure 4: Key findings and knowledge gaps highlighted in each chapter summarising the progression between chapters of the thesis

4.1 Relationship of Sequential Studies to Thesis Objectives

The overarching aim of this thesis was to identify risk factors for elimination and more specifically lameness elimination from British national endurance competitions. The thesis is constructed of a series of sequential studies. Each study addresses specific objectives with the outcome of each informing the subsequent study (shown in Appendix 9). Ethical approval was granted by the University of Hartpury Ethics committee (No: ETHICS2018-48 and ETHICS2020-48; Appendix 3) and a research collaboration agreement from Endurance GB was obtained to enable data to be collected and analysed for the purpose of the research.

The studies have been published, submitted for review or presented at the International Association of Veterinary Rehabilitation and Physical Therapy Symposium in 2022. The publications are listed below. The full version of each study/ conference abstract(s) are available in the appendices (4-8). Author contributions are documented as a front sheet prior to the presentation of the paper/ conference abstract.

4.2 Publications and Conference Proceedings

Publications:

Study 1: (Appendix 4)

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022a) Risk factors for lameness elimination in British endurance riding. *Equine Veterinary Journal.* DOI:10.1111/evj.13875

Study 2a: (Appendix 5)

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022b) A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019. *Comparative Exercise Physiology.* 18 (4), pp. 329-338. DOI:10.3920/CEP220003

Study 2b: (Appendix 6)

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022) Lameness eliminations in single loop and multi-loop British endurance rides in 2019. ***Under Review***

Conference Proceedings:

Study 3a: (Appendix 7)

Bloom, F., Bennet, E., Draper, S., Tabor, G., Marlin, D. and Williams, J. (2022) Inter-rater reliability of grading soft tissue palpation of the thoracolumbar epaxial musculature of endurance horses during competition: *Proceedings of the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapists (IAVRPT).* University of Cambridge, Cambridge, 18-20 August 2022. Available from: http://iarvpt2022.org/speakers

Study 3b: (Appendix 8)

Bloom, F., Bennet, E., Draper, S., Tabor, G., Marlin, D. and Williams, J. (2022) Back pain on epaxial muscle palpation as a risk factor for lameness elimination during endurance competitions: *Proceedings of the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapists (IAVRPT).* University of Cambridge, Cambridge, 18-20 August 2022. Available from: http://iarvpt2022.org/speakers

4.3 Participant inclusion/ exclusion criteria

Each study had differing objectives and therefore the participant inclusion and exclusion criteria differed slightly, this is detailed in Table 4. The first study, involved a purposive sampling technique, considering the entire population of horses registered to EGB competing distances of 64km and above. This allowed an in-depth insight into the data and avoided the risk of missing information. Whilst purposive sampling has been linked to researcher bias, this is mitigated by using the entire population (Etikan, Musa, and Alkassim, 2016). All the other studies used a convenience sample strategy, whereby competition venues around Britain were selected at different dates across the competitive seasons (i.e. 2019 for study 2a & b and 2020 for study 3a & 3b) and the data were collected in person by the researcher. It was not logistically possible for the researcher to attend every EGB competition, as multiple events across the country were run on the same day(s). It is acknowledged that convenience sampling inherently introduces bias. Generalisation of the results to the entire population of EGB must be done with caution, as it is not known whether the sample adequately represents the population of all EGB endurance riders (Etikan, Musa, and Alkassim, 2016). Attempts were made to reduce bias relating to location, by travelling to different locations across Britain, where terrain differed. Figure 5 shows the locations attended by the researcher in 2019 and 2020, whereas Figure 6 shows locations of rides for two months (June/July 2023) downloaded from the EGB website to demonstrate the researcher chose as close to 'typical' ride venues as was possible.

Table 4: Simplified inclusion/ exclusion criteria for each study

The number of horse starts and basic inclusion and exclusion criteria for each study contained within the thesis.

Study	Inclusion Criteria	Exclusion criteria	Number of Horse starts	Appendix
1	-Competitive starts logged by EGB, of rides of 64km and above in 2017-2018.	-Horses without any competitive history	1747	4
2a	-All GER and CER horses presenting to the veterinary panel at the seven rides attended during the 2019 competitive season	-Horses competing in pleasure rides	765	5
2b	-All GER and CER horses presenting to the veterinary panel at the seven rides	-Horses competing in pleasure rides	765	6

	attended during the 2019 competitive season			
3a	Horses presenting to Pleasure ride veterinary inspection	-All other horses at the competition	19	7
3b	-All GER and CER horses presenting to the veterinary panel at the five rides attended during the 2021 competitive season.	-Horses entering the pleasure ride	423	8

*EGB- Endurance GB *GER- Graded Endurance Ride *CER Competitive Endurance Ride
*Exclusion criteria for study 1- horses who had not previously competed in endurance would not be sufficiently qualified to complete a 64km ride. Therefore, in order to compete at this level, they would have a competitive history- if the competitive history was missing, the data set was considered incomplete and therefore the horse was excluded from the study.

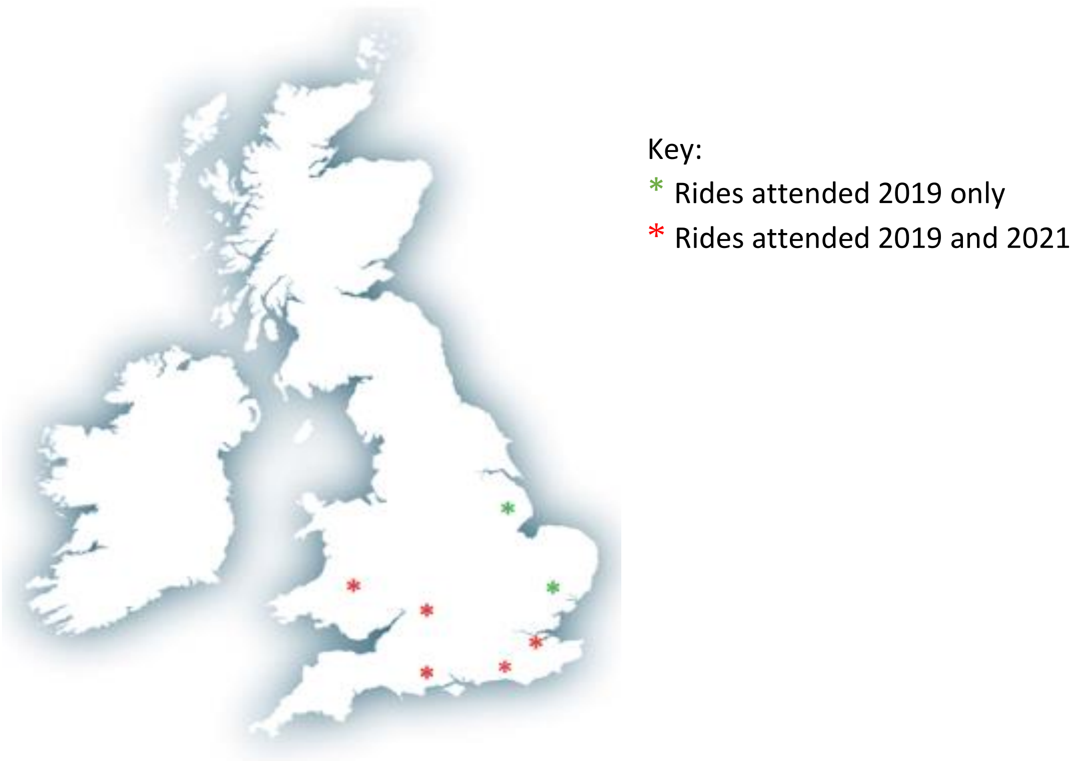

Figure 5: Locations of rides attended in 2019 and 2021
A map detailing location of rides that were attended in 2019 and 2021 to collect data for the second and third study.

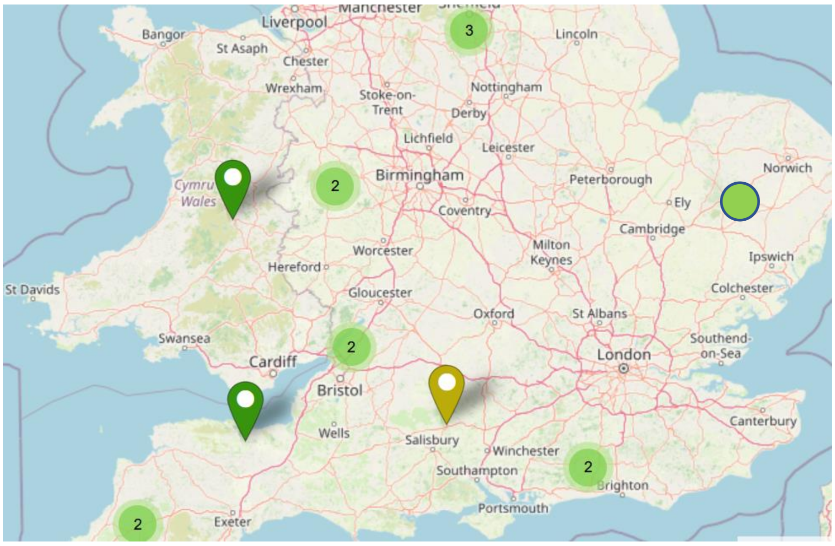

Figure 6: Locations of rides attended documented by EGB in a random two-month period (2023)
A map detailing location of rides over two months run by EGB to allow for a comparison of rides attended compared to distribution of rides (Endurance GB,2023).

4.4 Overarching study design and research philosophies

Each study details the specific methods within their own chapter; however, this chapter discusses the general methodology and methods, and rationalises the choices of these. All of the studies within this thesis are quantitative in design and are underpinned by a positivist research philosophy (Whaley and Krane, 2011). Fundamentally, following the pragmatism philosophy, the results should be meaningful and useful to bring about change (Morrison, 2016). Whilst pragmatism accepts elements of subjectivity, it is accepted as appropriate as it allows theory to be underpinned by practical application in the real-world situations, such as that in sporting competition (Jenkins, 2017).

The philosophy of positivism is important in the design of this thesis as it enables the data to be objectively assessed, independently of opinion (Moon and Blackman, 2014). However, the methods used within study two (a and b) and three (a and b), do allow some subjectivity from veterinarians, which fits into the post-positivist epistemological paradigm by pursuing objectivity but acknowledging the possibility of subjective bias (Moon and Blackman, 2014; Krane and Baird, 2005). The ontology of the post-positive approach is that all methods are imperfect and by utilising multiple methods the validity of the outcome is more robust (Moon and Blackman, 2014). As the researcher in attendance at all competitions, with experience as an international endurance competitor, there was a potential risk of unconscious and subconscious bias (Moon and Blackman, 2014; Krane and Baird, 2005). This risk was minimised by ensuring the veterinary examination was not changed throughout the research process. No opinions were discussed with the veterinary professionals and the data provided were taken from the event but not discussed with any other attendee.

Each of the studies in this thesis are quantitative in design. Whilst quantitative studies have been completed in endurance, these have been based thus far in international level competition (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2018a, 2018b, 2020; Marlin and Williams, 2018b, 2018a; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2010, 2014a, 2014b; Fielding *et al.*, 2011). The only study specifically surrounding British national endurance is a subjective, qualitative study (Nagy, Dyson and Murray, 2017). Consequently, current beliefs surrounding British endurance, at national level, are opinion based and lack objectivity.

The methods used differ for each study and are therefore suited to the specific research questions for each study. However, they all encompass the overarching aim to enable the conclusions of the thesis to add objectivity and ecological validity to the knowledge framework of British endurance, in order to improve the sport and the welfare of the horses competing in it.

4.5 Study 1

The purpose of this study was to gather and evaluate baseline information surrounding the status of British endurance with regards to lameness eliminations. A deductive research strategy was used (Majeed, 2019; Blackstone, 2018), as data were gathered as a starting as previous international studies have identified risk factors within endurance and have consequently provided existing knowledge. Whilst there have been no directly comparable studies between national and international competition levels, it can be assumed that the injury pathways are the same and therefore at least some risk factors may be analogous. The underpinning research theory was positivism, as data already existed and therefore could only be interpreted with an objective approach (Moon and Blackman, 2014).

Study 1 was a retrospective epidemiological cohort study, using the database held by Endurance GB. Epidemiological studies are common in human medicine, with the purpose of identifying risk factors that are significantly associated with a disease. In epidemiology, once the risk factors have been identified, then mitigation of risk can be implemented (Coggon, Barker and Rose, 2009). Whilst disease modelling is arguably the most important and well-known use of epidemiology, risk of injuries can also be considered. Epidemiological studies have been described as the fundamental first step in sports injury prevention and have become commonplace in identification of risk factors in horse sports (Bennet, Cameron-Whytock and Parkin, 2022; Bennet and Parkin, 2018b, 2018a; Georgopoulos and Parkin, 2016; Pinchbeck *et al.*, 2002, 2013; Williams *et al.*, 2013; Hitchens *et al.,* 2010; Murray *et al.*, 2005, 2010; Singer, Saxby and French, 2010; Parkin *et al.*, 2005; van Mechelen, Hlobil and Kemper, 1992). It was therefore deemed an appropriate design for the first study of this thesis.

The limitations of this study are inherent in retrospective analysis of real-world data which is not specific to the research question (Talari and Goyal, 2020). The quality of the data impacts on the quality of results, but the outcomes still provide meaningful information to support strategies to improve equine welfare within the sport of endurance despite these limitations. Changes to rules and regulations in horse sports have been brought about by findings from epidemiological studies, such as increasing MOOCP in endurance and fence design in the cross-country element in three-day eventing (Bennet and Parkin, 2020; Murray *et al.*, 2005). This further justifies the approach of an epidemiological study within this thesis.

The first study provided a baseline of data which enabled further research questions to be considered in order to answer the overarching aim of the thesis in a more specific manner.

4.6 Study 2

Study 2 was a prospective cohort study, with the research question established from identifying gaps from the previous study, by collecting further data, not available in the retrospective data set. This included speed, environmental and topographical information and more specific veterinary information, such as which limb(s) were identified as lame at the point of elimination. By using a prospective design, this enabled data missing from the first retrospective analysis to be collected to provide a greater depth of information and also allowed data to be collected in a consistent manner which increased the accuracy of the data set (Talari and Goyal, 2020). Whilst prospective studies can be flawed by selection bias of participants (Bookwala, Hussain and Bhandari, 2011), this was minimised by travelling to the different locations (Fig 2.) and including all levels of horse starts from novice to advanced.

This study followed the post-positivism research philosophy, whilst the majority of the data were objective, the study required licenced veterinarians to subjectively analyse lameness and utilise categorical scales to define the severity of it (Moon and Blackman, 2014; Krane and Baird, 2005). The post-positivism paradigm acknowledges that the possible impact of subjective bias, in this case, of the veterinarians can impact the objectivity of the results, but that the prior knowledge and experience is important to take into consideration for a robust picture (Moon and Blackman, 2014; Krane and Baird, 2005). As the veterinarians were experienced clinicians, their role within the sport is not to impose relativism but retain the concept of objectivity to promote the welfare of the horse (Moon and Blackman, 2014). Additionally, the data were collected within competition, as per competition rules which offers ecological validity to the research findings (Schmuckler, 2001). To consider the impact of the subjective bias the IRR of the veterinary gait assessment was assessed at each competition (see 7.2.3).

Historic data, including the risk factors identified from the first study and previous literature were collected from the publicly available website (EGB, 2022c). This enabled risk factors to be considered from both a historic and specific ride perspective, increasing the strength of the findings and has not been previously considered within the sport.

This second study, due to the large amount of data and findings is reported in two papers, one with the descriptive data elements (Bloom *et al.*, 2022a) and one with the risk factor modelling (Study 2b, Chapter 7). The findings from the second study provided new information, which informed the design of the third study.

4.7 Study 3

The findings of the first and second study allowed a deductive approach to be used in the final study (Blackstone, 2018). A hypothesis was derived from the outcome of the second study, where the hindlimb(s) were identified as more likely to be the cause of lameness elimination than forelimb lameness. Due to previous research identifying that back pain and hindlimb lameness can co-exist, and the number of hours a rider may spend in the saddle during competition, it was hypothesised that back pain was an additional risk factor for lameness eliminations (Greve and Dyson, 2013; Alvarez *et al.*, 2008; Landman *et al.*, 2004). The overarching aim of the third study was to test this hypothesis to allow the findings of the study to be used to help to inform and develop strategies to educate stakeholders within the sport on risk management and optimise the welfare of the horse. This study was conducted in two parts, the first assessing the IRR of the proposed method and scoring of back pain (Chapter 8). The second part of the study (Chapter 9), considered horses' back pain within competition, as an additional risk factor, to those identified from study 1 (Bloom *et al.*, 2022b) & 2b (Chapter 7).

4.8 General Data Collection & Analysis

4.8.1 Historic Data

For the initial study, historic data were provided directly by EGB; however, the majority of these data are publicly available on the EGB website (EGB, 2022b). Two years of competition (2017 and 2018) were analysed for the first study. Due to changes in recording of data by EGB in 2016, earlier data were not suitable for inclusion. For the remainder of the studies in which historic data were used (Studies 2a, b and 3b; Chapters 6, 7 and 9) the Endurance GB website was used to collect the information (EGB, 2022b).

For each ride entry, the database had eight possible outcomes: (1) Completion (C), the horse successfully completed and passed the final veterinary inspection; (2) Eliminated, the horse did not successfully complete the competition; this was split further into (a) eliminated due to lameness, (b) eliminated for metabolic reasons (MET), (c) retired (RET), the horse successfully passed the veterinary inspection but was subsequently withdrawn by the rider, (d) disqualified (DSQ), a breach of the rules resulted in disqualification, (e) out of time (OOT), the course was not completed within the maximum-minimum time requirements, (f) withdrawn (WDN), the horse was entered but was not presented to the initial veterinary inspection (EGB, 2022c; FEI, 2022b).

The first stage of analysis was to 'clean' the data (Broeck *et al.*, 2005). This involved removing duplicates and incomplete observations. This step was imperative to reduce the likelihood of errors (Broeck *et al.*, 2005). Incomplete observations, included horses without any competitive history. In the second and third study, horses competing in single loop rides may not have had any competitive history, and therefore this would not be considered an incomplete data set. However, horses in the first study had to have a competitive history, in order to be competing in a ride of 64km and above, therefore in these cases, horses without a history had an incomplete dataset and were excluded from the study. One reason for the data set to be incomplete in these cases is if the horse had competed abroad before coming to the UK to compete. In these circumstances the horse's qualifications would have to be checked by EGB to allow it to compete and the data should be uploaded onto the main EGB database, however this is often incomplete as it requires manual input, these data sets are then incomplete and missing completely at random. In some cases, variables such as average speed were missing, in these cases the horses did not complete or were eliminated from the ride. These data were considered missing not at random as the probability of the variable depended on itself. Each horse start was given a unique identifier. Continuous variables were assessed and transformed to categorical form where appropriate to identify the most appropriate form of each variable for analysis (Altman and Royston, 2006). This was an important step as the range of some of the historic data, such as the competitive history of the horse, contained distant outliers. Reference categories for categorised variables were carefully determined, using previous research in the field as guidance (Bennet and Parkin, 2018b, 2018a; Younes *et al.*, 2016; Fielding *et al.*, 2011; Murray *et al.*, 2010; Nagy, Murray and Dyson, 2010; Altman and Royston, 2006).

Data were initially received and downloaded on Microsoft Excel (2018). Data cleaning, as described above, was undertaken in Microsoft Excel before being transferred to Statistical Product and Service Solutions software (SPSS Version 26, IBM, United Kingdom Limited, Portsmouth, Hampshire, UK) for analysis. This involved removing of duplicates, or incomplete data sets, for example, if the final result was not recorded.

4.8.2 Inferential Statistics

With the exception of study 3a (Chapter 8), at this stage of analysis descriptive statistics were prepared, and where appropriate continuous variables were tested for normality using the Shapiro-Wilk test (Ghasemi and Zahediasl, 2012; Steinskog, Tjøstheim and Kvamstø, 2007). Inferential statistics were completed to answer the aims of the studies and allow extrapolation of the information to the wider population of endurance horses. A series of Spearman's Rank correlation analysis were completed in order to assess the strength and direction of the relationships between variables (Schober, Boer and Schwarte, 2018; Mukaka, M., 2012). Spearman's rank was selected as preliminary investigation showed non-parametric statistical tests were most appropriate given the lack of normality in the data (Murray *et al.*, 2005). The correlation coefficient was identified as either positive or negative, with the strength of the association being determined by its proximity to either +1 or -1. The closer to 1 (positive or negative), the stronger the association between the ranks (Schober, Boer and Schwarte, 2018). Correlation coefficients of 0.0-0.30 were considered negligible, values of 0.31-0.50 were considered low, 0.51-0.70 moderate, 0.71-0.90 high and 0.91-1 very high (Mukaka, M., 2012).

4.8.3 Risk factor modelling

Binary logistic regression was used to assess the association between variables and identify significant risk factors. The potential risk factors (exposure independent variables) used in the initial modelling were determined from previous literature and experience within EGB competitions and are provided in detail in Appendix 4, as a supplementary file to the publication of study 1 (Bloom *et al.*, 2022b).

In each case, initially univariable analysis was completed with two outcomes tested. Model A: the dichotomous outcome variable was pass (and therefore completed the ride)/did not pass (and therefore was eliminated from the ride) and Model B: the dichotomous outcome variable was lame/ not lame. Previous studies within the sport have considered additional outcomes such as metabolic elimination, however the focus of this thesis was lameness and as a result independent modelling on metabolic eliminations was not completed.

Risk factors significant at a P value ≤0.1 were taken forward to multivariable analysis (Dohoo *et al.*, 1997). Additional variables, which did not meet the required significance levels but were biologically plausible based on previous research were retained. Multivariable binary logistic regression models were constructed using a backwards-stepwise process. A backwards-stepwise process was selected to maximise predictability and to limit the suppressor effect which can occur in the forward method (Field, 2013). Risk factors with P value ≤0.05 in the final multivariable models were considered significant (Bennet and Parkin, 2018a, 2018b; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2014b). The performance of the model was assessed using the Omnibus test, which identified whether there was significant variation between the coefficients and ensured that any factors that had a significant effect on the model were not removed (Field, 2013). Nagelkerke's R^2 was used as a regression co-efficient to estimate causality, and the Hosmer Lemeshow goodness of fit test was used to compare the observed to predicted values of probability (Field, 2013; Hosmer and Lemeshow, 2000). Each model was assessed for predictability using Receiver Operating Characteristic curve analysis (Bandos, Rockette and Gur, 2010; Gardner and Greiner, 2006). The predictability of the model in each case was considered good if the area under the curve was >0.7 and excellent if >0.9 (Bandos, Rockette and Gur, 2010; Gardner and Greiner, 2006).

Post hoc analysis was conducted where appropriate using horse starts and rider starts as a random effect to identify any horse or rider level clustering. Biologically plausible interactions were assessed in the final model(s) where necessary. Multicollinearity was assessed using the variance inflation factor (VIF). Where the VIF was below 5, the factor remained in the model (Belseley, Kuh and Welsch, 1980).

4.8.4 Inter-rater reliability

To consider the impact of subjective bias, the IRR of the veterinary gait assessment and back examination was assessed (Chapters 7 and 8).

It is acknowledged that experience can influence grading between veterinary surgeons, therefore in order to assess the validity of the results of the veterinarians, IRR was assessed using a calculation of Fleiss's Kappa (k) for limb(s) identified as lame, the grade of lameness and the grade of thoracolumbar palpation (Merrifield-Jones, Tabor and Williams, 2019; Keegan *et al.*, 2010).

$$Kappa\ (k)=P-P_e/\ 1-P_e$$

Where P= total agreement, including chance agreement and P_e = expected chance agreement (Keegan *et al.*, 2010).

Interpretation of strength of agreement based on the co-efficient was considered good at >0.60 and very good at >0.80 (Mukaka, M., 2012). Previous studies looking at subjective analysis of lameness have reported poor IRR (Hammarberg *et al.*, 2016; Starke *et al.*, 2013; Keegan *et al.*, 2010; Keegan, 2007; Fuller *et al.*, 2006). However, some of these studies have used video analysis, rather than real time viewing, as was the case in study 2b (Chapter 7), which may be influential (Hammarberg *et al.*, 2016; Starke *et al.*, 2013). Additionally, some studies adopted a repeated-measures approach, where the impact of ordering may have been a limiting factor (Hicks, 2004). The impact of these factors was minimised in study 2b (Chapter 7) as the veterinarians all voted on the trot up at the same time, however the initial veterinarian may have had a biased opinion, having questioned the initial trot up (Hicks, 2004).

The impact of bias of the subjective analysis of lameness cannot be ruled out, however it was the most cost-effective approach in terms of time and finance during competition, and is in line with the current procedure within the sport offering ecological validity to the results (Schmuckler, 2001). By establishing the IRR of the veterinarians, a conclusion can be drawn surrounding the validity of this method during veterinary procedures. Additionally, it should be noted that the veterinary assessment during competition is not a diagnostic procedure but an assessment to limit the impact of lameness identified during competition in order to protect the welfare of the horse.

Currently, within the veterinary inspection of an endurance competition, the horse has their musculature, specifically the thoracolumbar epaxials palpated and are either given 'a tick in a box' during a GER or graded on an alphabetical scale of A-D (A being good, see Appendix 1) during a CER. However, there is no standardisation for what each letter or indeed 'tick' indicates. If the palpation of the epaxial musculature is to be used as an outcome measure for back pain and for the overall veterinary inspection for the welfare of the horse during competition, it must be considered a valid measurement. In order for outcome measures to be valid, they must be reliable and repeatable (Tabor and Williams, 2018; Lachin, 2004). As the current system for palpation within endurance competitions lacked standardisation, it was not considered a measurement that could offer IRR and therefore an alternative scale was used (Table 15). This scale had previously been identified as having excellent IRR amongst Association of Chartered Physiotherapists in Animal Therapy (ACPAT) physiotherapists (Merrifield-Jones, Tabor and Williams, 2019). However, the scale had not been tested for IRR with veterinary surgeons and no scale had been tested within a competition setting. In order to identify if this scale could be used to determine whether back pain was an additional risk factor for lameness eliminations, within competition, the first step was to conduct a reliability study (Study 3a, Chapter 8).

This reliability study was conducted within a competition setting for ecological validity (Schmuckler, 2001). As the scale had not yet been tested within competition, so as not to impact on competitive performance results, the study was conducted on horses partaking in a pleasure ride at an EGB organised event. The impact of order effects could not be ruled out in this instance as the IRR was assessed between a veterinary student and qualified veterinary surgeons. It was only possible to compare the veterinary student with each of the veterinary surgeons but not between each of the veterinary surgeons. This was due to the time taken within competition, for both veterinary surgeons and the veterinary student to palpate each horse would have had too much of an impact on competition timing, which could have had an impact on results of other horses competing. As the study was conducted within competition, it was important from both a regulatory and risk factor aspect that the qualified veterinary surgeon(s) palpated the horse(s) first in each case.

In both the assessment of lameness and back palpation, the veterinary surgeons and the veterinary student were blinded from each other’s results. Blinding the veterinarians to each other’s results is standard practice to avoid assessor bias (Merrifield-Jones, Tabor and Williams, 2019; Karanicolas, Farrokhyar and Bhandari, 2010; Hicks, 2004). Once the decision had been given to the rider, the voting slips were handed directly to the researcher for analysis. Whilst this had a possibility to introduce bias as the researcher was present and observing the veterinary examinations, the analysis was not completed until away from the competition venue and the only identifier on the voting slips was a number. The rationale for taking the voting slips immediately was for data protection purposes, to ensure the researcher had control of the data.

The results of each of the studies provide meaningful results which have allowed recommendations for the sport to be developed and are summarised at the end of the thesis (Chapter 10). Each study has limitations, discussed within their specific chapter, but efforts have been made to minimise these at each stage.

Chapter 5

5.0 Study 1: Risk factors for lameness elimination in British Endurance riding (Bloom *et al.,* 2022b)

(Published version see Appendix 4)

5.1 A summary

A retrospective cohort study was completed using data provided by EGB for all horses competing in rides of 64km and above in the competitive seasons of 2017-2018. The rationale for choosing horses competing in rides of 64km and above was to include those at open level (see Appendix 1 for details on levels) and above, demonstrating some previous experience of the sport. The aim of this study was to fulfil the first objective of the thesis by identifying risk factors associated with elimination and specifically lameness eliminations of horses registered with EGB, with some previous experience within the sport, competing distances of 64km and above, from information recorded and identify gaps within the data.

5.2 Methods:

5.2.1 Participants (Horse starts)

A total of 1747 single day ride entries were recorded, representing 512 unique horses and 385 unique riders, all were appropriate for inclusion.

5.2.2 Risk factors

Previous literature findings and anecdotal experience within EGB competitions were used to identify potential risk factors (Appendix 4) to be considered at horse, rider and ride-level that were included in the initial stage of modelling (Bennet and Parkin, 2018a, 2018b; Younes *et al.*, 2016; Fielding *et al.*, 2011; Nagy, Murray and Dyson, 2010). All continuous variables were assessed firstly in continuous form before converting to categorical or binary. Various models were tested with those in the final results displaying the best model fit.

5.2.3 Data analysis

A series of Spearman's rank correlations ($p<0.05$) examined the relationship between the number of times a horse had been eliminated in their entire career and the following variables: age of horse, career length (years), number of rides attempted, number of rides completed, distance attempted, and distance completed. A separate series of correlations examined the relationship between the same variables and the number of times a horse had been eliminated due to lameness in the entire career.

5.2.4 Univariable and multivariable analysis

Univariable modelling informed the multivariable analysis as described in section 4.8.3. Two deleterious outcomes were considered: A) Eliminated (any reason) and B) Eliminated due to lameness.

5.2.5 ROC Analysis

Further analysis was completed using the receiver operating curve analysis to consider the predictability of lameness when considering the percentage of rides the horse completed within its career, the percentage of kilometres the horse completed within its career, the percentage of rides the horse completed in the 2017-2018 competitive season and the percentage of kilometres completed in the 2017-2018 competitive season.

5.3 Results:

5.3.1 Descriptive Statistics

Throughout the study, the unit of observation was a ‘horse start’. Of the 1747 competitive horse starts, 91.5% were ridden by female riders (n = 1598) and the majority of horse starts, (n = 1625; 93.0%) were ridden by riders in the senior age (over 21 years old) category. EGB do not report on riders exact age, but record whether they are a senior, young or junior rider. Mean horse age was 13.9±3.3 years. Most of the entrants to the rides (n = 1571; 89.9%) had ridden as a horse and rider combination previously within the 2017-2018 competitive season.

However, within the set of data recorded there were some horses and riders with single starts and some with multiple starts. The data set of 1747 single day ride entries consisted of 512 unique horses and 385 unique riders. Of the 512 horses 26.4% (n=135) started only one single ride of 64km and above within the time frame studied. Within this group of horses, 54.1% (n=73) of horses completed and passed the ride, the remaining 45.9% (n=62) were eliminated. These eliminations consisted of 56.5% lame (n=35), 24.2% were retired on course by the rider (n=15), 11.3% were eliminated for metabolic compromise (n=7) and 8.1% for other or undisclosed reasons (n=5).

The remaining 73.6% (n=377) horses had multiple starts of over 64km and above within the study time frame. The mean number of starts for the horses included in the data set were 3.4 +/- 2.4 SD. Within this group of horses, the number of eliminations ranged from

0-6 (Mean 1.1 S.D. +/- 1.1), 28.4% (n=107) successfully passed all of the rides of 64km and above within the time frame studied, 36.1% (n=136) had one elimination and 35.5% had more than one elimination (n=134). Within the group of horses that had multiple starts, 53.6% had no lameness eliminations (n=202), 28.4% (n=107) had a single lameness elimination and 18.0% (n=68) had more than one lameness elimination recorded in the data set studied. The maximum number of lameness eliminations recorded for a single horse in the study period, in rides of 64km and above was 5, two horses recorded this number of eliminations. Fifty-one horses had two lameness eliminations, ten horses had three lameness eliminations and five horses had four lameness eliminations recorded. The 385 unique riders consisted of 23.1% (n=89) unique starts 89.9% (n=80) of which were female riders and 10.1% (n=9) of which were male. The remaining 76.9% (n=296) riders recorded multiple starts within the data set, 93.6% (n=277) were female riders and the remaining 6.4% (n=19) were male riders.

Table 5 demonstrates the significant correlations between the number of times a horse was eliminated in its career and the variables recorded in the data set, table 6 demonstrates the significant correlation between the number of times a horse was eliminated due to lameness within its career and the variables recorded in the data set.

Table 5: Correlations between historic competition factors and the total number of eliminations within horse career (study 1)
A series of Spearman's rank correlations to identify associations between historic competition factors and the number of eliminations within a horses career. Data taken from Endurance GB database.

Correlation Variables	Spearman's Rank
Km horse attempted in career	R=0.73 N=1747 p<0.001
Rides attempted in career	R=0.67 N=1747 p<0.001
Km horse completed in career	R=0.62 N=1471 p<0.001
Number of years horse competing	R=0.64 N=1471 p<0.001
Number of rides completed in horse career	R=0.57 N=1471 p<0.001
Age of horse	R=0.47 N=1471 p<0.001

Table 6: Correlations between historic competition factors and total number of lameness eliminations within horse career (study 1)

A series of Spearman's rank correlations to identify associations between historic competition factors and the number of lameness eliminations within a horses career. Data taken from Endurance GB database.

Correlation Variables	Spearman's Rank
Km horse attempted in career	R=0.72 N=1747 p<0.001
Rides attempted in career	R=0.66 N=1747 p<0.001
Number of years horse competing	R=0.63 N=1471 p<0.001
Km horse completed in career	R=0.62 N=1471 p<0.001
Number of rides completed in horse career	R=0.57 N=1471 p<0.001

Across the sample, 69% (n = 1205) of horse and rider combinations successfully completed the competitions they entered. The remaining 31% (n=542) were eliminated. The most common reason for elimination was lameness (n=304). The reasons for elimination are shown in Figure 7.

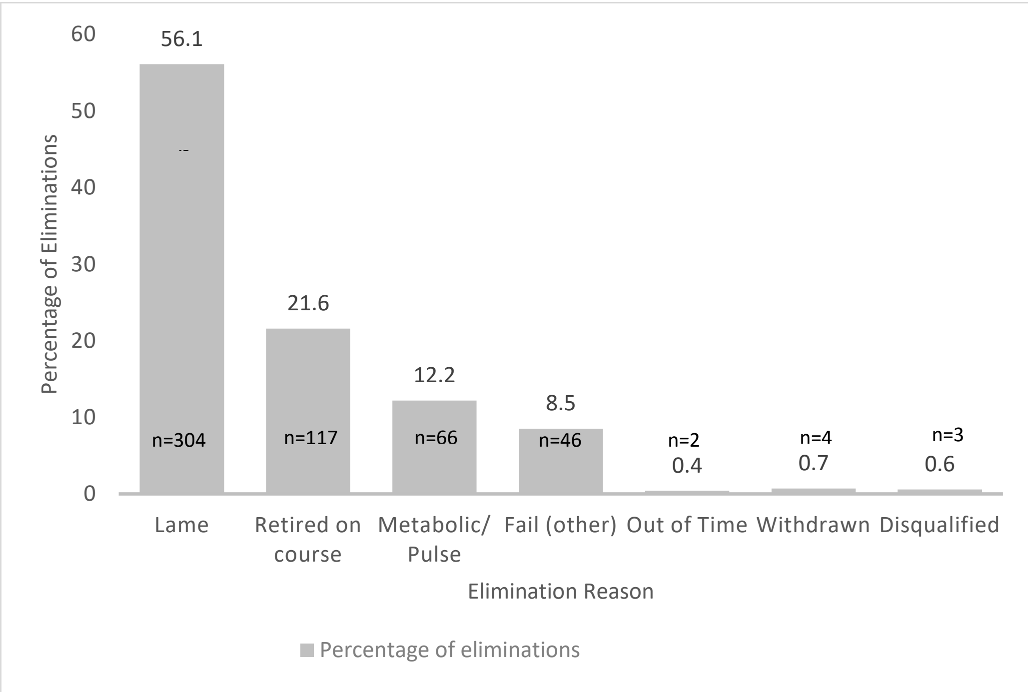

Figure 7: The reasons horses registered with Endurance GB were eliminated from competitions during the 2017-2018 competitive seasons.

Displayed as percentages of eliminated horses. Data from Endurance GB's database.

5.3.2 Model A: Elimination outcomes

Forty-two variables from the univariable analysis were significant at p≤0.1 and were taken forward to multivariable analysis, additionally all previous distance attempted and completed, and number of starts and completions were included as biologically plausible factors. Five variables were significantly associated (p<0.05) with an elimination outcome (Table 6). Seven variables remained in the final model multivariable model with five demonstrating they were significantly associated with an elimination outcome (Table 7), the remaining two variables improved the model fit. Horse and rider combinations who had not competed together previously were at increased odds of elimination, compared with combinations who had competed together previously (Adjusted Odds Ratio, OR 2.2, 95% confidence interval, CI: 1.5-3.02). Compared with rides which were run under EGB rules, those competing in FEI 1* competitions had increased odds of an elimination outcome (OR 1.7, CI 1.3-.2.3) and those in FEI 2* and above had increased odds of elimination compared to those competing under EGB rules (OR 4.7, CI: 3.5-6.5). Horses that had two competitive starts within the previous 60 days were at increased odds of elimination compared to those who had not competed in the last 60 days (OR 1.8 CI: 1.3-2.5). Previous elimination results impacted on the odds of an elimination outcome, with horses having more than one elimination within the last 365 days having increased odds (OR 2.2, CI: 1.3-3.7) compared with horses who had no elimination results in the previous 365 days. Two variables (eliminated in the last 60 days and eliminated in the last 365 days) were not significant at p<0.05 alone but their inclusion improved the overall fit of the model, with an improved ROC (0.68). When these two factors were not included in the model, the ROC was 0.62.

The final model was checked for biologically-plausible interactions. There were no statistically significant, biologically plausible interactions when considering the interaction between the distance attempted within the last 365 days, with the number of rides completed in the last 60 days, the number of eliminations in the last 90 days, the number of eliminations in 365 days and the number of lameness eliminations in the last 365 days.

Collinearity was also assessed and identified between the distance attempted in the previous 365 days and the number of lameness eliminations in the previous 365 days. Whilst collinearity existed, it was weak, with the Variance Inflation Factor (VIF) below 5 (1.3 and 3.8 respectively) and the condition index was well below 30 (6.8), however they reached variance proportions of 0.5 (0.50 and 0.64 respectively). Both factors were retained within the model as the collinearity was weak, as per the guidance documented by Belseley, Kuh and Welsch (1980). Collinearity was also identified between the number of times a horse was eliminated (any reason) in the previous 365 days and the number of lameness eliminations with in the last 365 days. However, the VIF was again below 5 (4.3 and 3.8 respectively) and the condition index was again below 30 (5.4). The collinearity is an inherent limitation of these real-world data. This is recognised as a limitation, but the results remain useful in improving equine welfare despite these limitations.

In testing the impact of an individual horse and individual rider as a random effect, the proportion of variance (p) associated with individual horses was p=0.35 and the proportion of variance associated with individual riders was p=0.12 this would indicate that individual horses and riders had no impact on overall variance in the model.

Table 7: Model A: Results of the multivariable model for all horse starts for any elimination outcome

Risk factors associated with elimination for horses registered with Endurance GB, competing in rides of >64km during the 2017-2018 competitive seasons. Data from Endurance GB's database.

Risk Factor	Cases: Eliminated n (%)	Controls: Pass n (%)	Adjusted OR	95% CI	P value
Returning Combination					
Yes	467 (29.7)	1104(70.3)	Reference	-	<0.001
No	75 (42.6)	101 (57.4)	2.15	1.53-3.02	<0.001
FEI Level					
Not FEI	294 (24.7)	898 (75.3)	Reference	-	<0.001
1*	116 (35.4)	212 (64.6)	1.71	1.31-2.25	<0.001
2 *+	132 (58.1)	95 (41.9)	4.74	3.48-6.46	<0.001
Distance attempted in 365 days					
0-100km	47 (29.7)	111 (70.3)	Reference	-	0.05
101-200km	121(31.2)	267 (68.8)	1.12	0.73-1.72	0.6
201-300km	150 (32.7)	309 (67.3)	1.11	0.73-1.71	0.6
301-400km	117 (30.3)	269 (69.7)	0.88	0.56-1.38	0.6
401-500km	69 (27.6)	181 (72.4)	0.63	0.38-1.04	0.07
>500km	38 (35.8)	68 (64.2)	0.75	0.40-1.38	0.4
Number of starts in 60 days					
0	121 (27.9)	313 (72.1)	Reference		0.002
1	253 (30.9)	567 (69.1)	1.15	0.87-1.52	0.3
2	139 (37.7)	230 (62.3)	1.78	1.28-2.47	0.001
3+	29(23.4)	95 (73.4)	1.01	0.61-1.67	>0.9
Eliminated last 60 days					
No	466 (29.5)	1114(70.5)	Reference	-	-
Yes	76 (45.5)	91 (54.5)	1.33	0.90-1.96	0.2
Eliminated last 365 days					
0	282 (27.0)	764 (73.0)	Reference	-	0.02
1	175 (33.0)	355 (67.0)	1.31	0.88-1.92	0.2
2+	85 (44.5)	106 (55.5)	2.15	1.25-3.68	0.005
Eliminated lame last 365 days					
No	340 (28.0)	876 (72.0)	Reference	-	-
Yes	202 (38.0)	329(62.0)	1.03	0.70-1.52	0.9

OR, adjusted odds ratio, 95% CI, 95 % confidence interval. Model fit was good: Omnibus p<0.001, Hosmer-Lemeshow p=0.43. ROC =0.68

FEI, Fédération Equestre Internationale.

5.3.3 Model B: Failure to qualify due to lameness outcomes

Forty variables related to horse starts were significantly associated with an elimination due to lameness outcome at univariable level at $p \leq 0.1$, all variables relating to distance attempted and completed and the number of rides started and completed were included in the model as biologically plausible, regardless of whether they met the significance level. Nine variables remained in the final multivariable model with four being significantly associated ($p < 0.05$) with a lameness outcome, the remaining five remained as they improved the model fit (Table 8). Riders and horses who had not competed as a combination before were at a higher likelihood (OR 2.3, CI: 1.5-3.4) of being eliminated with a lameness outcome than those who had competed together. Rides categorised as GER were associated with reduced odds of lameness compared to CER rides (OR -0.6, CI: 0.4-0.8). Horses competing at FEI 2* and above had an increased likelihood of lameness (OR 1.9, CI: 1.2-3.06) when compared to horses competing under EGB rules.

The final model was tested for biologically-plausible interactions. When distance attempted within the last 30 days interaction was tested with starts in the last 60 days, starts in the last 90 days, completed last 180 days and lameness eliminations within the last 365 days, there were no statistically significant biologically-plausible interactions.

Within this model, collinearity was found between the number of starts in 60 days and the number of starts in 90 days. Whilst collinearity existed the VIF was below 5 (3.9 and 4.8 respectively), the condition index was below 30 (9.9), however they reached the variance proportions of 0.5 (0.6 and 0.9 respectively). As collinearity was weak, the factors were retained within the model, acknowledging that as these again are real word data, collinearity is often inherent, but results can still be meaningful (Belseley, Kuh and Welsch, 1980).

In testing the impact of an individual horse and individual rider as a random effect, the proportion of variance (p) associated with individual horses was p=0.42 and the proportion of variance associated with individual riders was p=0.09 this would indicate that individual horses and riders had no impact on overall variance in the model.

of variance associated with individual riders was p=0.09 this would indicate that individual horses and riders had no impact on overall variance in the model.

Significant associations were found between the outcome of elimination due to lameness and previous lameness eliminations, with horses being 0.5 times less likely to be eliminated lame if their previous lameness was 91-365 days ago, compared with horses that had a lameness elimination within the last 45 days. There was a decreased likelihood of a lameness elimination outcome (OR 0.4, CI: 0.3-0.8) when the horses previous lameness was over a year ago and a decreased likelihood of a lameness elimination if the horse had never been eliminated for lameness (OR 0.3, CI 0.2-0.6) when compared with horses who had a lameness elimination in the past 45 days.

Table 8: Model B: Results of the multivariable model for all horse starts for the elimination due to lameness outcome
Risk factors associated with lameness eliminations for horses registered with Endurance GB, competing in rides of >64km during the 2017-2018 competitive seasons. Data from Endurance GB's database.

Risk Factor	Cases: Lame n-per category (%)	Controls: Not Lame n-per category (%)	Adjusted OR	95% CI	P value
Returning Combination					
Yes	261 (16.6)	1310 (83.4)	Reference	-	<0.001
No	43 (24.4)	133 (75.6)	2.26	1.52-3.37	<0.001
Class Code					
CER	189 (25.3)	559 (74.7)	Reference	-	<0.001
GER	115 (11.5)	884 (88.5)	-0.54	0.35-0.81	0.003
FEI Level					
Not FEI	153 (12.8)	1039 (87.2)	Reference	-	0.02
1star	77 (23.5)	251 (76.5)	1.21	0.76-1.91	0.4
2 stars+	74 (32.6)	153 (67.4)	1.90	1.18-3.06	0.008
Distance attempted last 30 days (km)					
0	167 (16.9)	824 (83.1)	Reference	-	0.6
1-55	54 (15.4)	296 (84.6)	0.93	0.62-1.38	0.7
56-79	31 (17.7)	144 (82.3)	1.12	0.69-1.84	0.6
80-100	41 (22.4)	142 (77.6)	1.23	0.78-1.92	0.4
>100	11 (22.9)	37 (77.1)	1.71	0.76-3.87	0.2
Distance change from previous ride					
Distance decrease	39 (13.3)	254 (86.7)	Reference	-	0.2
Equal distance	60 (22.7)	204 (77.3)	1.56	0.98-2.50	0.1
Increase ≤ 55km	205 (17.2)	985 (82.8)	1.22	0.80-1.88	0.4
Rides completed previous 180 days					
0	33 (13.3)	216 (86.7)	Reference	-	0.4
1	83 (17.4)	395 (82.6)	1.00	0.55-1.81	>0.9
2	83 (19.2)	349 (80.8)	1.25	0.66-2.37	0.5
3+	105 (17.9)	483 (82.1)	1.44	0.73-2.81	0.3
Starts last 60 days	83 (17.4)	395 (82.6)			
0	83 (19.2)	349 (80.8)	Reference	-	0.04
1	105 (17.9)	483 (82.1)	1.05	0.64-1.71	0.9
2	79 (19.9)	290 (73.2)	1.61	0.83-3.15	0.2
3+	16 (12.9)	108 (87.1)	0.74	0.29-1.89	0.5
Starts last 90 days					
0	31 (10.8)	256 (89.2)	Reference	-	0.03
1	114 (19.6)	468 (80.4)	1.64	0.81-3.30	0.2
2	92 (17.2)	442 (82.8)	0.92	0.40-2.14	0.9
3	116 (28.1)	297 (71.9)	1.03	0.39-2.72	>0.9
Days since previous Lameness					
Within 45 days	25 (34.2)	48 (65.8)	Reference	-	<0.001
46-90	31 (34.1)	60 (65.9)	1.15	0.57-2.30	0.7
91-365	70 (19.4)	291 (80.6)	-0.51	0.28-0.92	0.03
>365	109 (16.4)	554 (83.6)	-0.44	0.25-0.78	0.005
No previous lameness	69 (12.5)	484 (87.5)	-0.33	0.18-0.59	<0.001

OR, adjusted odds ratio, 95% CI, 95% confidence interval. Model fit was good: Omnibus p<0.001 Hosmer-Lemeshow p=0.24. ROC=0.72 GER, graded endurance ride (capped speed), CER, competitive endurance ride (no capped speed) FEI, Fédération Equestre Internationale

5.3.4 ROC Predictive Analysis

Using a 95 % sensitivity cut off value, horses that had <70% ride to lameness elimination completion ratios will be more likely to be eliminated due to lameness (Area under the curve 0.77, p<0.001, 95% C.I 0.73-0.81, Sensitivity 0.95, 1-Specificity 0.83).

Considering the percentage of kilometres, the horse had completed within its career, using a 95% sensitivity cut off value, horses that had completed < 61.5% were more likely to be eliminated for lameness (Area under the curve 0.77, p,0.001, 95% C.I. 0.74-0.81, Sensitivity 0.95, 1- Specificity 0.82).

Within the 2-year study period of 2017-2018, horses that completed <49% of the rides they started were more likely to be lame (Area under the curve 0.81, p<0.001, 95% C.I. 0.77-0.85, Sensitivity 0.95, 1-Specificity 0.85). Within the data studied, 48 horses fell into this category. The average number of rides they attempted was 6±4.

Horses that completed <33% of the distance they attempted were more likely to be eliminated lame (Area under the curve 0.82, p<0.001, 95% C.I. 0.78-0.85, Sensitivity 0.95, 1-Specificity 0.90). When calculating the average kilometres completed in horses who achieved <33% completion rate the cut-off point was 294±227km.

5.4 Impact and Implications of Study 1

The findings of this initial study suggest that multiple, repetitive non-completions in horse and rider combinations should be considered a ‘red flag’ for welfare and management of endurance horses. Additionally, the results suggest that the cumulative total of the number of rides and total distances completed represent a significant equine welfare and performance issues. Horses competing in rides of 64km and above were more successful when fewer rides were attempted, with increased lameness related eliminations occurring in the once horses attempted 6±4 rides. This supports the need for rest periods, which under current EGB rules, do not echo the additional days added for consecutive lameness events within FEI (EGB, 2022c; FEI, 2022b). It also suggests the number of rides entered should perhaps be capped. This occurs in the horse's novice season, where the number of rides the horse may start is ten, it would seem from the results that ten should be an absolute maximum to attempt throughout each competitive season.

The Global Endurance Injuries Study clearly demonstrated that horses which returned to competition earlier following a lameness elimination, were more likely to be eliminated for lameness in their subsequent competition (Bennet and Parkin, 2018a). The benefits to horse welfare of increasing the MOOCP was clearly indicated at international level (Bennet and Parkin, 2020). Under current EGB rules standard MOOCP echo that of the FEI, except in the event of lameness/ metabolic elimination (EGB, 2022c; FEI, 2022b). Under FEI rules, if a horse has three consecutive lameness eliminations within a rolling year, they must have the standard compulsory rest period (dependent on the distance completed) plus 180 days and undergo a specific veterinary examination before being able to compete at national or FEI level (FEI, 2022b). In EGB rules, FEI registered horses follow FEI rest periods regardless of whether they are in a national or FEI event (EGB, 2022c). Non-FEI horses follow EGB rules, which adds 8 days to the rest period if vetted out lame, but no additional days are added if there are consecutive lameness episodes (EGB, 2022c; FEI, 2022b). The results of this study indicate that the MOOCP should be re-visited by EGB.

Prior to the completion of this study, anecdotally, there was a perception that lameness eliminations were not as problematic in British Endurance as they were at international level. Education of riders and trainers surrounding this is key to improving realisation and understanding that the issue of lameness is present in British Endurance and not just on an international level. Research acknowledges that educating riders has challenges, but fundamentally is imperative for the welfare of the horse, as outside of the day of competition it is the rider/ owner/ trainer that is in charge of the horses welfare (Williams and Marlin, 2020; McLean and McGreevy, 2010). This first study, demonstrates that the risk factors surrounding lameness are not solely related to the day of the ride, but indeed encompass historic competitive history, which is in agreement with studies at FEI level. (Bloom *et al.*, 2022b; Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2020). This indicates that riders need to understand these risks to be able to manage the welfare of the horse outside of the day of competition, to reduce the risks of subsequent lameness eliminations. It does not however, suggest that riders do not consider their horses welfare a priority because evidence in British endurance did not previously exist and therefore the ability to use evidence-informed strategies to minimise risk pre, peri and post competition are lacking. This first study provides an initial step towards developing at least the first step of risk awareness in British Endurance.

Historic lameness eliminations were found to be of significance to the ride outcome, suggesting more chronic issues are likely to be impacting the horses competing. Consideration should be given to the appropriate return to competition following a lameness elimination. To repeatedly be eliminated lame from competition, highlights a welfare issue, which should be investigated to minimise the possibility of long term, musculoskeletal damage. Additionally, as CER’s were found to be of higher risk than GER’s, when riders are upgrading or starting CER’s from a background of GER’s, improved education surrounding the change of demands of the horse and awareness of the management of the horse pre, peri and post competition should be considered.

These results were presented to the Chair of the Welfare Committee of EGB and subsequently a presentation of the results to riders within the sport was approved. This was completed in February 2021. Feedback was positive and EGB requested that the presentation remained available online for future viewing. This demonstrated that EGB is committed to horse welfare and the SLO of the sport by demonstrating key components of SLO including transparency and communication, taking proactive steps to assist in rider education (Douglas, Owers and Campbell, 2022; Williams and Marlin, 2020).

Whilst the findings identify several key risk factors which impact on lameness information, it also demonstrated gaps within the current data which may give further information relating to lameness eliminations. Several studies, specifically within endurance have demonstrated that speed is a risk factor for lameness eliminations, yet the speed at which the horses are competing at when they are eliminated from EGB competitions is not recorded (Bennet and Parkin, 2018b; Marlin and Williams, 2018b, 2018a; Younes *et al.*, 2016). The point or stage of elimination (i.e. after one loop, or further into the competition) is also not documented in EGB data. This would assist in establishing whether ride pacing strategies may be a contributing risk factor, as has been found at international level (Marlin and Williams, 2018b, 2018a; Adamu *et al.*, 2014).

The specific limb(s) which are most frequently identified as lame and the severity of lameness occurring within competition were not able to be identified within the EGB retrospective data. This has not been identified at international level as the veterinary examinations are not for diagnostic purposes, nor is their time to undertake diagnostic examinations within the competition setting. However, with lameness representing clinical presentation and not a diagnosis, it was felt that this information would assist in providing greater details surrounding lameness limitations, which in turn, may give information as to preventative and management strategies. The second study completed sought to identify this information. The first stage of this was to descriptively identify the prevalence of forelimb and hindlimb lameness within British endurance competitions and record data that were absent in the retrospective analysis of the first study in order to establish if additional risk factors were impactful on lameness eliminations.

Chapter 6

6.0 Study 2a: A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019 (Bloom *et al.*, 2022a)

(Published version see Appendix 5)

6.1 A summary

The first study (Bloom *et al.*, 2022b) confirmed that risk factors for eliminations and specifically lameness eliminations exist at British national level. However, it identified that the retrospective data set did not contain all the details required for the risk factors that may occur within the competition itself. Therefore, the purpose of the next stage of the thesis was to conduct a prospective study to capture the missing data.

Within EGB endurance competitions while records are kept for horses that have been eliminated for lameness, details surrounding the lameness are not specified/recorded. Ordinarily, outside of competition, when a veterinarian is examining a horse for lameness, a series of diagnostic tests, such as nerve blocks and/or appropriate imagery may be performed to identify the source of the lameness (AAEP, 2019). Whilst it is recognised that the veterinary examinations during competition are not diagnostic, and lameness is often multifactorial, further information could be gathered. Additionally, the current options for veterinary eliminations are usually for 'lameness' or 'metabolic' despite the case that some metabolically compromised horses also present lame and vice versa. A greater depth of information surrounding lameness at the point of elimination was required, such as which limb(s) are most commonly affected, the severity of lameness' and whether this changes dependent on the competition level and distance. This would facilitate a more accurate evaluation of risk factors which would potentially allow more in-depth awareness and enable preventative strategies to be considered and implemented.

Therefore, this study aimed to consider lameness eliminations in more detail than previously studied, by identifying the most commonly affected limb(s), understanding the severity of lameness presented, and if changes found were dependent on the stage or level of competition. Subsequent relationships between risk factors and lameness across national level British endurance are reported in the following chapter.

6.2 Methods:

6.2.1 Participants (Horse starts)

Following agreement from EGB, seven national rides were attended between June-October 2019, totalling thirteen days of competition. Throughout the study the unit of observation was a 'horse start' i.e. an entry made to the competition where the horse was presented to the veterinary inspection at the start of the ride. Prior to each ride, an information sheet was sent via email to the ride organisers, technical stewards, ground jury and attending veterinarians detailing the study and the data that would be requested. Horses competing across all distances in rides run under EGB rules, with full veterinary examinations were included in the study. A power calculation using Epitools Epidemiological Calculators (Sergeant, ESG, 2018) was completed, using the first study full cohort as the sample size estimation. With a significance criterion of α=0.05 and a power of 0.80, the minimum sample size was determined as n=370. The researcher attended the rides known to have higher entries to gain power by numbers and the final sample of n=765 was obtained.

6.2.2 Measures

At the rides attended, information collected by EGB as standard was obtained by taking copies of the official results, including, the start and finish time for each loop and the duration of the ride, time taken to present to the veterinarian (multi-loop rides only) and the official heart rate of the horse at the veterinary inspections during the ride and at the finish. In addition, the subjective steepness of the ride, based on the route description documented on the ride entry schedule (e.g. serious hills or flat forest tracks) and trot up surface were documented by the researcher. The air temperature and relative humidity were recorded using a calibrated digital temperature and humidity meter (Peak-Meter PM6508).

During the veterinary inspection, at each of the rides attended, if a horse was asked to re-trot within any of the veterinary inspections throughout the ride, each member of the veterinary panel (VP) watching the horse trot was asked to note whether they believed the horse to be lame/not lame. If they considered the horse to be lame, they were then asked to identify which limb(s) they considered the horse to be lame on, and to assess the severity of lameness using the AAEP 6-point scale (Table 1). It is acknowledged that the AAEP lameness examination involves more than a straight-line trot up, which is the only requirement during an endurance veterinary examination, however the AAEP scale was selected due to the clearly defined categories, with the intention of reducing subjectivity and increasing repeatability between veterinarians where possible. It was anticipated that horses that were considered lame would score 3-5 on the AAEP scale, as these are visible during a straight-line trot-up.

Voting slips were handed to the ground-jury member to give the decision to the rider as to whether the horse had passed or failed the veterinary inspection. The ground jury then handed the slips to the researcher to analyse. No external intervention was required or placed upon participants and all data were anonymised. The only addition to the standard vetting procedure was the notation of limb(s) and grade; there were no changes to the physical veterinary examination.

Horse demographics such as age, sex and breed were collected and historic information for each horse taking part was downloaded from the Endurance GB website.

6.2.3 Data Analysis

A series of Spearman's rank correlations ($p<0.05$) examined the relationship between the number of times a horse had been eliminated in their entire career and the following variables: age of horse, career length (years), number of rides attempted, number of rides completed, distance attempted, and distance completed. A separate series of correlations examined the relationship between the same variables and the number of times a horse had been eliminated due to lameness in the entire career.

6.3 Results:

Competitive results from 765 entries were collected and evaluated. Of the 765 entries, there were 494 unique horses, 61.5% of these horses (n=304) appeared in the dataset once, the remaining 38.5% of horses (n=190) had more than one result recorded. The number of starts for horses with multiple entries in the dataset ranged from 2-6 (Mean 2.0 S.D. +/- 1.0). Within the group of horses with more than one start, 12.1% (n=21) had elimination(s) recorded, 7.4% (n=14) had multiple eliminations. Five horses recorded two lameness eliminations. No horses recorded more than two eliminations for any reason. The 765 entries consisted of 461 unique riders, 58.4% (n=269) of which were recorded once within the dataset, the remaining 41.6% (n=192) had more than one result recorded. Within the group of riders with more than one result recorded, 76.0% (n=146) had multiple results with just one horse, the remaining 24.0% (n=46) were competing on more than one horse. When more than one result was recorded for a rider, the mean number of starts was 2.6 S.D. +/- 0.9 (range 2-6). Fifteen riders recorded two eliminations, eight of these were recorded by riders riding more than one horse, one rider (with two horses) recorded three eliminations and one rider (with two horses) recorded four eliminations. Seven riders recorded two lameness eliminations. There were no riders that recorded more than two lameness eliminations.

Results were obtained from rides ranging from a single loop ride (22-48km), to six loop rides over two or three days, with a maximum distance of 174km. Only one ride had the veterinary inspection on hard ground (concrete), whilst the other six were on grass. One ride was considered ‘steep’, with the ride information detailing ‘serious hills’, the other rides were considered to have ‘minimal climbs’. Temperature ranged from 8.4-29.8°Celcius. Relative humidity ranged from 39.1% to 100%, with bright sunshine to heavy rain.

The greatest number of entries were in single loop rides (distances 22-48km) n=526 (68.7%). Single loop rides were all categorised as GER with a completion speed of 11.7± 1.9 kmh^{-1}. Two-loop rides (GER’s), 64-80km accounted for 14.1% of entries (n=108) with a completion speed of 12.5± 1.6 kmh^{-1}. Rides of three loops and above, which ranged from 80-174km accounted for 17.1% of entries (n=131), within these rides 64.1% (n=84) were categorised as CER with a completion speed of 12.5± 2.9 $kmh^{-1}$and the remaining 35.9% were GER with a completion speed of 12.0± 1.1 kmh^{-1}. Table 9 summarises the completion and elimination data for each loop.

Table 9: Ride entries and results of rides attended in 2019

Data collected from rides attended during the 2019 Endurance GB competitive season.

Number of loops	1	2	3	4	5	6	All rides
Entries (n)	526	108	105	7	2	17	765
Entries %	68.76	14.12	13.72	0.92	0.26	2.22	100
Completions (n)	466	77	65	4	1	11	624
Completions %	88.59	71.30	61.90	57.14	50.00	64.71	81.57
Eliminated(n)	60	31	40	3	1	6	141
Eliminated %	11.41	28.70	38.10	42.86	50.00	35.29	18.43
Lame (n)	33	16	27	2	0	5	83
Lame % of eliminations	55.00	51.61	67.50	66.67	0	83.33	58.87
FL Lame (n)	15	4	12	1	0	1	33
FL Lame % of Lame	45.45	25.00	44.44	50.00	0	20.00	39.76
HL Lame (n)	18	12	15	1	0	4	50
HL Lame % of Lame	54.55	75.00	55.56	50.00	0	80.00	60.24
MET(n)	5	3	2	0	0	0	10
MET % of eliminations	8.33	9.68	5.00	0	0	0	7.09
RET(n)	11	12	8	0	1	1	33
RET % of eliminations	18.33	38.48	20.00	0	100.00	16.67	23.40
Eliminated other (n)	11	0	3	1	0	0	15
Eliminated other % of eliminations	18.33	0	5.00	33.33	0	0	10.64
Eliminated Start (n)	5	4	1	0	0	0	10
Eliminated Start % of eliminations	8.33	12.90	2.50	0	0	0	7.10
Eliminated during ride (n)	4	20	30	2	1	6	63
Eliminated during Ride % of eliminations	6.67	64.52	75.00	66.67	100.00	100.00	44.68
Eliminated End (n)	51	7	9	1	0	0	68
Eliminated End % of eliminations	85.00	22.58	22.50	33.33	0	0	48.23

*Percentages not exact due to rounding. Forelimb (FL), Hindlimb (HL), Metabolic elimination (MET), Retired by rider (RET)

The total number of veterinarians that examined horses across the study was 22, two of these veterinarians examined horses at two different competition venues. Of horses that were eliminated, the highest percentage, 58.9% (n=83) were eliminated for lameness. In single loop rides 55% (n=33) of all eliminations were due to lameness. Lameness eliminations accounted for 51.6% (n=16) in two-loop rides and 68% (n=34) in rides of three loops and above. Hindlimb lameness accounted for 60.2% (n=50) of all lameness eliminations. Figure 8 demonstrates the split between single loop and multi-loop rides. A chi-squared test of independence identified a statistically significant association between the lame limb and the number of loops, $X^2(1)=5.4$, $p=0.02$.

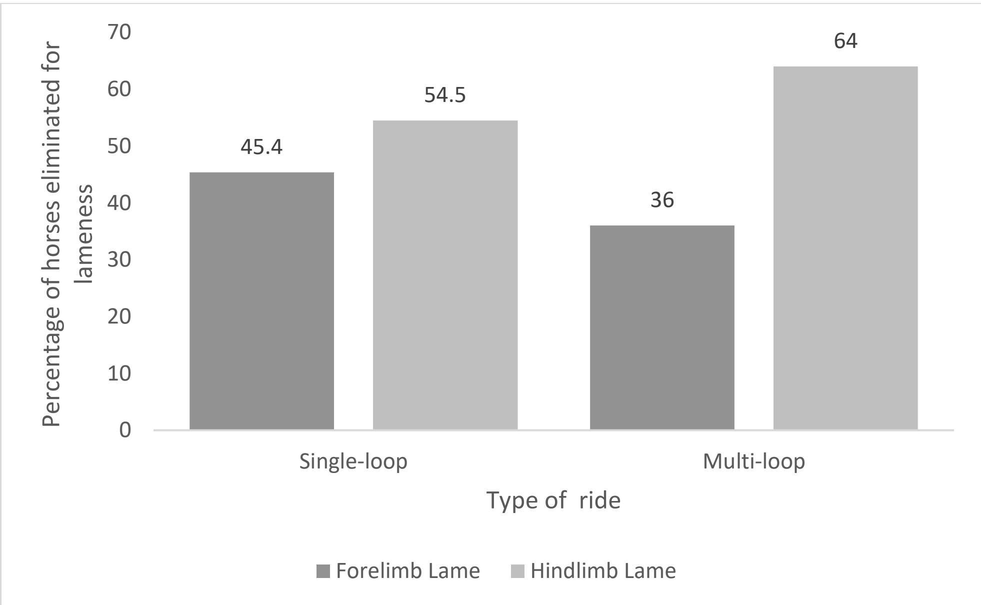

Figure 8: Percentage of lame horses eliminated for forelimb or hindlimb lameness for single and multi-loop rides in 2019

Horses eliminated as lame from competition from single loop rides (up to 55km) and multi-loop rides (>55km) categorised as forelimb or hindlimb lame, determined by the veterinarians at the time of elimination and calculated as a percentage, from data collected at Endurance GB rides in 2019.

Excluding single loop rides, where there is only a veterinary examination at the start and the finish, the majority of horses were eliminated during the ride 72.8% (n = 59). Of those that were eliminated, 21% (n = 17) were at the end of the ride. The remaining 6.2% (n = 5) of eliminations were declared lame at the pre-ride veterinary inspection. No horses were declared lame at the start in rides consisting of four loops and above.

Examining veterinarians agreed on which limb was lame in 100% of cases where two veterinarians observed the re-trot (a re-trot is the second trot up requested if the initial examining veterinarian requests one for a horse that they consider may be lame, or trotted poorly and therefore requires a second trot with a panel of veterinarians). Agreement was only slightly less (83%) when three veterinarians observed the re-trot. The highest grade of lameness was a grade four. This occurred in three cases. One was a forelimb lameness at the penultimate ride of the competitive season, and the other two cases were hindlimb lameness's at the final ride of the season. The median lameness grade was 2±1.

6.3.1 Historic Horse Data:

The competitive history and demographics for the horses competing varied considerably with some horses having competed in lower distances the previous day, and others having not competed for several years. Table 10 shows the background information on the horses competing. A Kruskal-Wallis test was completed to understand the differences in parameters by loop, the p value is displayed in table 10.

Table 10: Historic data for horses competing in 2019

Descriptive data for horses competing in seven Endurance GB rides in the competitive season of 2019

Variable	Single loop Median ±IRQ (Range)	2 loops Median ±IRQ (Range)	3 loops Median ±IRQ (Range)	Kruskal-Wallis P value
Age	11 ±5 (5-29)	12 ±6 (6-24)	11 ±4 (6-24)	p=0.008
Number of years competing	2 ± 5 (0-19)	3 ±4 (0-17)	4 ±5 (1-14)	p<0.001
Days since previous ride	34 ±50 (1-1980)	27 ±22 (6-3314)	34 ±35 (5-757)	p=0.020
Distance of previous ride	40 ±10 (16-160)	44 ±28 (16-144)	80 ±38 (31-143)	p=<0.001
Days since previous elimination	223 ±441 (6-3716)	265.5 ±286.75 (7-2618)	294 ±405 (2-2944)	p<0.001
Days since previous lameness elimination	371.5 ± 711.25 (14-3710)	307 ±558.75 (21-2652)	395 ±612.75 (20-3591)	P<0.001
Eliminations 2019	0 ±1 (0-4)	0 ±1 (0-3)	0 ±1 (0-5)	p=0.010
Eliminations career	1±3 (0-21)	2 ±5 0-21)	3 ±5 (0-18)	p<0.001
Lameness eliminations 2019	0+0 (0-3)	0 ±1 (0-3)	0 ±1 (0-3)	p=0.010
Lameness eliminations career	0 ±1 (0-15)	1 ±3 (0-10)	1 ±3 (0-10)	p<0.001
Rides attempted 2019	3 ±5 (0-15)	4 ±2 (0-12)	4 ±3 (0-11)	p=0.011
Rides completed 2019	3 ±4 (0-14)	3±4 (0-11)	3 ±3 (0-9)	p=0.028
Rides attempted in career	10.5 ±23 (0-200)	29 ±31.75 (3-90)	23 ±30 (2-98)	p=0.11
Rides completed in career	9± 20 (0-180)	29 ±31.75 (3-90)	18 ±28 (1-87)	p<0.001
Km attempted 2019	114 ±195 (0-694)	26 ±25 (3-83)	216 ±238 (0-898)	p<0.001
Km completed 2019	105 ±171 (0-694)	178.5 ± 156.5 (0-822)	189 ±178 (0-698)	p<0.001
Km attempted career	364 ±1057 (0-10924)	1090 ±2029.5 (110-5628)	1357 ±1835 (104-6904)	p<0.001
Km completed career	327.5 ±877 (0-9364)	931 ±1382 (110-5161)	1106 ±1500 (80-5746)	p<0.001

6.3.2 Historic Correlations:

Across all distances, significant positive correlations were found between all historic parameters investigated, and the number of competitive rides horses had previously been eliminated from for all elimination reasons (Table 11) and for lameness eliminations only (Table 12).

Table 11: Correlations between historic competition factors and total number of eliminations within horse career (study 2)

A series of Spearman's rank correlations to identify associations between historic competition factors and number of eliminations within a horse's career. Data taken from Endurance GB database.

Number of Loops	Correlation Variables	Spearman's Rank
All Rides		
	km attempted in career	R=0.797 N=765 p<0.001
	Rides attempted in career	R=0.777 N=765 p<0.001
	Years competing	R=0.744 N=765 p<0.001
	km completed in career	R=0.736 N=765p<0.001
	Rides completed in career	R= 0.717 N=765 p<0.001
	Age	R=0.474 N=765 p<0.001
Single Loop	km attempted in career	R=0.765 N=526 p<0.001
	Rides attempted in career	R=0.753 N=526 p<0.001
	Years competing	R=0.721 N=526 p<0.001
	km completed in career	R=0.709 N=526 p<0.001
	Rides completed in career	R=0.697 N=526 p<0.001
	Age	R=0.456 N=526 p<0.001
2 Loops	km attempted in career	R=0.756 N=108 p<0.001
	Rides attempted in career	R=0.753 N=108 p<0.001
	km completed in career	R=0.673 N=108 p<0.001
	Rides completed in career	R=0.671 N=108 p<0.001
	Years competing	R=0.670 N=108 p<0.001
	Age	R=0.452 N=108 p<0.001
3+ Loops	km attempted in career	R=0.798 N=131 p<0.001
	Rides attempted in career	R=0.781 N=131 p<0.001
	Years competing	R=0.754 N=131 p<0.001
	km completed in career	R=0.707 N=131 p<0.001
	Rides completed in career	R=0.684 N=131 p<0.001
	Age	R=0.601 N=131 p<0.001

Table 12: Correlations between historic competition factors and the total number of lameness eliminations within horse career (study 2)

A series of Spearman's rank correlations to identify associations between historic competition factors and number of lameness eliminations within a horse's career. Data taken from Endurance GB database.

Number of Loops	Correlation Variables	Spearman's Rank
All Rides	km attempted in career	R=0.739 N=765 p<0.001
	Rides attempted in career	R=0.712 N=765 p<0.001
	km completed in career	R=0.686 N=765 p<0.001
	Years competing	R=0.676 N=765 p<0.001
	Rides completed in career	R=0.662 N=765 p<0.001
	Age	R=0.457 N=765 p<0.001
Single Loop Rides	km attempted in career	R=0.691 N=526 p<0.001
	Rides attempted in career	R=0.677 N=526 p<0.001
	km completed in career	R=0.643 N=526 p<0.001
	Rides completed in career	R=0.631 N=526 p<0.001
	Years competing	R=0.631 N=526 p<0.001
	Age	R=0.420 N=526 p<0.001
2 Loop Rides	km attempted in career	R=0.683 N=108 p<0.001
	Rides attempted in career	R=0.652 N=108 p<0.001
	Years competing	R=0.613 N=108 p<0.001
	km completed in career	R=0.611 N=108 p<0.001
	Rides completed in career	R=0.575 N=108 p<0.001
	Age	R=0.397 N=108 p<0.001
3+ Loop Rides	km attempted in career	R=0.787 N=131 p<0.001
	Years competing	R=0.764 N=131 p<0.001
	Rides attempted in career	R=0.755 N=131 p<0.001
	km completed in career	R=0.709 N=131 p<0.001
	Rides completed in career	R=0.688 N=131 p<0.001
	Age	R=0.652 N=131 p<0.001

6.4 Impact and Implications of Study 2a

This study demonstrates that lameness is the most common cause of eliminations from endurance competitions in Britain across all distances. In addition, this study identified a higher frequency of hindlimb lameness, compared to forelimb lameness. The reasons for this should be explored further to allow early intervention and appropriate management and rehabilitation to maximise welfare and performance. Notable differences in eliminations existed between the distances where single loop riders have the highest success. The step-up to two loop rides increases the incidence of MET and RET eliminations, whilst this is not the focus of this thesis, it alludes to more attention required for education and training as competitors increase their distances higher than the single loop rides, which are perhaps more within the physiological norms of the horse. The highest percentage of lameness eliminations occurring in rides of three-loops or more. The incidence of hindlimb lameness also increases from single to multi-loop rides, which may be associated with the increased distance between single loop and multi-loop rides. The reasons for these differences warrant further exploration to develop specific education, training and risk mitigation strategies, appropriate to the level of competition which can improve the welfare and competitive success of the endurance horse.

This second study provided an overall view of the data recorded at the time of competition and partially fulfilled the second objective of this thesis which was to record risk factors considered missing in the previous, retrospective data set. For clarity, given the large amount of data it was elected to report the findings first descriptively before converting these to potential risk factors and assessing them to confirm whether or not they impacted on eliminations and lameness eliminations. The data in this second study supported the findings of the first study, with the increased cumulative distance and increased number of competitions the horse had taken part in being the strongest correlation with eliminations and more specifically lameness eliminations. Differences were identified within the frequency and stage of eliminations between entry level, single loop rides and higher-level multi-loop rides, which has not previously been considered by previous research in endurance. Additionally, this second study partially fulfilled the third objective which was to determine which limb(s) are most frequently identified as lame at the point of elimination from competition and whether this changes depending on the level of competition.

This study gave an overview of the data, however in order to confirm if the findings were valid, it was important to know if the veterinarians' examination, specifically regarding lame limb identification and severity of lameness was reliable. In order to do this IRR of the veterinarians had to be undertaken. This was a particularly important stage, as previous studies have found subjective lameness assessments to have poor IRR (Hammarberg *et al.*, 2016; Starke *et al.*, 2013; Keegan *et al.*, 2010; Keegan, 2007; Fuller *et al.*, 2006). To conclude, the implications of the second study were (1) hindlimb lameness is more prevalent in British national level endurance competitions than forelimb lameness. (2) increase cumulative distance and increased competition starts are most strongly correlated with eliminations and specifically lameness eliminations. (3) Further analysis was required to identify the validity of the findings and to evaluate the additional risk factors recorded at competition to establish if they have an impact on deleterious outcomes. (4) Differences between entry level competition and higher-level competition is alluded to within this descriptive study, but further analysis was warranted to further understand this.

Chapter 7

7.0 Study 2b: Lameness eliminations in single loop and multi-loop British endurance rides in 2019 (manuscript under review)

(Full manuscript see Appendix 6)

7.1 Introduction

Despite lameness being identified as the leading cause of elimination, there is little information surrounding the details of the lameness. The reasons for this are multifactorial. The gait examination identifies if there is an issue that for horses welfare and whether they should not continue, and is not a full clinical, diagnostic examination. A survey of FEI veterinarians concluded that even experienced veterinarians found gait assessment difficult in Endurance due to poor handling, poor trot up area, muscular asymmetry and fatigue (of both horse and veterinarian) being cited as some of the challenges encountered (de Mira *et al.*, 2019). The purpose of this study was to identify risk factors associated with elimination outcomes and more specifically lameness outcomes within national rides run under EGB rules. In addition, the study aimed to identify which limb(s) were primarily affected by lameness at the time of elimination from competition. This information should give valuable information to riders, trainers, veterinarians and all stakeholders within the sport to proactively manage and minimise risks of lameness, improve equine welfare within the sport and in turn increase competitive success.

7.2 Materials and Methods:

7.2.1 Participants (Horse starts):

The horses included within this study and method of collecting data was identical to that in study 2a (Chapter 6).

7.2.2 Additional veterinary data:

At each of the rides attended, if a horse was asked to 're-trot' during the veterinary inspection, each of the members of the VP watching the second trot up were asked to note, without discussion with their colleagues, whether they believed the horse to be 'lame' or 'not lame'. The VP were also asked, if they considered the horse to be lame, which limb(s) they believed the horse to be lame on and the severity of the lameness based on the AAEP six-point scale (Table 1) (AAEP, 2019). The member(s) of the VP handed their voting slips to the official ground jury who gave the decision to the competitor as to whether the horse had passed the veterinary inspection. The ground jury passed the voting slips directly to the researcher.

Historic data:

Information on each of the entrants to the competitive rides was downloaded from the official EGB results database, which is publicly available, including horse demographics and competitive history. This information is presented in Supplementary file 2 of Appendix 6.

7.2.3 Statistical analysis:

Inter-rater reliability of the veterinary surgeons was assessed using a calculation of Fleiss's Kappa (k) for limb(s) identified as lame and the grade of lameness.

$$Kappa\ (k) = P - P_e / 1 - P_e$$

Where *P*= total agreement, including chance agreement and P_e = expected chance agreement (Keegan *et al.*, 2010).

Interpretation of strength of agreement based on the co-efficient was considered good at >0.60 and very good at >0.80 (Keegan *et al.*, 2010; Eugenio and Glass, 2004). All horses that presented to the initial vetting were included in this analysis. A chi-square test of independence was performed to examine the relationship between which limb(s) were lame (forelimb/ hindlimb) and the number of loops within the ride (single loop/ multi-loop).

7.2.4 Model building:

Prior to model building, horses which did not pass the initial veterinary inspection or did not complete the loop, and therefore had no speed recorded, were removed (Figure 9). Two deleterious outcomes were assessed: (1) Eliminated (any reason); and (2) Eliminated lame. For each model, the initial stage was to fit univariable models for each of the potential risk factors. Risk factors were considered significant to take forward to multivariable analysis with a *P* value of ≤ 0.1 (Dohoo *et al.*, 1997). Risk factors considered for univariable analysis, are provided as supplementary material (Appendix 6: Supplementary file 2).

Multivariable logistic regression models were constructed using a backwards-stepwise process, with an omnibus test of model co-efficients applied at each step. The goodness-of-fit of each of the models were assessed using the Hosmer-Lemeshow test (Hosmer, D.W and Lemeshow, S., 2000). The predictive ability of the model(s) were assessed using the ROC curve analysis (Bandos, Rockette and Gur, 2010; Gardner and Greiner, 2006). Risk factors with *P* values of <0.05 were considered significant in the final multivariable model(s).

For single loop rides, due to the low number of lameness eliminations, only univariable analysis was completed.

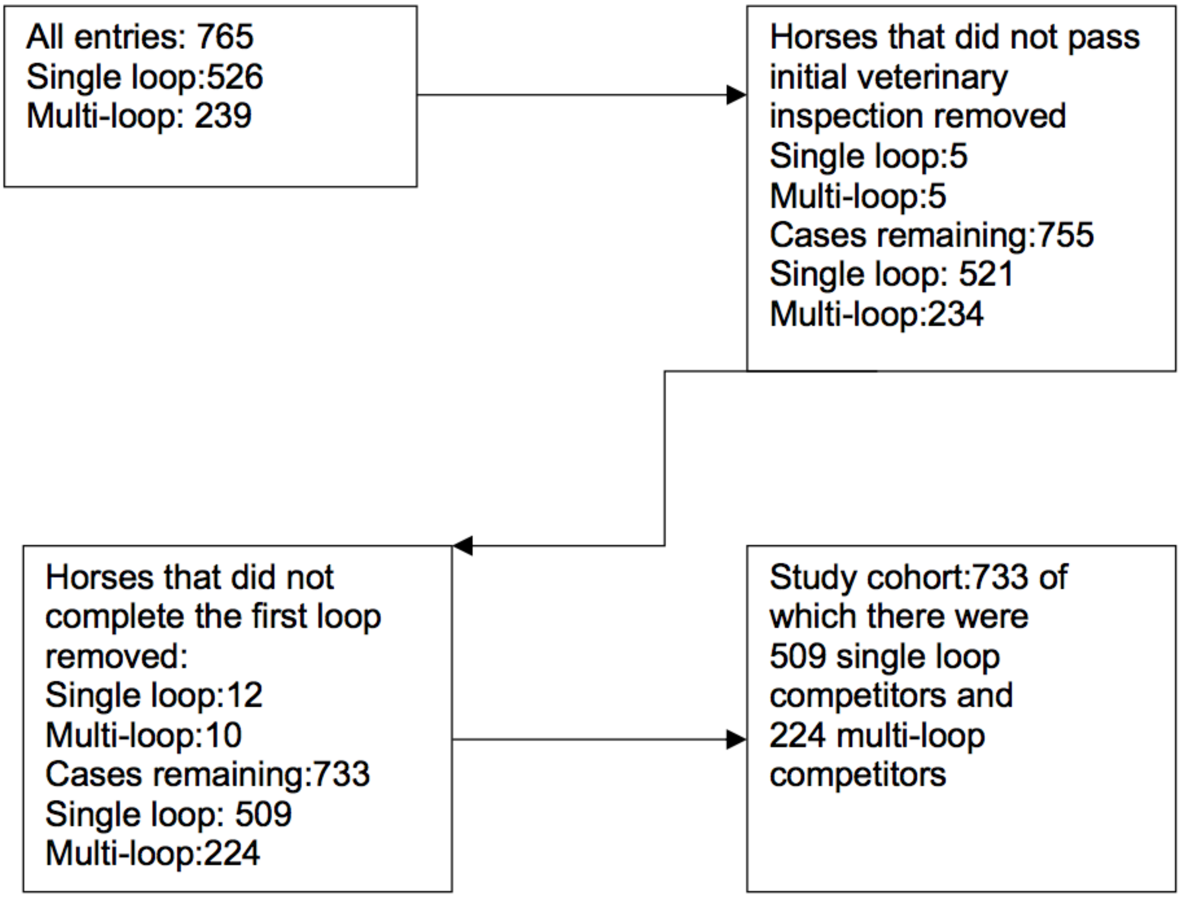

Figure 9: Process of removing incomplete data for model building

The process of removing horse starts that did not have full data required for the multivariable analysis for rides attended in 2019. Information collected from the rides attended.

7.3 Results:

7.3.1 Descriptive statistics:

A total of 765 entries in rides run under EGB rules, from June-October 2019, across seven different venues were analysed. Results were taken from rides ranging from a single loop ride (22- 48 km), to six loop rides, over two or three days with a maximum distance of 174km. The longest single day ride consisted of four loops and a total of 101 km. Only one ride had the veterinary inspection on hard ground (concrete), the other six were on grass. Temperature ranged from 9.1-27.4°C. Relative humidity ranged from 39.1% to 100%, with bright sunshine to heavy rain. The greatest number of entries was in single loop rides (n = 526; 68.8%). Single loop ride distance ranged from 22-47 km, median distance± interquartile range was 36±9 km and all were categorised as GER. Two-loop rides, 64-80 km, median distance 66±14 km, accounted for 14.1% of entries (n = 108) and were also all GER. Rides of three loops and above, 80-174 km, median distance 80±3km, accounted for 17.1% of entries (n = 131), within these rides 64.1% (n = 84) were categorised as CER and the remaining 47 (35.9%) were GER. Ride success was high with 81.6% (n = 624) of all those that started completing the ride. The most common reason for failing to complete was lameness, accounting for 58.9% (n = 83) of all eliminations.

7.3.2 Inter-rater reliability:

For horses that were eliminated lame which had two members of the VP observing the trot (n=51), there was total agreement as to which limb was lame (K=1, p<0.001, C.I.0.86-1.14). In this group of horses there was high agreement on the severity of lameness (K=0.85, p <0.001, C.I. 0.66-1.03).

For horses that were eliminated lame with three members of the VP observing the trot (n=32), there was a strong agreement in which was the lame limb (K=0.83, p<0.001, C.I.0.75-0.9). There was reduced agreement on the severity of lameness (K=0.53, p<0.001, C.I. 0.40-0.66).

7.3.3 Forelimb/ Hindlimb lameness

In single loop rides, 45.5% (n=15) of horses that were eliminated lame were forelimb lame, and 54.5% (n=18) were hindlimb lame. In multi-loop rides, 36.0% (n=18) were forelimb lame and 64.0% (n=32) were hindlimb lame. A chi-squared test of independence was conducted between the limb identified as lame (forelimb/ hindlimb) and the number of loops of the ride (single loop/ multi-loop). All expected cell frequencies were greater than five. There was a statistically significant association between the lame limb and the number of loops, $X^2(1)=5.4$, p=0.02.

7.3.4 Eliminations Single loop rides:

A total of eight variables were significant at univariable analysis and were taken forward for multivariable analysis. Table 13 shows the significant (*P*<0.05) results of the multivariable model. Horses who had never completed a ride before were at increased odds of an elimination (OR 3.07; 95% C.I. 1.10-8.51) compared to horses who had passed their previous competition. Horses who had attempted >10 rides in their competitive career at increased odds of elimination, compared to those who had attempted <10 rides (OR 3.88; C.I. 1.23-12.18). There was a small association between the number of kilometres attempted and the likelihood of an elimination outcome, with horses who had attempted >2500 km less likely to be eliminated compared to those who had attempted 500km or less (OR 0.13; C.I. 0.21-0.76). The steepness of the ride was also a significant factor in an elimination outcome with horses being 1.96 times more likely to be eliminated if the ride was steep (C.I. 1.02-3.77).

Table 13: Results of the multivariable model for single loop starts for any elimination outcome
Final multivariable model showing elimination risk factors for horses competing in Endurance GB single loop rides (22-48km) from June-October 2019 at seven different venues.

Risk Factor	Cases: ELIM Total n=44 n per category (%)	Controls: Passed ride Total n=465 n per category (%)	OR	95% C.I.	P value
Result Previous Ride					
Completed	34 (8.3)	377 (91.7)	Reference	-	0.077
Eliminated	3 (5.5)	52 (94.5)	0.63	0.16-2.42	0.449
No previous ride	7 (16.3)	36 (83.7)	3.07	1.10-8.51	0.032
Days since previous Lame					
≤180	4 (4.8)	79 (95.2)	Reference	-	0.099
>180	16 (12.3)	114 (87.7)	2.81	0.86-9.16	0.087
No previous Lameness Elimination	24 (8.1)	272.(91.9)	1.30	0.37-4.59	0.688
Rides Attempted Career					
≤10	19 (7.5)	234 (92.5)	Reference	-	0.020
>10	25 (9.8)	231 (90.2)	3.88	1.23-12.18	0.020
Distance (Km) Attempted Career					
≤500km	25 (9.0)	253 (91.0)	Reference	-	0.056
501-2500km	17(9.2)	167 (90.8)	0.35	0.12-1.06	0.064
>2500km	2 (4.3)	45 (95.7)	0.13	0.02-0.76	0.023
Steepness					
Minimal climbs	22 (6.3)	325 (93.7)	Reference	-	0.080
Steep	22 (13.6)	140 (86.4)	1.96	1.02-3.77	0.044

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.003, Hosmer and Lemeshow 0.38, ROC: 0.73

7.3.5 Elimination due to lameness:

Due to the low numbers of lameness eliminations in single loop rides, only univariable analysis was completed; three risk factors were considered significant at $p \leq 0.1$. These risk factors included; steepness of the ride, the number of rides the horse had attempted within its career and the distance the horse had attempted in 2019 (Appendix 6: supplementary file 3).

7.3.6 Eliminations Multi- loop rides:

A total of 19 variables were significant at univariable analysis and taken forward for multivariable analysis. Table 14 shows the significant (P<0.05) results of the multivariable model for eliminations across multi-loop rides. The ride attended had a small but significant association with an elimination, with a decreased odds of elimination at the third (OR 0.17, CI 0.05-0.59) and fifth ride (OR 0.13, CI 0.03-0.66), compared to the final ride of the competitive season. Horses were more than twice as likely (OR 2.25, CI 1.07-4.72) to be eliminated in competitions of more than two loops when compared to two loop rides. A horse that completed the first loop at >14 kmh^{-1} had a small reduction of risk of elimination (OR 0.07, CI 0.02-0.26) compared to those that completed the first loop at less than 12 kmh^{-1}. However, horses that had a final average speed of >12 kmh^{-1} were at increased odds of elimination (OR 2.88, CI 1.15-7.24) compared with those that finished at less than 12 kmh^{-1}. Horses that had a final heart rate of 55 beats per minute (bpm), or more, (recorded from the vetting at which they were eliminated, or at the final vetting if they completed all the loops) were more than four times as likely to be eliminated compared with those who had a final heart rate of less than 55bpm. Horses with a competitive history of 6 or more years were more than twice as likely to be eliminated (OR 2.39, CI 1.19-4.80) than those who had been competing for 5 years or less. If the outcome of the previous competition was elimination there was an increased risk (OR 2.26, CI 1.01-5.04) of elimination when compared to horses who successfully passed their previous competition.

Table 14:Results of the multivariable model for multi-loop rides for the elimination outcome

Final multivariable model showing elimination risk factors for horses competing in Endurance GB multi-loop rides (64-174km) from June-October 2019 at seven different venues.

Risk Factor	Cases: Eliminated Total n=73 n per category (%)	Controls: Passed ride Total n=151 n per category (%)	OR	95% C.I.	P value
Ride					
1	2 (66.7)	1 (33.3)	1.71	0.02-194.69	0.823
2	8 (33.3)	16 (66.7)	0.32	0.07-1.43	0.136
3	22 (25.9)	63 (74.1)	0.17	0.05-0.57	0.005
4	9 (33.3)	18 (66.7)	0.34	0.08-1.45	0.146
5	5 (26.3)	14 (73.7)	0.13	0.03-0.66	0.014
6	16 (34.0)	31 (66.0)	0.28	0.07-1.21	0.088
7	11 (57.9)	8 (42.1)	Reference	-	0.117
Loops					
2 loops	25 (24.5)	77 (75.5)	Reference	-	0.043
>2loops	48 (39.3)	74 (60.7)	2.25	1.07-4.72	0.032
Loop 1 speed					
<12 kmh^{-1}	26 (31.0)	58 (69.0)	Reference	-	<0.001
12-14 kmh^{-1}	40 (40.8)	58 (59.2)	1.04	0.45-2.39	0.927
>14 kmh^{-1}	7 (16.7)	35 (83.3)	0.07	0.02-0.26	<0.001
Final Heart Rate					
<55	38 (24.7)	116 (75.3)	Reference	-	<0.001
55+	35 (50.0)	35 (50.0)	4.23	2.03-8.81	<0.001
Average speed					
<12 kmh^{-1}	25 (26.9)	68 (73.1)	Reference	-	0.033
>12 kmh^{-1}	48 (36.6)	83 (63.4)	2.88	1.15-7.24	0.025
Years competing					
1-5	41 (28.3)	104 (71.7)			Ref
6+	32 (40.5)	47 (59.5)	2.39	1.19-4.80	0.015
Result previous ride					
Completed	53 (29.4)	127 (70.6)	Reference	-	0.202
Eliminated	20 (45.5)	24 (54.5)	2.26	1.01-5.04	0.046

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.001, Hosmer and Lemeshow 0.78, ROC: 0.79

Elimination due to lameness: Multi- loop rides

Following univariate analysis 9 risk factors were taken forward to multivariable analysis. The results of the final multivariable analysis are shown in Table 15. Speed had the most significant association with lameness eliminations with horses that averaged a speed of >12 kmh^{-1} over the total distance being more than three times as likely (OR 3.09, CI 1.32-7.26) to show lameness compared with horses that completed at less than 12 kmh^{-1}. Horses completing the first loop at >14 kmh^{-1} were at a slightly reduced risk of lameness elimination (OR 0.13, CI 0.03-0.53).

Table 15: Results of the multivariable model for multi-loop starts for the elimination due to lameness outcome

Final multivariable model showing elimination due to lameness risk factors for horses competing in Endurance GB multi-loop rides (64-174km) from June-October 2019 at seven different venues.

Risk Factor	Cases: Lame Total n=44 n per category (%)	Controls: Not Lame Total n=180 n per category (%)	OR	95% C.I.	P value
Loops					
2 loops	12 (11.8)	90 (88.2)	0.45	0.18-1.15	0.094
>2loops	32 (26.2)	90 (73.8)	Reference	-	0.073
Loop 1 speed					
<12 kmh^{-1}	13 (15.5)	71 (84.5)	Reference	-	<0.001
12-14 kmh^{-1}	27 (27.6)	71 (72.4)	1.30	0.54-3.09	0.557
>14 kmh^{-1}	4 (9.5)	38 (90.5)	-0.13	0.03-0.53	0.004
Final Heart Rate					
<55	26 (16.9)	128 (83.1)	Reference	-	0.132
55+	18 (25.7)	52 (74.3)	4.23	2.03-8.81	0.097
Average speed					
<12 kmh^{-1}	12 (12.9)	81 (87.1)	Reference	-	0.013
>12 kmh^{-1}	32 (24.4)	99 (75.6)	3.09	1.32-7.26	0.010
Loop 1 finish time					
Before 11:30am	31 (27.7)	81 (72.3)	Reference	-	0.054
After 11:30am	13 (11.6)	99 (88.4)	-0.04	0.15-0.95	0.013

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.001, Hosmer and Lemeshow 0.32, ROC: 0.75

7.4 Discussion:

The results of this study demonstrate that hindlimb eliminations are more prevalent in multi-loop rides when compared to single loop rides. High IRR between the VP was identified, which should provide confidence in their decision making for the horses' welfare. This study demonstrates that risk factors for elimination and lameness eliminations in single loop rides and multi-loop rides differ. Identification of which limb(s) are most predominantly classified as lame had not been possible previously as these data were not routinely recorded in endurance veterinary inspections. The high frequency of hindlimb lameness identified supports the findings of the veterinary examinations of endurance horses presenting for investigation at the Animal Health Trust where the tarsus was identified as the most common location for injury in endurance horses (Murray *et al.*, 2006). Additionally, a small study of 22 horses who were examined during competition with a portable inertial sensor-based system identified the highest percentage (41.7%) of lameness's were attributed to hindlimb lameness (Lopes, Eleuterio and Mira, 2018). The reasons behind the higher prevalence of hindlimb lameness observed is likely to be multifactorial.

This study demonstrates that the veterinary panel at EGB competitive events have strong agreement with regards to which limb is identified as lame, which should go some way to reassuring riders and associates that the veterinary decision, despite being a subjective analysis, is likely to be the correct one. This information would be of benefit to share with riders, associates and stakeholders within the sport to reduce the confrontations or challenges faced by the VP (de Mira *et al.*, 2019). The inter-rater reliability of the grade of lameness was reduced for rides when three veterinarians observed the trot up, where agreement was only moderate. Participating VP members were sent information describing the AAEP scale prior to the study, however it was found that the majority of veterinarians were using the most widely used British lameness scale of 0-10 (Wyn-Jones, G., 1988), and then dividing by 2. The AAEP scale was chosen due to its clear descriptions for each grade, however as some veterinarians used the AAEP scale as requested and others used the Wyn-Jones scale and halved it, the grading in this case cannot be considered wholly reliable and could explain the variability observed between veterinarians.

7.4.1 Single loops:

Despite single loop rides being the entry level competitions for all horses and riders, there have been no studies to date looking at the risk factors surrounding elimination and lameness for these competitions. The findings of this study provide valuable insight to considerations of risk management in lower distance rides. Horses competing in single loop rides, who had attempted more than ten rides in their career were at a higher risk of an elimination outcome. Bennet and Parkin (2018a) also reported that an increased number of competitive rides increased horses chances of elimination in international level endurance. The association between ride frequency and elimination may be due to accumulation of microtrauma or injury – reversible/irreversible in musculoskeletal structures. Clinical symptoms may not present as injuries may be subclinical until horses are asked to increase their workload outside of their normal physiological parameters, such as during a competitive endurance ride (Bennet and Parkin, 2018a, 2018b; Martig *et al.*, 2014; Fielding *et al.*, 2011; Henley *et al.*, 2006; Parkin *et al.*, 2005; Bailey *et al.*, 1997). Horses who are competing more, may have less time between rides to recover from any microtrauma. Increasing rest periods at FEI level have been found to decrease deleterious outcomes and implementing a similar approach may be of benefit at a national level (Bennet and Parkin, 2020). Appropriate return to training and competition post elimination has not been considered specifically in endurance, perhaps fundamentally because lameness within the sport is not fully understood. Whilst there is evidence supporting appropriate return to competition following specific injuries in other equestrian disciplines, diagnosis and veterinary follow up of the causality of lameness elimination in endurance is poor. Therefore professional guidance on return to competition may be either absent entirely or is not tailored to the sport specific requirements, which may contribute to the multiple eliminations found within this study (Nagy, Dyson and Murray, 2017; Kaneps, 2016).

This study found that horses competing in their first competition were more than three times more likely to be eliminated when compared with horses who successfully completed their previous competition. This may be associated with a lack of experience of the horse and/or the rider. These findings are supported by other studies in both endurance and thoroughbred racing which have found experienced horses are at a lower risk of a negative outcome, compared to those who are less experienced, although in endurance, this has again only been considered at FEI level (Nagy, Dyson and Murray, 2017; Georgopoulos and Parkin, 2016). This outcome is important for the sport, if the first experience a competitor has is a negative one (i.e. an elimination) they may be more likely to have a negative perception of the sport and may not return. It is therefore worth considering the information provided by EGB to newcomers within the sport and whether this can be improved to reduce the likelihood of a negative first experience. Additionally, when a negative first experience is combined alongside the findings that an increased number of rides results in an increased number of lameness eliminations, the wider public perception of the sport must be considered in order to safeguard the future of the sport and its SLO (Roly Owers, 2017; Teixeira *et al.*, 2012).

Whilst the steepness of a ride has not been previously investigated within endurance it was found that horses competing in single loop rides were more likely to be eliminated when the ride was steep. This may indicate a potential lack of training or ride preparation, possibly due to a lack of awareness of the demands on the endurance horse of the less experienced competitor or the technicality of the route, supported by the findings of this study that those competing for the first time were more likely to be eliminated. Perhaps the lack of ride preparation, when competitions are steeper could be supported by studies which have demonstrated the increased demands on the hindlimb musculature when travelling on an incline. Munoz-*Nates et al.* (2017), demonstrated horses transfer weight to increase the loading on the hindlimbs when travelling uphill, compared to travelling on the flat. This would increase the propulsion to travel uphill, but in turn increases muscular demand, which would be an issue if the horse was not sufficiently prepared for this increase in demand. *Electromyography* studies have identified the *gluteus medius* and the *tensor fascia latae,* responsible for the coxofemoral joint action significantly increases when going uphill, demonstrating increased muscular demand of the hindlimb musculature (Crook, Wilson and Hodson-Tole, 2010; Robert, Valette and Denoix, 2010). The findings therefore suggest perhaps those competing in single loops, where the odds of elimination are increased in competitions with steeper gradients are insufficiently prepared for the demands and further training is required for such rides. There is currently no objective evidence relating to the most appropriate methods of training the endurance horse specifically. Studies to determine optimum training and management strategies for the endurance horse and rider would be of benefit in order to provide guidance at all levels, but particularly for entry level competitors (Williams *et al.*, 2021).

7.4.2 Multi-loops:

Speed was found to be a significant factor both for elimination and lameness, with horses competing at the higher speeds more likely to have a deleterious outcome; this has been found in previous studies identifying risk factors within endurance (Bennet and Parkin, 2018b; Younes *et al.*, 2015, 2016; Coombs and Fisher, 2012). However, the speeds in which elimination and lameness are identified under EGB rules are much lower than those with deleterious outcomes at FEI level. This could indicate the greater experience and physiological capabilities of the international horses and riders translating to the capability of competing at higher speeds, or it could be an indication that the technicality of the courses may be different, which may reduce the speeds in EGB rides. For example, the highest speeds are currently recorded in Middle Eastern countries, where the tracks are specifically made for competition, whereas the British tracks vary dependent on where in the country you compete and utilise natural terrain. In the Middle East competitors will not have to open or close any gates, whereas in Britain there are some rides which travel across fields containing livestock, which would necessitate the rider opening and closing gates, therefore significantly impacting on speed. Here horses were likely to be eliminated at rides attended earlier in the competitive season (June), when the ground conditions were subjectively drier than the reference category ride (October) which could be described as 'muddy and slippery'. Muddy terrain has previously been found to be a significant factor in sweat fluid and electrolyte losses in endurance horses, which could be a consideration for fatigue-based injuries (Lindinger and Ecker, 2010).

The final heart rate of the horse was a significant factor in elimination, this is not surprising as the heart rate is deemed an important factor in evaluating the endurance horse during the veterinary inspection and therefore considered a relevant determinant of performance (EGB, 2022c; FEI, 2022b; Adamu *et al.*, 2014). Foreman and Lawrence (1991) found a correlation between the degree of heart rate increase and the severity of lameness in horses at rest and when recovering from exercise. In addition to this, predictive modelling in multi-loop endurance rides outside of the UK has identified that slow heart rate recovery times can be indicative of a higher chance of a deleterious outcome at the following veterinary inspection (Younes *et al.*, 2015, 2016).

The increased odds of elimination when the horse has competed for six years or more could be explained by an accumulation of subclinical musculoskeletal damage which may become more apparent during competition where increased demands are placed on the horse. Whilst typically these findings have been previously attributed to older horses in endurance and racing, the same principles of accumulative damage over a longer career would be considered likely (Bennet and Parkin, 2018a; Fielding *et al.*, 2011; Henley *et al.*, 2006; Parkin *et al.*, 2005; Bailey *et al.*, 1997).

The increased likelihood of elimination when the outcome of the previous ride was elimination is also in line with previous studies (Bennet and Parkin, 2018a). It is thought this may be due to insufficient recovery from injury, as identified in racehorses (Georgopoulos and Parkin, 2016). Interestingly, due to the findings of Bennet and Parkin (2018a), the FEI imposed longer MOOCP, with additional days added for elimination, lameness and elimination due to metabolic compromise and further days added if there is a subsequent deleterious outcome to allow horses a greater length of time to recover (FEI, 2022b). This was found to have had a positive impact in reducing the eliminations in FEI competitions (Bennet and Parkin, 2020). Currently EGB has shorter MOOCP when a horse is eliminated for any reason compared to the FEI, with only eight additional days being added for lameness eliminations for EGB horses, regardless of the number of times the horse has been eliminated as lame, where as a horse with three consecutive lameness eliminations who is registered with the FEI would face an additional 180 days MOOCP and a veterinary examination prior to being allowed to compete at either national or FEI level (EGB, 2022c; FEI, 2022b). The results of this study suggest the MOOCP duration should be extended at national level, whilst further evidence is required to define the time period, current best evidence would suggest alignment with the FEI recommendations (Bennet and Parkin, 2020).

7.4.3 Limitations:

The relatively low numbers of deleterious outcomes in the lower distance single loop competitions and the lower number of ride entries in the higher distance, multi-loop rides may limit the wider extrapolation of these data, however it does give a clear indication that single loop rides have differing risk factors to multi-loop rides.

7.5 Conclusions:

The results of this study demonstrate that hindlimb lameness eliminations are more prevalent than forelimb lameness eliminations across all distances, but significantly more so in multi-loop rides compared with single loop rides in national level endurance. Additionally, this study demonstrates that single loop and multi-loop rides have differing risk factors for veterinary eliminations and for lameness eliminations. Education on the demands of the sport, appropriate pre, peri and post competition risk management need to be tailored accordingly, dependent on the competitive level and experience of the competitor.

This study demonstrates that the veterinary panel at competitive events have strong IRR when identifying a lame limb, which should go some way to reassuring stakeholders within the sport that the veterinary professionals working within endurance are skilful and aware of the welfare needs of the horses competing. Their decisions must be taken seriously and riders should consider professional veterinary follow up post elimination for appropriate diagnosis and management of injury to facilitate a successful return to competition.

7.6 Impact and Implications of Study 2b

The findings of this study were presented to EGB members in 2021 and were well received. Members asked how they could improve for the benefit of their horse. As a result, in discussion with EGB, a “Winter education series” was developed, which ran September 2021-March 2022. Members had the opportunity to attend monthly online sessions with a variety of topics presented by professionals in the field. Topics included: Farriery/ shoeing/ padding of the endurance horse, nutrition of the endurance horse, winter strengthening programmes for core activation, flexibility, travelling horses abroad and management of horses in a race ride vet-gate. The sessions were open to not just members, but those with a specific interest in the area, for example the farriery session, which was presented by the British team farrier, was open to all farriers who shoe endurance horses. The aspiration of these educational sessions was to give competitors more specific knowledge in order to allow them to make informed decisions when preparing their horses for competition, during competition and in their time away from competing. In turn, hopefully this will improve the welfare of horses competing and increase the success and longevity of their career.

This study fulfilled the second and third objectives, and partially fulfilled the fifth objective (Appendix 9). This study found excellent IRR between the veterinary professionals when identifying a limb for lameness (Keegan *et al.*, 2010; Eugenio and Glass, 2004). As a result, riders should have confidence with the veterinary professional at rides and that riders should have confidence that veterinary professionals are making the correct decisions for the welfare of the horses, regardless of whether the rider can identify the lameness, which previous evidence suggests is often the case (Dyson and Pollard, 2020; Keegan *et al.*, 2010; Eugenio and Glass, 2004). Additionally, this would indicate that a diagnosis for the clinical signs of lameness should be sought by the rider on the return from competition in order to gain professional advice to allow the lameness to full heal and formulate an appropriate management plan for return to competition. Riders and trainers need to move on from the anecdotal view that the lameness is 'just bad luck' and 'down to the trot up', which this study has identified, is not the case.

This study also confirmed the higher prevalence of hindlimb lameness compared to forelimb lameness to a statistically significant level. This is an important finding and if it is possible to reduce the lameness occurrences consideration must be given as to why, particularly as the incidence of hindlimb increased in multi-loop compared to single loop competitions. It was hypothesised that back pain was a plausible rationale. Alvarez *et al.* (2008) concluded that back kinematics were altered by even low grade hindlimb lameness and surmised that back pain and dysfunction could be induced by hindlimb lameness. Landman *et al.* (2004) conducted a large study with 805 horses with orthopaedic issues and identified that 74.3% of horses which had back pain were also lame, indicating a strong link between back pain and lameness. This is especially notable when considering that Nagy, Dyson and Murray (2017) found that, after lameness, the second most common veterinary issue reported by owners of horses registered with EGB was thoracolumbar pain.

The impact of rider asymmetry on thoracolumbar movement of the horse has been identified previously, with common causes of back pain in horses linked to poor saddle fit and rider position (MacKechnie-Guire *et al.*, 2020; Gunst *et al.*, 2019). In endurance, saddles marketed specifically for the sport tend to focus on being light weight and rider comfort, rather than the fit for the horse. However, there is no requirement to have a specific endurance saddle, and it is down to rider preference as to what type of saddle they ride in. In addition, endurance riders adopt different positions within the saddle, such as a two-point seat, where the weight of the rider is through the stirrups and there is no contact on the seat of the saddle (Figure 10), or a three-point seat (Figure 11) where the rider spends most of their time seated in the saddle. Additionally, an adapted 3-point seat (Figure 12) is sometimes seen where the rider sits within the seat of the saddle, with longer stirrups and the upper body slightly further back (Williams *et al.*, 2021). The impact of these different riding styles, may of course differ depending on rider experience and it is not clear which style may be the most sympathetic to the horse, with each having positive and negative implications (Williams *et al.*, 2021). Horse riders frequently ride asymmetrically, which will impact on the horse biomechanics and ultimately performance, this is likely to increase as riders fatigue (Symes and Ellis, 2009). Although this has not been specifically studied within endurance riders, it is worth considering, given the higher prevalence of lameness eliminations in multi-loop rides compared to single loop rides.

Figure 10: 2-point seat
(photograph authors own)

Figure 11: 3-point seat
(photograph authors own)

Figure 12: Adapted 3-point seat 'desert seat'
(photograph authors own)

Given the number of hours that endurance riders spend in the saddle in comparison to other sports (minimum of 2, maximum of 13 hours), it is possible that equine back pain may be a contributing factor to increased hindlimb lameness and this warrants further investigation. Palpation of the thoracolumbar back musculature does take place within the veterinary inspection of an endurance ride, but data are not available to assess if back pain could be a contributing factor to lameness. The third study within this thesis study sought to assess IRR of veterinary back examinations within the competition environment to consider if they were valid to then consider as a potential risk factor for elimination.

Chapter 8

8.0 Study 3a: Inter-rater reliability of grading soft tissue palpation of the thoracolumbar epaxial musculature of endurance horses during competition.

8.1 Introduction

This study was presented at the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapy, Cambridge 2022, the abstract is provided in Appendix 7.

During the second study, it was identified that lameness eliminations from competition were more likely to be associated with hindlimb lameness than forelimb lameness (Bloom *et al.*, 2022a). Lameness, and more specifically hindlimb lameness, has previously been associated with back pain in horses (Burns, Dart and Jeffcott, 2018; Alvarez *et al.*, 2008; Landman *et al.*, 2004). There is currently a lack of evidence to support whether back pain is a cause of poor performance in competition, or is associated with lameness during an endurance competition, despite back pain being the second most common issue identified by EGB riders when surveyed about their horses' veterinary history (Nagy, Dyson and Murray, 2017). Given that riders reported that back pain was an issue for their horses, coupled with previous evidence identifying that back pain and lameness were linked in horses, it would seem plausible to hypothesise that there may be an association between back pain in endurance horses and lameness eliminations during competition (Burns, Dart and Jeffcott, 2018; Nagy, Dyson and Murray, 2017; Greve and Dyson, 2013; Landman *et al.*, 2004).

As the purpose of this thesis was to identify risk factors for lameness eliminations, the rationale of the following studies was to consider whether horses' thoracolumbar back pain was a risk factor for elimination. Firstly, however, consideration had to be given on how to record and identify back pain in the endurance horses, without altering the veterinary procedure during competition, as any changes to the veterinary procedure could impact competitive results, which would not have been approved by EGB or accepted the riders taking part in the competitions.

During competitions, each veterinarian has a 'vet writer' who notates the information the examining veterinarian dictates to them on a 'vet sheet'. Currently, on a GER vet sheet there is no place to document any information surrounding back palpation, other than in the pre-ride declaration by the rider, despite palpation of muscle tone being part of the veterinary examination (EGB, 2022c). During a CER, the vet sheet is the same as during an FEI ride (EGB, 2022c; FEI, 2022b). There is no specific mention about back pain, but a space to notate muscle tone, scored A-D. However, there is no standardised documentation as to what would constitute an A or any other letter. This may lead to variability between veterinarians and reduce the validity of the examination.

In order to be used to identify whether or not back pain is a variable worth considering in endurance horses an appropriate measurement must be taken in a standardised format which is relevant, user friendly, and feasible within the vetting procedure. It must be time and cost efficient in order for it to be used within a competition environment. The measurement must also have good IRR in order for it to have meaningful validity (Tabor and Williams, 2018, 2020; Tabor *et al.*, 2020; Randle *et al.*, 2017).

During the veterinary examination, the horse's musculature is palpated and therefore, in order not to disrupt the veterinary procedure, it would make logical sense to utilise an examination already taking place but establish whether it can be completed in a valid way. Palpation scales exist but have not been tested within a competition environment (Merrifield-Jones, Tabor and Williams, 2019; De Heus *et al.*, 2010; Jepsen *et al.*, 2006; Varcoe-Cocks *et al.*, 2006; Bendtsen *et al.*, 1995). The first stage of considering whether back pain in endurance horses was a risk factor for lameness was to test a palpation scale within a competition environment to assess not only the IRR, but also ecological validity.

Merrifield-Jones, Tabor and Williams (2019) used a palpation scoring scale (Table 16) modified from others, including the Modified Ashworth Scale (Ravara *et al.*, 2015; Varcoe-Cocks *et al.*, 2006; Ashworth, 1964). The scoring scale had clear descriptors for the 0-5 score system and was found to have excellent IRR when assessed using ACPAT Physiotherapists. It was the purpose of this study to assess the IRR of this scale when used in an endurance competition setting, where veterinarians of mixed experienced would be assessing the horses presented.

Table 16: Epaxial muscle palpation scoring system

Epaxial Muscle Palpation scoring system as described by Merrifield- Jones, Tabor and Williams (2019), modified from Varcoe- Cocks et al (2006) and the Modified Ashworth Scale (Ravara et al, 2015).

Score	Description
0	Soft, low tone
1	Normal
2	Increased muscle tone but not painful
3	Increased muscle tone and/or painful (slight associated spasm on palpation, no associated movement)
4	Painful (associated spasm on palpation with associated local movement, i.e., pelvic tilt, extension response)
5	Very painful (spasm plus behavioural response to palpation, i.e., ears flat back, kicking)

8.2 Methods

8.2.1 Subjects

Nineteen horses of mixed breeding who were entered into a 'Pleasure Ride' (PR) run by Endurance GB were included in the study. Eleven of the horses were geldings and the remaining eight horses were mares. Mean age of the horses was 11.7 ± 1.07 years (range 4-20). The horses had been entered to the PR by their owners/ riders and therefore anticipated to be in sufficient health to take part in the PR, which was a marked route of 13-34km across bridleways and farmland, predominantly over chalk tracks with minimal hills or climbs.

As is standard practice at an EGB PR, all the horses were presented to the examining veterinarians prior to being allowed to start the ride (EGB, 2022c). When the horses presented to the veterinarians, the handler was asked if they gave consent for the horse to take part in the study. Competitors had been sent the study information prior to attending the ride, additionally a copy of the information was displayed in the ride office on the day of the competition. The horses taking part in the PR were randomly assigned to one of the veterinarians to observe their trot up. The veterinarian who watched the horse trot was then asked to palpate the horse's epaxial musculature.

Horses were asked to complete their trot up prior to palpation to ensure that the study did not interfere with their competition and the decision as to whether they could start their PR was given to the competitors prior to data collection taking place. All nineteen horses were declared fit to start the PR and therefore progressed to data collection.

8.2.2 Data Collection

Two licensed equine veterinarians, one with a special interest in equine backs, and a fourth-year veterinary student assisted with data collection. The veterinary student had been on clinical placement with the veterinarian who had a special interest in equine backs. The instructions offered to the veterinarians was to palpate as they normally would in a cranial-caudal direction along the thoracolumbar epaxials on both the near and off side of the horse. The veterinarians were asked to palpate each side of the epaxials individually, rather than palpating both sides at the same time, as illustrated in Figure(s) 13, 14 and 15.

Figure 13: Correct palpation technique

Photograph (authors own) showing correct palpation in a cranial-caudal direction and palpating left and right side individually.

Figure 14: Incorrect palpation technique (i)

Photograph (authors own) showing incorrect palpation by palpating left and right side together.

Figure 15: Incorrect palpation technique (ii)

Photograph (authors own) showing incorrect palpation by palpating left and right side together.

Horses' backs were palpated post trot up both at the initial veterinary inspection and at the final veterinary inspection post completion of the ride. The palpation was performed by the examining veterinarian, who gave their score to the vet writer, who noted it on a pre-prepared sheet.

Despite every effort to circulate the information to the attending veterinarians, due to a last-minute personnel change, due to COVID-19, only the veterinarian with the special interest in backs had seen the information surrounding the study prior to the morning of the competition. Although is considered a limitation, it allowed conclusions to be drawn about the ease of use and clarity of the scale.

The description of each of the grades was available to the veterinarians and the student at all times if they wished to refer to it. The student and the veterinarians were blinded from each other's scores at all times to prevent the likelihood of bias to endeavour to make the results as robust as possible (Merrifield-Jones, Tabor and Williams, 2019; Karanicolas, Farrokhyar and Bhandari, 2010; Hicks, 2004).

Following this initial inspection, the competitors started and completed their ride. On return to the competition venue, as per the ride rules, the horses were represented to the veterinarians (EGB, 2022c). They were again randomly assigned to one of the veterinarians, i.e. horse number one may have been seen by veterinarian number 1 at the start of the competition but may have been seen by veterinarian number two at the end. Following the trot up, the examining veterinarian was once again asked to palpate the epaxial musculature and inform the vet writer of their score. The student was then asked to palpate the epaxial musculature and give the vet writer their score. No discussion took place between the veterinarians and the student regarding scoring throughout the competition to avoid the impact of bias (Merrifield-Jones, Tabor and Williams, 2019; Karanicolas, Farrokhyar and Bhandari, 2010; Hicks, 2004). At the end of the competition, the scores were handed to the researcher for analysis.

At the start of the competition veterinarian 1 assessed seven horses and veterinarian 2 assessed twelve horses. At the end of the competition, veterinarian 1 assessed thirteen horses and veterinarian two assessed six horses. The veterinary student palpated all of the horses (n = 19).

8.2.3 Data Analysis

Inter-rater reliability of palpation scores was tested with a series of Fleiss' kappa analyses, using the equation:

$$Kappa\ (k)=P-P_e/\ 1-P_e$$

Where P= total agreement, including chance agreement and P_e = expected chance agreement (Keegan *et al.*, 2010).

The Fleiss Kappa were completed for IRR of veterinarian 1 and the student at the start and at the finish, veterinarian 2 and the student at the start and at the finish, the overall agreement between veterinarian 1 and the student and the overall agreement between veterinarian 2 and the student. In each case the null hypothesis was that the agreement between each veterinarian and the student was no different to agreement by chance (Keegan *et al.*, 2010; Sim and Wright, 2005). Interpretation of strength of agreement based on the co-efficient was considered good at >0.60 and very good at >0.80 (Keegan *et al.*, 2010; Eugenio and Glass, 2004).

Null hypothesis:

H_0:x=0

In each case, the alternative hypothesis was that agreement between the examining veterinarian and the veterinary student was over and above chance.

Alternative hypothesis:

$H_{A:}$ x ≥0

8.3.1 Inter-rater reliability between veterinarian 1 and veterinary student.

The agreement between the veterinarian and the student at the start was significant and considered 'moderate': K = 0.60 (95% CI 0.59 - 0.6), p = 0.004.

At the end of the ride the veterinarian and the student had total agreement in back palpation scores: K = 1.00 (95% CI 0.99 -1.01), p = .001.

Overall, the agreement between veterinarian 1 and the veterinary student was excellent: K = 0.89 (95% CI 0.88 - 0.89), p < 0.001.

In each case, the null hypothesis was rejected and the alternative hypothesis accepted.

8.3.2 Inter-rater reliability between veterinarian 2 and veterinary student.

The agreement between the veterinarian and the student at the start was significant and considered 'good': K = 0.72 (95% CI 0.71 - 0.73), p < 0.001.

At the end of the ride the veterinarian and the student had total agreement in back palpation scores: K = 1.00 (95% CI 0.99 - 1.01), p < 0.001.

Overall, the agreement between veterinarian 2 and the veterinary student was excellent: K = 0.82 (95% CI 0.81 - 0.83), p < 0.001.

In each case, the null hypothesis was rejected and the alternative hypothesis accepted.

8.3.3 Overall agreement between licensed veterinarians and veterinary student.

The overall agreement between the veterinarians and the veterinary student was excellent:

K = 0.86 (95% C.I 0.67 - 1.04), $p < 0.001$.

8.4 Discussion

The results of this study indicate that using a categorical grading scale for manual epaxial muscle palpation has excellent IRR when used during a veterinary examination during an endurance competition. Based on the findings of this study, it is strongly recommended that this scale is adopted for the veterinary examination. The palpation scale used in this study has previously been identified to have excellent IRR between ACPAT Physiotherapists (Merrifield-Jones, Tabor and Williams, 2019). Whilst previous concerns have been raised that categorical scales are open to subjective interpretation, the detailed descriptors given of the palpation scale used would appear to reduce the impact of subjectivity, despite the fact that the assessors used had various levels of experience and had not all had prior training on the use of the scale (Landman *et al.*, 2004; Annett, 2002). The implications or presence of back pain and the rationale behind the consideration of back pain in endurance horses was not the focus of this study but is considered in the following study.

8.5 Limitations

The sample size in this study was small, however by palpating left- and right-hand sides, pre- and post- PR, a total of seventy-six palpation scores were considered. The sample size in this study (n=19) is similar to that in the study by Merrifield- Jones, Tabor and Williams (2019), (n=22). In human literature, Powell *et al.* (2021) evaluated at intra- and IRR in musculature testing and only used a sample size of n=12 and Bruce *et al.* (2017) used a sample size of n=17. This suggests that the sample size used in study 3a, whilst small, can offer meaningful results, particularly as it offers strong ecological validity, having been undertaken in a 'real-life' competition environment, rather than a manufactured setting (Kihlstrom, 2021; Schmuckler, 2001).

Specific instructions on how to palpate the epaxial musculature, other than in a cranial to caudal direction were not given, the rationale for this was firstly not to interfere with competition and secondly to establish if the IRR was impacted by differing palpation techniques, which the result of this study suggest it was not (Kihlstrom, 2021; Schmuckler, 2001).

When testing inter- and intra-rater reliability in human practice, Mota *et al.* (2013) also gave simple instructions, such to 'palpate the musculature' and acknowledged that different levels of experience could impact on the scoring but concluded that palpation was sufficiently reliable to use in practice. The only instruction given to the veterinarians in this third study was to palpate in a cranial-caudal direction, this was to palpate in the direction of the muscle fibres and the horses' coat, rather than against the coat, which could cause friction and a false-positive response (Walker *et al.*, 2016). Other studies have considered it to be best practice to have a standardised protocol for palpation taught both verbally and practically to the veterinarians, however in this instance palpation technique was not taught to have the base line data for ecological validity by capturing the data in a real competition scenario (Merrifield-Jones, Tabor and Williams, 2019).

8.6 Conclusion

This study identified that the categorical rating scale used for manual palpation of the equine epaxial musculature during endurance competition had excellent IRR between experienced and specialist veterinary surgeons and a veterinary student. In order to establish the validity of the scale during competition and whether back pain has an association with lameness during competition, further information and testing was necessary.

Chapter 9

Study 3b: Back Pain on epaxial muscle palpation as a risk factor for lameness elimination during endurance competitions.

This study was presented at the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapy, Cambridge 2022, the abstract is provided in Appendix 8.

9.1 Introduction

Following identification of excellent IRR of the categorical palpation scale as described by Merrifield-Jones, Tabor and Williams (2019), during the veterinary inspection of EGB pleasure ride horses (study 3a, Chapter 8), it was considered appropriate to use this categorical scale to identify back pain in endurance horses at the time of competition and consider whether this was a risk factor for lameness elimination.

9.2 Methods

9.2.1 Participants (Horse starts):

Following agreement from EGB, ride data and statistics were collected from eight days of competitions, across five different venues were attended during the competitive season of 2021, between May and October. Prior to the competition, information surrounding the study and the data that would be requested was circulated to the ride organisers, attending veterinarians and technical stewards. The ride organiser was asked to upload the participant information sheet onto the specific ride portal on EGB's website to allow riders to read the information prior to attending the ride and opt out should they wish to. This information was also displayed on the ride noticeboard on the day of the competition and was available in the vetting area for riders to read should they wish. There was no additional intervention placed upon horses and all data were anonymised. Data were collected from all classes and distances run under EGB rules, form all horses that presented to a pre-ride veterinary inspection. Throughout the study the unit of observation was a 'horse start' i.e. an entry made to the competition where the horse was presented to the veterinary inspection at the start of the ride. A power calculation using Epitools- Epidemiological Calculators, again using the first cohort study of 1747 as a sample size estimation, with a significance of α=0.05 and power=0.80, the minimum sample size required was determined to be n=370. A total of 423 entries in GER (n=385) or CER (n=38) competitions were evaluated.

9.3 Measures:

9.3.1 Competition data:

As with the second study (chapters 6 & 7), information ordinarily collected at EGB competitions was gathered at the time of competition. This included: (1) the category of competition CER or GER; (2) the distance entered (km); (3) the start and finish time of each loop; (4) the average speed (kmh^{-1}) for each loop and for the entirety of the ride, (5) the time taken to present to the vet (multi-loop rides only, during the competition but excluding the final vetting), and (6) the heart rate of the horse as documented during each veterinary inspection.

The trot up surface was documented as either concrete (one ride only) or grass. The 'steepness' of the ride was recorded as 'steep' or 'minimal climbs' subjectively based on the description of the route, documented in the ride entry information. The temperature and relative humidity were recorded using a calibrated digital temperature and humidity meter (Peak-Meter PM6508) every hour and the average per loop and average for the duration of the competition was calculated.

9.3.2 Historic data:

The competitive history of each of the horses was downloaded from the EGB publicly available results database, this included (1) number of previous competitions entered within the horses career and in the 2021 competitive season, (2) number of competitions successfully completed within the horses career and in the 2021 competitive season, (3) number of km previously attempted within the horses career and in the 2021 competitive season, (4) number of km successfully completed within the horses career and in the 2021 competitive season, (5) previous number of eliminations (any reason) within the horses career and in the 2021 competitive season, (6) previous number of lameness eliminations within the horses career and in the 2021 competitive season, (7) length of time (days) since previous competition start, (8) result of previous competition, (9) distance of previous competition (10) length of time (days) since previous eliminations (any reason), (11) length of time (days) since previous lameness, and (12) the number of years the horse had been competing. Additionally, it was documented at what level the horse and rider were at (novice, open or advanced), whether the horse and rider had previously competed as a combination and the age, sex and breed of the horse.

9.3.3 Additional veterinary data:

During each veterinary inspection, at the point which the examining veterinarian palpated the horses' back, they were asked to assign a score of 0-5, for the left and right side of the thoracolumbar musculature based on the scale in table 15 (Merrifield-Jones, Tabor and Williams, 2019). The veterinarian dictated the score to the ‘vet writer’ who noted it on an additional form provided prior to the start of the competition. The vet writers were shown how to record the scores on the sheets provided. The vet writers handed the documented scores directly to the researcher at the end of the veterinary inspections.

The veterinarians had the scale visible during the veterinary examination and prior to the competition. The information provided to the veterinarians requested that they palpate as they would normally, both sides of the back, in a cranial to caudal direction. This instruction was necessary to ensure that the study did not interfere with the competition results.

Additionally, if a horse was asked to re-trot during the veterinary inspection, each of the veterinarians observing the second trot were asked to notate without discussion, as per competition rules, whether they believed the horse to ‘pass’ or whether they assessed the horse to be lame and therefore ‘fail’. On their voting slip, in addition to marking the pass or fail box, which is standard on a voting slip, the veterinarians were asked, if they considered the horse to be lame, to record which limb(s) they believed to be lame, and additionally they were asked to grade the lameness. The veterinarian passed the voting slips to the ground jury to give the result to the competitor, before handing the voting slips directly to the researcher for analysis.

9.3.4 Statistical analysis:

Frequency analysis of factors was completed for each ride. A series of Spearman's Rank Correlations ($p<0.05$) examined the relationship between the number of times a horse failed, or was eliminated in their career, and the age of the horse, the length of their competitive career (years) the number of rides the horse had attempted in their career and successfully completed in their career, the distance (km) the horse had attempted in their career and the distance (km) the horse had successfully completed in their career. These relationships were also examined against the number of times a horse had been eliminated due to lameness within their career.

A series of Fisher's exact tests were completed to establish if there was a significant difference between back palpation scores, in terms of whether the scores were symmetrical or asymmetrical at the start or at any point in the ride, and whether the horse passed the competition or not and whether the horse was eliminated lame or not at any point in the competition. Further Fisher's exact tests were completed to test the difference between horses who scored 0-1 (hypotonic or considered normal) or 2+ (hypertonic to painful), both at the start and again at any point in the competition and whether they passed or failed, and whether they were lame or not. These tests were repeated for horses scoring 0-2 (hypotonic, normal and hypertonic) or 3+ (painful response) at the start, and again at any point in the competition, and whether they passed or failed and if they were lame or not. Results were considered significant when $P<0.05$ (Field, 2013).

9.3.5 Model building

Prior to model building, horses which did not pass the initial veterinary inspection or did not complete the loop and therefore had no speed recorded were removed. Two deleterious outcomes were assessed: (1) Eliminated (any reason); and (2) Eliminated lame. The models were constructed and interpreted as described in section 4.8.3. Univariable models informed the multivariable models.

9.4 Results

9.4.1 Descriptive Statistics

A total of 423 competitive entries from five different venues, across eight days of competition, were analysed. The entries consisted of 325 horses, 78.8% (n=256) of which had one start recorded, the remaining 21.2% (n=69) were horses with more than one start recorded in the dataset. Within the group of horses that had multiple starts recorded, the range of starts was 2-5 (Mean 2.4 S.D.+/- 0.8). Two horses had two eliminations recorded, one of these horses was considered lame at the initial veterinary inspection and was not allowed to start the competition, on the other occasion, the horse lost a shoe during the competition and trotted up lame on the limb it had lost the shoe on. The second horse had one lameness elimination on the third loop veterinary inspection and was retired by the rider at another competition.

Table 17 shows the entries and results according to the different ride venues. One ride was considered steep, the others had minimal climbs. Only one ride had a trot up on concrete, the others were trotted on grass, not specifically mown or turfed for the competition, but usually on the flattest part of the venue field. The majority of horses (n=356, 84.2%) completed the competition they entered and successfully passed the vetting. Of the horses that were eliminated 68.7% (n=46) were eliminated for lameness. Hindlimb lameness accounted for 65.2% (n=30) of lameness eliminations. Fifteen veterinarians were involved in the study, with two of those being present at two separate competition venues.

Table 17: Ride entries and competitive results across five venues in 2021

Details of ride entries, completions, eliminations and elimination reasons across five competition venues in the competitive season of 2021.

Ride	1	2	3	4	5	All rides
Entries (n)	24	85	163	125	26	423
Completions (n)	23	79	141	90	23	356
Completions %	95.8	92.9	86.5	72.0	88.5	84.2
Eliminated (n)	1	6	22	35	3	67
Eliminated%	4.2	7.1	13.5	28.0	11.5	15.8
Lame (n)	1	2	18	25	0	46
Lame % of eliminations	100	33.3	81.8	71.4	0	68.7
FL lame (n)	0	2	7	7	0	16
FL Lame % of lame	0	100	38.9	28.0	0	34.8
HL lame (n)	1	0	11	18	0	30
HL lame %of lame	100	0	61.1	72.0	0	65.2
MET(n)	0	1	1	3	0	5
Met % of eliminations	0	16.7	4.6	8.6	0	7.5
RET (n)	0	3	0	7	3	13
RET % of eliminations	0	50.0	0	20.0	100	19.4
Other	0	0	3	0	0	3
Other % of eliminations	0	0	13.6	0	0	4.5
Eliminated start (n)	0	0	1	8	0	9
Eliminated start % of eliminations	0	0	4.5	22.9	0	13.4
Eliminated during ride (n)	1	3	5	12	0	22
Eliminated during ride % of eliminations	100	50.0	22.7	34.3	100	32.8
Eliminated End (n)	0	3	16	15	0	32
Eliminated End % of eliminations	0	50.0	72.7	42.9	0	47.8

Forelimb (FL), Hindlimb (HL), Metabolic elimination (MET), Retired by rider (RET)

9.4.2 Historic Correlations

The competitive history and correlation between the number of times horses were eliminated within their career and the number of times they were eliminated lame within their career are shown in Table 18 and Table 19 respectively.

Table 18: Correlation between competitive history of horses competing in 2021 and the number of eliminations within their career

A series of Spearman's rank correlations for historic competitive history and the number of eliminations a horse had within its career, for horses taking part in the competitions at the five venues attended in the 2021 competitive season. Historic data downloaded from the Endurance GB website

Number of loops	Correlation Variables	Spearman's Rank
Single loop		
	Km attempted	$r_s(308)=0.803$, $P<0.001$
	Rides attempted	$r_s(308)=0.792$, $P<0.001$
	Years competing	$r_s(308)=0.754$, $P<0.001$
	Km completed	$r_s(308)=0.749$, $P<0.001$
	Rides completed	$r_s(308)=0.735$, $P<0.001$
	Age	$r_s(308)=0.562$, $P<0.001$
Multi loop		
	Km attempted	$r_s(111)=0.879$, $P<0.001$
	Rides attempted	$r_s(111)=0.837$, $P<0.001$
	Years competing	$r_s(111)=0.793$, $P<0.001$
	Km completed	$r_s(111)=0.822$, $P<0.001$
	Rides completed	$r_s(111)=0.771$, $P<0.001$
	Age	$r_s(111)=0.656$, $P<0.001$
All Rides		
	Km attempted	$r_s(421)=0.841$, $P<0.001$
	Rides attempted	$r_s(421)=0.819$, $P<0.001$
	Years competing	$r_s(421)=0.777$, $P<0.001$
	Km completed	$r_s(421)=0.790$, $P<0.001$
	Rides completed	$r_s(421)=0.762$, $P<0.001$
	Age	$r_s(421)=0.572$, $P<0.001$

Table 19: Correlation between competitive history of horses competing in 2021 and the number of eliminations for lameness within their career
A series of Spearman's rank correlations for historic competitive history and the number of lameness eliminations a horse had within its career, for horses taking part in the competitions at the five venues attended in the 2021 competitive season. Historic data downloaded from the Endurance GB website

Number of loops	Correlation Variables	Spearman's Rank
Single loop		
	Km attempted	$r_s(308)=0.751$, $P<0.001$
	Rides attempted	$r_s(308)=0.738$, $P<0.001$
	Km completed	$r_s(308)=0.705$, $P<0.001$
	Years competing	$r_s(308)=0.704$, $P<0.001$
	Rides completed	$r_s(308)=0.689$, $P<0.001$
	Age	$r_s(308)=0.563$, $P<0.001$
Multi loop		
	Km attempted	$r_s(111)=0.816$, $P<0.001$
	Rides attempted	$r_s(111)=0.794$, $P<0.001$
	Years competing	$r_s(111)=0.768$, $P<0.001$
	Km completed	$r_s(111)=0.775$, $P<0.001$
	Rides completed	$r_s(111)=0.741$, $P<0.001$
	Age	$r_s(111)=0.698$, $P<0.001$
All Rides		
	Km attempted	$r_s(421)=0.787$, $P<0.001$
	Rides attempted	$r_s(421)=0.765$, $P<0.001$
	Km completed	$r_s(421)=0.744$, $P<0.001$
	Years competing	$r_s(421)=0.733$, $P<0.001$
	Rides completed	$r_s(421)=0.715$, $P<0.001$
	Age	$r_s(421)=0.583$, $P<0.001$

9.4.3 Palpation Scores

Across all national rides 44 horses started the ride with an asymmetrical back palpation score, of those 29.5% (n=13) were eliminated for lameness. In single loop rides 10.6% (n=33) of horses started with an asymmetrical back, 30% of which were eliminated for lameness (n=10), 9.1% (n=4) of two loop horses presented with an asymmetrical back, one of which was not allowed to start due to lameness, the other three completed and 11.7% (n=7) of three loop horses started with an asymmetrical back, again one of which was not allowed to start due to lameness. None of the horses starting the four or six loop rides presented with an asymmetrical back palpation score at the pre-ride veterinary inspection. However, three out of the four lameness eliminations in the four and six loop rides developed an asymmetrical back score during the ride, each of which was at least one vet gate prior to their elimination for hindlimb lameness.

In total, eight horses, which were entered in rides consisting of one-three loops had a palpation score of ‘5’ at some point during the ride. Two of the horses which were given a ‘5’, were given this score at the start and declared not fit to start due to lameness. No horses in the four or six loop rides were scored a five at any point in the ride. Table 20 shows the palpation scores by number of loops entered. Figure 16 shows the percentage of horses that completed, were eliminated for any reason and more specifically eliminated as lame, Figure 17 displays this as true numbers of horses. Whilst limbs were identified and recorded, unfortunately only seven grades of lameness were recorded throughout the study, with the main reasons cited as forgetting to do so during a busy day.

Table 20:The highest epaxial muscle palpation score by the number of loops entered

The highest epaxial muscle palpation scores as given by the examining veterinarian at the competition venues in 2021. Additional descriptive explanations are also offered to assist with interpretation of the data.

Highest Palpation score	Total	Pass N	Fail N	Lame N	Comments
Single loop	310	273	37	24	
0	2	2	0	0	Started and finished low tone- both Arabian horses.
1	147	135	12	4	1 lame at start (forelimb), 3 lame at finish, 5 retired on course, 3 exceeded the speed allowed for novice level.
2	85	74	11	10	1 ROC, 2 lame at start (both forelimb), 8 lame at end. Of the 8, 4 were forelimb (one had lost a shoe), 4 were hind limb
3	50	42	8	4	1 lame (hindlimb at start- asymmetrical palpation). 2 metabolic eliminations. 2 Retired on course- one due to rider fall. Of those lame at the end, 1 had a forelimb lameness, 1 was bilaterally hindlimb lame palpated 1 for both left and right at the start and 3 for both left and right at the end. The other was right hind lame, palpated 1 bilaterally at the start and 2 left, 3 right at the finish.
4	20	15	5	5	All hind limb lame- one at the start (asymmetrical palpation score). The other four, lame at the end, two started with a symmetrical palpation score, which worsened asymmetrically, the other two started with an asymmetrical score which worsened. In each case, the higher palpation score was on the same side as the hindlimb lameness.
5	6	5	1	1	One scored Left 4 Right 5 at start and was eliminated lame right hind at the start. The others started with lower scores but palpated a 5 at the finish.
Two loops	44	39	5	4	
0	0	0	0	0	
1	20	19	1	0	Retired on course
2	11	10	1	1	One horse eliminated lame started with a score of one bilaterally, palpated left 2 and right 1 at the half-way vetting and was eliminated lame left hindlimb at the final vetting.
3	8	7	1	1	The horse that failed had a symmetrical palpation score. Hindlimb lame. Started with a score of 3 bilaterally, but the score improved during the ride.

4	4	3	1	1	Started with palpation score of 3 bilaterally, remained 3 bilaterally in half-way vetting. Palpation scores at finish left 4 right 2. Eliminated lame Left hind at end.
5	1	0	1	1	Did not start. Lame Right hind. Palpation score left 4 right 5.
Three loops	60	43	17	14	
0	0	0	0	0	
1	18	14	4	4	1 did not start- hindlimb lame. Remaining 3 lame at second vet gate- palpation scores remained the same throughout. (1 forelimb, 2 hindlimb lameness).
2	22	16	6	4	1 retired on course, 1 metabolically eliminated at end of ride. 1 failed at the first vet gate- right hindlimb lame- palpation score stared symmetrically with a score of 1, was asymmetrical left 1 right 2 at point of elimination. The other three failed at the second vet gate (two forelimb, one hindlimb)- in two cases, the horses presented with an asymmetrical palpation score at the first vet gate, having been symmetrical at the start.
3	13	10	3	2	1 metabolic elimination at the end. 1 lame vet gate 2- (left hindlimb) started with a palpation score of 1 symmetrically, scored 2 symmetrically at vet gate 1 and 3 symmetrically at the point of elimination. 1 horse lame at the end- right hindlimb lame at vet gate preceding elimination palpated 2 on left and 3 on right, despite having started symmetrically and reached vet gate 1 symmetrically.
4	6	2	4	4	1 did not start- lame left hindlimb- palpation score left 4 right 2. 3 lame at end. 1 right hind lame- start and vet gate 1 symmetrical palpation scores, vet gate 2 asymmetrical left 1, right 2, palpation score at finish 4 bilaterally. 1 right hind lame- started symmetrically with score of 2, scored 3 bilaterally at vet gate 1 and 2, palpated 3 left 4 right at the point of elimination. 1 right hind lame- started with asymmetrical palpation score left 4, right 3, improved in vet gate 1 and 2 to score 2 bilaterally, palpated a score of 2 left, 3 right at the finish and point of elimination.
5	1	1	0	0	Started with a score of 1 bilaterally, became 2 bilaterally at vet gate 2, at the finish scored 3 left, 5 right.
Four loops	2	0	2	1	
0	0	0	0	0	
1	0	0	0	0	
2	0	0	0	0	
3	1	0	1	1	Started symmetrically, asymmetrical at second vet gate, eliminated at third vet gate hindlimb lame.

4	1	0	1	1	Started symmetrically, asymmetrical at second vet gate, eliminated hindlimb lame at third vet gate
5	0	0	0	0	
Six loops	7	1	6	2	
0	0	0	0	0	
1	1	0	1	0	Metabolic elimination- end of first day
2	2	0	2	1	1 Lame left forelimb at vet gate 2- back palpation bilaterally 1 at start and first vet gate, scored 2 bilaterally at point of elimination. 1 retired on course- presented to vet and passed but retired having observed a cracked heel prior to starting the second day.
3	3	1	2	1	1 rider injured so retired- had started bilaterally with a palpation score of 1, palpated 2 bilaterally at first and second vet gate and 3 bilaterally at the third vet gate, where the rider retired. 1 lame right hind- palpated 1 left, 2 right at vet gate preceding elimination and 2 left 3 right at point of elimination (third vet gate).
4	1	0	1	0	Rider retired the horse having passed the vetting at the start of the second day as the horse had had a minor colic overnight. Palpated 3 bilaterally at the start, 2 bilaterally at vet gate 2 and 4 bilaterally at the third vet gate.
5	0	0	0	0	

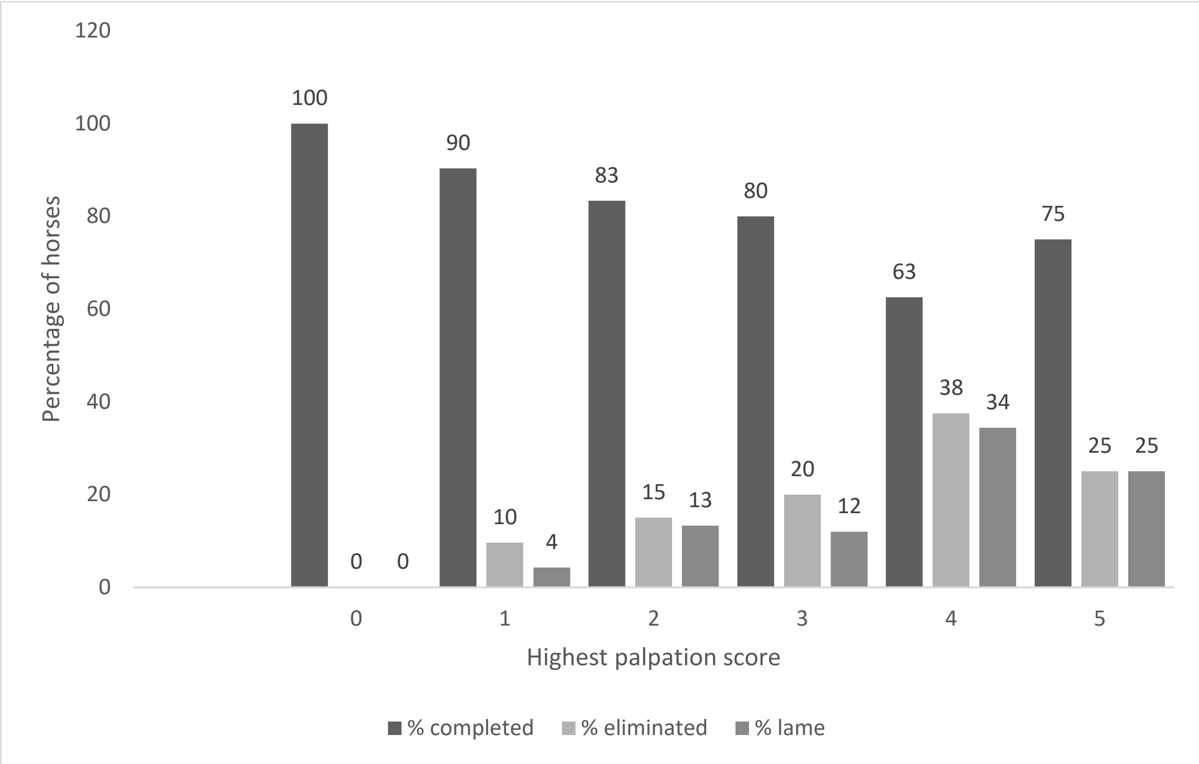

Figure 16: The percentage of horses that completed the ride, were eliminated for any reason or were eliminated lame against the highest palpation score

The lameness eliminations are included in the elimination for any reason data.

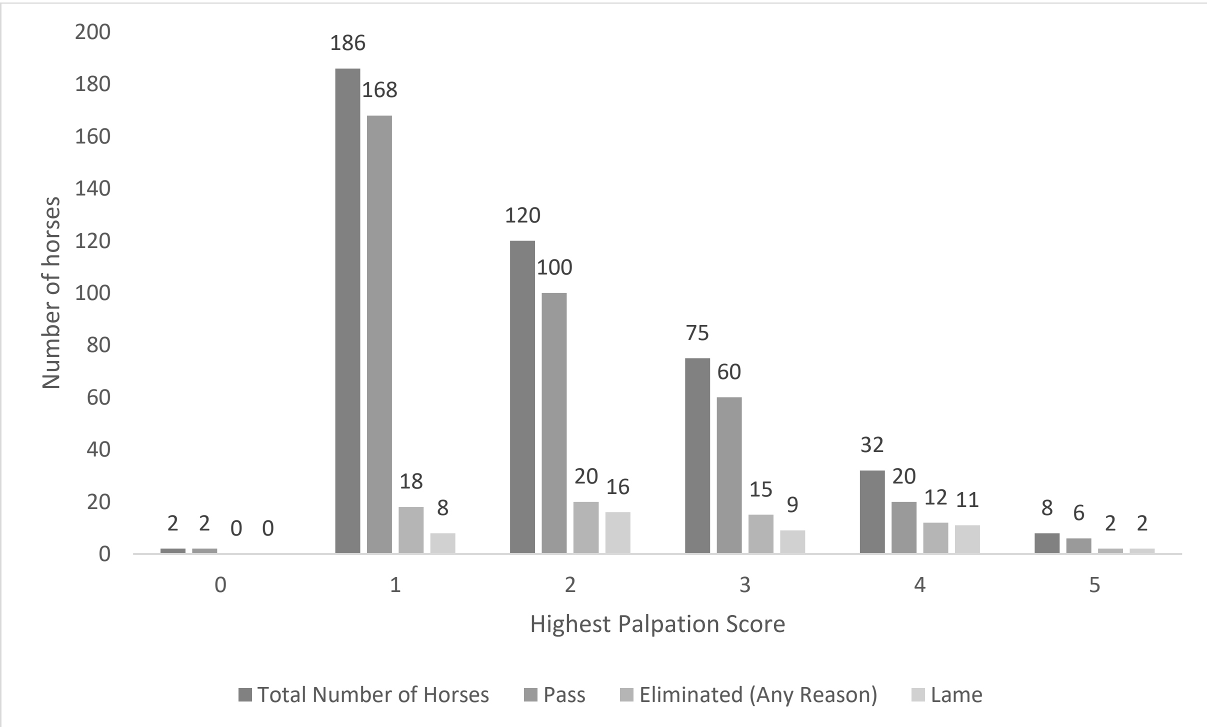

Figure 17: The number of horses that completed the ride, were eliminated for any reason or were eliminated lame against the highest palpation score

The lameness eliminations are included in the elimination for any reason data.

9.4.4 Test of Difference:

Significant differences (P<0.05) were identified between horses that passed the veterinary inspection and those that were eliminated (for any reason) if their palpation score was documented to have a pain response (scores of three and above) compared with horses that had a palpation score of two or less. The significant difference was also found between horses that were identified by the veterinarians as lame and those that were not lame. The differences were not found to be significant when the variables were categorised with palpation scores for hypotonic/ normal (scores of 0-1) and hypertonic/ painful (scores of 2+). Significant differences were found if horses had an asymmetrical back palpation score either at the start or at any point within the competition. The results of the Fisher exact tests are shown in Table 21.

Table 21: Results of epaxial palpation scores between groups using Fishers exact tests
A series of Fishers exact tests to identify the significance of association between the outcomes assessed (Pass/ Eliminated and Lame/ Not lame) and different epaxial muscle palpation results. Data collected from veterinary examinations at five different competition venues in 2021.

Point of competition	Outcome assessed	Variable 1	Variable 2	P Value
Start	Pass vs Eliminated	Symmetrical palpation score	Asymmetrical palpation score	0.006
Start	Pass vs Eliminated	Palpation score 0-1	Palpation score 2+	0.21
Start	Pass vs Eliminated	Palpation score 0-2	Palpation score 3+	0.001
Start	Lame vs Not Lame	Symmetrical palpation score	Asymmetrical palpation score	0.001
Start	Lame vs Not Lame	Palpation score 0-1	Palpation score 2+	0.16
Start	Lame vs Not Lame	Palpation score 0-2	Palpation score 3+	<0.001
Any veterinary inspection during the competition	Pass vs Eliminated	Palpation score 0-2	Palpation score 3+	0.001
Any veterinary inspection during the competition	Lame vs Not Lame	Palpation score 0-2	Palpation score 3+	<0.001

9.4.5 Model building

Horses which did not pass the initial veterinary inspection or failed to complete the first loop were removed from the analysis.

At univariable level 36 variables were entered; 28 were significant at $p \leq 0.1$for Model A: Pass vs Did Not Pass, while 17 were significant at $p \leq 0.1$for Model B: Lame vs Not Lame. Table 22 and Table 23 show the final multivariable analysis for pass vs did not pass (Model A) and lame vs not lame (Model B) respectively.

Table 22: Model A: final multivariable analysis for Pass Vs Did Not Pass in 2021 competitive season
Final multivariable model showing elimination risk factors for horses competing in Endurance GB rides in 2021 at five different venues.

Risk Factor	Cases FTQ Total n= 53 N per category (%)	Controls Passed Ride Total n=353 N per category (%)	OR	95% CI	P value
Asymmetrical Any point					
Yes	22	66	2.31	1.15-4.62	0.018
No	31	287	Reference		
Horse level					
Novice	13	145	2.75	0.95-7.94	0.062
Open	15	75	2.97	1.04-8.46	0.042
Advanced	25	133	Reference		
Ride Category					
GER	33	331	Reference		
CER	20	44	12.43	4.63-33.40	<0.001
Km attempted 2021 (continuous)	53	353	1.01	1.00-1.08	<0.001
Loop 1 Speed (continuous)	53	353	1.18	1.02-1.35	0.023

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus $p<0.001$, Hosmer and Lemeshow 0.85, ROC: 0.82

Table 23: Model B: Final multivariable analysis for Lame vs Not Lame in 2021 competitive season

Final multivariable model showing lameness elimination risk factors for horses competing in Endurance GB rides in 2021 at five different venues.

Risk Factor	Cases FTQGA Total n= 32 N per category (%)	Controls Did not FTQGA Total n=374 N per category (%)	OR	95% CI	P value
Asymmetrical Any point					
Yes	16	72	4.16	1.92-9.01	<0.001
No	16	302	Reference		
Loop 1 Speed (continuous)	32	374	1.15	1.01-1.31	0.030
Horse level					
Novice	7	151	1.35	0.36-5.10	0.661
Open	13	77	3.62	1.13-7.28	0.030
Advanced	12	146	Reference		
Lame career (continuous)	32	374	1.17	1.05-1.31	0.004

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.001, Hosmer and Lemeshow 0.54, ROC: 0.81

9.5 Discussion

The results of this study reaffirmed that lameness is the most common cause for elimination from endurance competitions in GB national competition (Bloom *et al.*, 2022b, 2022a) and as identified in previous international research (Bennet and Parkin, 2018a, 2018b; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2010, 2014a, 2014b; Nagy, Dyson and Murray, 2012; Fielding *et al.*, 2011). Hindlimb lameness eliminations were more frequent than forelimb lameness eliminations, in agreement with Bloom *et al.* (2022a).

This study considers back pain of endurance horses within competition and is the first study to identify that asymmetrical palpation scoring of the thoracolumbar epaxial musculature is a significant risk factor for elimination, and more specifically lameness elimination during competition. This outcome supports the riders' assessment of thoracolumbar back pain being the second most common veterinary issue in endurance horses as reported by Nagy, Dyson and Murray (2017). It confirms the findings of Fielding *et al.* (2011) who found back and wither pain were significantly associated with lameness eliminations in the first half of the competition.

The palpation of thoracolumbar epaxial musculature demonstrated that as the palpation grade increased (with the exception of those scoring a five), so too did the percentage of horses who were eliminated or were identified as lame (Figure 14). Whilst the palpation grade was not identified in the final multivariable analysis as a significant risk factor, this is an interesting trend, particularly as significant differences were identified between horses who scored 0-2 (hypotonic, normal and hypertonic) and those that scored 3+ (pain reactions) and the ride outcomes of pass/ eliminated and lame/ not lame (Table 21). The finding that the horses scoring a five did not follow the trend of increased elimination or lameness rate, could perhaps be explained by eliminations occurring prior to the horses normally reaching a level of five, which would suggest that back pain as has been identified previously is secondary to hindlimb lameness, and is due to the altered kinematics of the spine to compensate for pain in the hindlimbs (Alvarez *et al.*, 2008). This is supported by Table 20 which shows two horses (one in single loop and one in two loop rides) having a palpation score of five at the pre-ride veterinary inspection and were eliminated as hindlimb lame and therefore not allowed to start the competition. Additionally, it is worth noting that no horses in the higher distances of four and six loops had a palpation score of five. The rationale for this may be multifactorial, whether this is due to the more experienced riders, eligible for entering the longer distances being more aware of the demands of the sport and management of the horse pre, peri and post competition, is unclear, as rider level did not demonstrate significance in the final multi variable model. However, the awareness of the sport would seem to be better in the higher distances as no horses were presented to the initial veterinary inspections lame in the four and six loop competitions.

The majority of eliminations in the highest level of competition of six loops was due to the rider retiring the horse, which although a failure in competition, perhaps signifies the rider being aware of the limitations of the horse during that particular competition and not pushing it to the point of veterinary elimination, which should be seen as a positive outcome. The less experienced 'open level' horses were at increased odds of elimination and lameness in the final multivariable models, when compared to advanced horses. Other equestrian sports have identified that less experienced horses are at higher risk of failure within their sport, for example, less experienced event horses, are at an increased risk of falling on the cross-country course (Bennet, Cameron-Whytock and Parkin, 2022). Specifically, within endurance, at international level more experienced horses have been found to be at a decreased risk of elimination (Nagy, Murray and Dyson, 2014b). Additionally, cumulative lameness' within the horse's career increased the odds of a lameness elimination and cumulative kilometres increased the odds of an elimination for any reason. This further supports the evidence identified both in this thesis and international studies that injuries are likely to be chronic in nature and further consideration should be given to appropriate management of these injuries to improve horse welfare (Bloom *et al.,* 2022b; Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2020; Bennet and Parkin 2018a).

Loop 1 speed was also identified as a risk factor for elimination and lameness elimination, this is in agreement with Marlin and Williams (2018) who found that horses who completed loop one speed at a faster speed were at a higher risk of elimination, indicating that pacing the horse is imperative for competition. This is supported by the finding that horses competing in CER's where they are racing other competitors, rather than setting their own 'pace' were found to be more at risk of elimination, which was also identified in retrospective analysis (Bloom *et al.,* 2022b).

9.5.1 Asymmetrical palpation

The finding that asymmetrical palpation of the back musculature is associated with lameness eliminations is not surprising, given that back pain and lameness are known to co-exist (Burns, Dart and Jeffcott, 2018; Alvarez *et al.*, 2008; Landman *et al.*, 2004). However, what is currently unclear is whether the lameness is the primary clinical issue with back pain a secondary issue to hindlimb lameness, or whether the back pain is primary and causative of lameness. It is of course reasonable to assume this is likely to differ depending on the individual horse and situation. For example, those horses which presented with an asymmetrical back palpation score at the start and were subsequently eliminated either at the initial veterinary inspection or during the ride, are perhaps more likely to have developed lameness, exacerbated by competition. However, for the horses that started symmetrically and became asymmetrical during the ride, back pain may have preceded lameness. These horses may have been influenced by an asymmetrical rider, which initially manifested in a change in palpation score but eventually presented as lameness (MacKechnie-Guire *et al.*, 2020; Gunst *et al.*, 2019; Symes and Ellis, 2009). Without further information, this is impossible to clarify and no rider details, such as saddle used, rider weight or subjective riding ability was allowed to be collected. This information would enhance the findings and allow greater extrapolation of the results.

9.5.2 Limitations

This study was limited as it was completed during the Covid-19 pandemic which meant that numbers of competitors at events were restricted, subsequently the number of entries to competition was lower than pre-pandemic level. There was no ability to identify the impact that the pandemic had had on horses' and/or riders' fitness, training and competition regime. Numbers of support team members, known as 'crew', were also restricted which may have had an impact on the usual handling of the horse. As a condition to allowing the study to go ahead, EGB specified no subjective or objective information regarding rider ability/ weight/ fitness or saddle type/ fit were allowed to be collected which may have provided an additional dimension to the study. The method of palpation varied between veterinarians; however, it was imperative not to interfere with competition results and therefore instructions on how to palpate were not allowed to be given in any more detail than otherwise described. However, the study on IRR demonstrated that the scale used had excellent IRR and therefore reduced the risk of differing palpation techniques impacting too heavily on the results. Nevertheless, the results provided meaningful data which are useful for progressing the welfare within the sport.

9.6 Conclusion

This research has added a dimension to the veterinary inspection not previously evaluated and has identified that an asymmetrical thoracolumbar epaxial musculature palpation score is an additional risk factor for elimination and more specifically lameness elimination from British national endurance competitions. Further work would be of benefit to identify if management pre-ride or within the vet holds could reduce the impact of this risk factor and improve horse welfare.

9.7 Implications of study 3

The fourth and fifth objectives outlined at the start of this thesis were met by this study. A significant difference was identified between horses that were successful and unsuccessful in competition when the veterinary palpation of the thoracolumbar epaxial musculature was considered. Whilst a higher palpation score was significant on univariable analysis, an asymmetrical score was significant in the final multivariable models for both pass/did not pass and lame/not lame. This suggests that the palpation scale provides meaningful information. As the scale has high IRR, it is strongly recommended that the palpation scale is added to the veterinary examination during competition in order to safeguard the welfare of the horse and uphold the sport's SLO.

The study findings are not able to identify if back pain was causative of lameness or lameness existed and caused the back pain. Further work needs to be completed to better understand the relationship of back pain and lameness within the sport, which may give rise to better management and risk reduction strategies that can safeguard equine welfare.

Chapter 10

10.0 Summary, limitations and recommendations for future work and practical management of endurance horses

10.1 Summary

The findings within this thesis provide new evidence on risk factors for eliminations and more specifically lameness eliminations in British national level endurance.

The results of all of the studies within this thesis confirm lameness is the most common reason for elimination across all levels of British national endurance competitions. This is in agreement with previous studies and statistics within the sport at national and international level and is not a surprise (FEI, 2020; Bennet and Parkin, 2018a; Younes *et al.*, 2016; Nagy, Murray and Dyson, 2010, 2014b; Fielding *et al.*, 2011). This thesis has identified that risk factors exist from historic competitive results and within specific competitions.

10.1.1 Competitive history risk factors

All of the studies within this thesis demonstrated that historic competitive results could impact on the risk of a horse being eliminated from a competition. The first study (Bloom *et al.*, 2022b) identified a higher odds of elimination if a horse had attempted 401-500km in the previous 365 days, or two competitive starts in the previous 60 days . The second study (Chapter 7; Appendix 6) found that horses competing in multi loop ride were more likely to be eliminated in single loop rides if they had attempted more than 10 rides within their career and if they had attempted >2500km within their career. In multi-loop rides, horses were more likely to be eliminated if they had been competing for more than six years. In the third study (Study 3b; Chapter 9) horses were more likely to be eliminated if they had attempted >125km within that competitive season of 2021. The distance threshold is likely to have been lower in 2021 due to the COVID-19 pandemic, where training is likely to have been impacted due to restrictions imposed by the government at the time.

All three studies identified strong, significant correlations between eliminations and specifically lameness eliminations when comparing against the distance and number of competitions horses had attempted within their career. Previous eliminations within the horse's career were also identified throughout this thesis as risk factors for deleterious outcomes. The first study (Bloom *et al.*, 2022b) identified a higher odds of elimination when the horse had previously been eliminated two or more times within the previous 365 days. The odds of a lameness elimination decreased when the previous lameness elimination was >90 days previously. The second study (Chapter 7; Appendix 6) identified an increased risk of elimination if the result of the previous ride had been an elimination.

These findings highlight that multiple competitive starts, repeated eliminations and specifically lameness eliminations are a red flag for welfare. These risk factors have previously been identified in international level competition (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2018a, 2020; Nagy, Murray and Dyson, 2014b). This thesis provides the evidence that was previously absent at national level, that historic competitive results must be taken into account when considering appropriate rules and regulations for the sport at national level, which must have horse welfare at the forefront and for competitors to make evidence-informed decisions on both preparing for and entering competitions. These historic risk factors suggest that the eliminations and specifically lameness eliminations are due to chronicity of injuries, the clinical symptoms of which may not present until the horses are outside of their normal physiological parameters, as they may be at competition. Efforts should be made to educate the riders competing on this, to move away from the perception the elimination was 'bad luck' due to a slip or trip and move towards better management of the horses pre, peri and post competition, to reduce the likelihood of long-term musculoskeletal damage and consequently improve competitive performance. A 'winter education series' has been developed following the initial studies, with previous recordings available from the EGB website (EGB, 2022a). It would be of benefit if these were mandatory viewing for competitors as they progress through the competitive levels. Education series already exist in other disciplines, such as 'bridging the gap' in British Eventing and British Dressage 'horse care' (British Dressage, 2020; British Eventing, 2018). Whilst these are aimed at developing youth squads as they progress through the competitive levels, there is no reason why education series cannot be tailored to all levels. Continuing to update knowledge through education is a key component of the SLO, which all horse sports must be mindful of.

The findings would also suggest consideration needs to be given to capping the number of starts a horse has within the year. Multiple eliminations should be considered more critically, bringing the MOOCP for repeated lameness in line with the FEI may be a judicious starting point (FEI, 2022b; Bennet and Parkin, 2020).

10.1.2 Within competition risk factors

This thesis provided interesting findings, which in some cases echo or share similarities to those found at international level, and others which have not previously been considered or identified. The first study, (Bloom *et al.*, 2022b) highlighted that there was limitations in the data that is currently recorded at national level which the subsequent studies sought to rectify. For example, speed was not recorded, yet horses were found to be more at risk in CER competitions when racing against others, rather than GER's when the speed was capped, which would elucidate to potentially higher speeds being of concern.

The second study in this thesis (Chapter 7, Appendix 6) identified higher speed combinations were more at risk of elimination in multi loop rides, overall and specifically for lameness. The third study agreed, although due to lower numbers in the third study modelling was not carried out separately for single and multi-loop rides. Speed as a risk factor has been identified at FEI level endurance (Bennet and Parkin, 2018b; Marlin and Williams, 2018a, 2018b; Younes *et al.*, 2016). The speeds in British national endurance are much lower than that at FEI level, which is perhaps why the anecdotal perception that it is not an issue at national level arises from. Whilst it is plausible that the horses competing at FEI level have greater experience and therefore physiological capabilities have been developed, it is also possible that the speeds recorded in Britain are lower due to the technicality of the courses slowing riders down to cross a road, or open/shut a gate. This would seem a reasonable explanation given that the second study identified that the ride itself was a risk factor for elimination where horses were less likely to be eliminated in the earlier rides (June/ July) when the ground conditions were drier than in the later competitions which could be considered muddy and slippery.

The technicality of the course in terms of steepness was also identified as a risk factor for elimination in the second study, but only for horses competing in single loop competitions. When this is combined with the finding that horses who had never competed before were also at a higher risk of elimination, it suggests that education and information provided to competitors when they start endurance competitions could be improved. The physiological demands and requirements of the horses are perhaps underestimated and therefore the horses are under-prepared and lack the fitness, particularly when the technicality of the course increases. This underestimation of the requirements of the horse can be further demonstrated by looking at the descriptive data in the second study (Bloom *et al.,* 2022b; Chapter 5; Appendix 5). This shows the greatest number of retirements on course and metabolic eliminations were in the rides consisting of two loops, the first step up from the single loop rides which, unless technical in terms of steepness, would ordinarily be deemed within the horses normal physiological capabilities.

Previous epidemiological studies in endurance have focussed on international level competitions, perhaps potentiating competitor perception that the risk is only apparent at these levels. This thesis demonstrates that risk factors are present at every level but the second study has identified that risk factors change as the competitive levels change. This is an important finding as it highlights the need to develop understanding of the changing demands on the endurance horse at different competition levels. This is an important finding and requires the governing body of the sport to communicate clearly, as part of the requirements of their SLO, that issues exist at all levels within the sport and to educate competitors on how to manage this risk. That may be by reducing the number of competitions entered or learning more about sport specific training. The governing body, EGB has shown proactive steps in improving the sport and maintaining its SLO by allowing this research to go ahead. It would be judicious of the governing body to use this research to make evidence-based decisions for their rules and regulations, to ensure horse welfare remains at the forefront and for competitors to make evidence-informed decisions on both preparing for and entering competitions.

10.1.3 Identification of limb lameness

The second and third studies within this thesis (Chapter 6, 7 and 9; Appendices 5 and 6) identified hindlimb lameness as more common at the point of elimination than forelimb lameness. The rationale for hindlimb lameness being of higher prevalence is likely to be multifactorial, but is in agreement with a smaller objective analysis of endurance horses in competition (Lopes, Eleuterio and Mira, 2018) and the findings of a diagnostic study of horses who presented to a referral centre with lameness issues (Murray *et al.*, 2006). Whilst a diagnosis cannot be given at the point of elimination, this information gives insight into anatomical structures that could be impacted and it was this that drove the third study to consider palpation of the epaxial musculature.

Palpation of the horses thoracolumbar epaxial musculature was found to have a significant impact on lameness eliminations, with asymmetrical scores identified as a significant risk factor. This finding seemingly confirms a link between back pain and hindlimb lameness at the point of competition elimination. It is not possible from the results to identify whether the lameness was exacerbated or caused by the back pain. Identifying the primary issue, whether lameness, or back pain, would be difficult within competition as diagnostic examinations and imagery are not available, but the link is clear and in agreement with previous literature (Burns, Dart and Jeffcott, 2018; Greve and Dyson, 2013; Landman *et al,* 2004). The findings that there is a significant link between back pain and lameness elimination would suggest that back pain/ epaxial palpation should for a stringent part of the veterinary examination and it is recommended that a repeatable scale is used, such as the one used in this thesis and by

Merrifield- Jones, Tabor and Williams (2019). As asymmetry was seen in a vet inspection prior to many of the lameness eliminations, it would suggest that action should be taken at this point. As there is no clear definition of functional asymmetry specific to endurance horses, perhaps increasing the use of professionals such as physiotherapists within the sport, within the vet gate holds would allow prompt treatment and continuation of the horse within competition, or to give expert advice to retire the horse, where appropriate. Physiotherapy has been found to alter horses thoracolumbar posture at short-term intervals of thirty and sixty minutes (Shakeshaft and Tabor, 2020). This is an interesting time period within endurance riding due to the vet hold time period which ranges from 30-50 minutes (EGB, 2022c; FEI, 2022b). If horses were to present at a veterinary inspection with a palpation score which gave some concerns to the veterinary panel, for example an increased palpation score or a change to an asymmetrical score but no presence of lameness, the horses could have physiotherapy during the hold period and return for a re-inspection to the veterinary panel to establish if changes have been made and concerns reduced. The FEI requires musculoskeletal therapists, including physiotherapists, to be registered as Permitted Equine Therapists (PET) in order to work on horses during competition (FEI, 2022a). They must identify themselves to the veterinary panel and are restricted to certain therapies within competition (FEI, 2022a). This is not required at British national level. Anecdotally many riders and/or support crews can be seen attempting massage techniques alongside other techniques which they have not had training in and may be of detriment to the horse. Perhaps, promotion of appropriately qualified professionals would be of benefit to the sport, not least in terms of horse welfare management but also in terms of the SLO. Whilst it may be argued that treatment during competition may be unethical, having appropriately qualified professionals would at least encourage appropriate treatment and support the riders to make the correct decisions as to whether to continue with the competition or they should retire their horse from the competition.

10.1.4 Inter-rater reliability of veterinarians

A key finding in this thesis has been the high IRR of veterinarian assessment, of lame limb(s) and epaxial muscle palpation. This finding is important to share with competitors, to provide them with high confidence in the veterinary panel, and that if the decision is taken to eliminate them, it is the correct one for the horse's welfare. This is especially important having identified hindlimb lameness as the most frequently identified limb, as previous studies have demonstrated that owner recognition of lameness and particularly hindlimb lameness is poor (Dyson and Pollard, 2020). If competitors were aware of this finding, it may reduce the problems that veterinary surgeons have faced within the sport, being challenged by competitors over the decision to eliminate (de Mira *et al.*, 2019) resulting in a more positive experience for all within the sport. Having a high degree of confidence in the veterinary surgeons decision(s) may also encourage competitors to seek a specific diagnosis and appropriate management post competition elimination. This in turn, may lead to a more successful return to competition, reducing the number of repeated eliminations which has been identified as a red flag for welfare. The results within this thesis identified that increased cumulative distances and rides are risk factors for lameness indicating that lameness in endurance horses is likely to be chronic in nature, manifesting at rides where the demands on the physiological and musculoskeletal system are increased. Previous research identified a lack of veterinary follow up (Nagy, Murray and Dyson, 2017). Identifying high IRR between veterinary surgeons, combined with increased education and promoting awareness may in turn encourage riders to seek more professional follow up post veterinary elimination. This could aid horses undergoing appropriate treatment and rehabilitation post lameness, prior to returning to competition, resulting in improved welfare and competitive career longevity.

10.2 Limitations within the thesis

Whilst limitations for each of the studies exist and have been acknowledged, the information provided within this thesis contributes to the knowledge framework of British endurance. The limitations of the first study, exist predominantly in the nature of design of the study, being retrospective in nature, the data set did not have the specific research question in mind at the time of recording the data. Therefore gaps within the data existed and as such could not be directly comparable to international studies, which had additional data such as speed and pacing strategies available (Zuffa, Bennet and Parkin, 2022; Bennet and Parkin, 2018b; Marlin and Williams, 2018b, 2018a; Younes *et al.*, 2015, 2016; Adamu *et al.*, 2014; Nagy, Murray and Dyson, 2010, 2014b, 2014a; Nagy, Dyson and Murray, 2012). This limitation was minimised by the second study.

Grading of the limbs in the second study using the AAEP scale was selected as it offers the most defined categories, which as demonstrated within this thesis, gave rise to credible IRR, but perhaps did not allow for the lower grades of lameness to be accurately documented.

Within the third study the method veterinarians performed to palpate the horses back was not standardised, except for the cranial- caudal direction. It was imperative that the study did not to interfere with the competition results and therefore no changes could be made to the veterinary examination. Whilst this may be considered a limitation in the palpation methods, it does give rise to stronger ecological validity of the results.

The number of horse starts, particularly in the 2021 competitive season, was lower than ideal, as numbers were limited due to COVID-19 government guidelines, however it was imperative to complete the studies within the competition environment, again to optimise ecological validity of the results. Additional information regarding saddle design and fit, rider standard and rider weight were not allowed to be collected but may have provided additional dimensions to further establish the cause-effect relationship between back pain and hindlimb lameness during endurance competitions. Perhaps future work could consider this.

Finally, the studies relating to back palpation were completed during the Covid-19 pandemic, it is not possible at this point to ascertain the impact this had on the results of the horses. Further information surrounding the change(s) to their preparation and competition scheduling would be required.

10.3 Recommendations for industry and future work

This thesis aimed to identify risk factors for elimination and specifically lameness elimination in British endurance. As risks have now been identified at British national level as well as international level, work on risk reduction, should be a priority. Based on the results of this thesis, the following recommendations are made:

Recommendation 1: Increase MOOCP

Bennet and Parkin (2020) demonstrated that risk reduction works with extending MOOCP at international level**.** The findings in this thesis suggest that extending the MOOCP would be of benefit as chronicity of injury has been demonstrated across the studies, with repeated eliminations, cumulative kilometres and cumulative starts within a competitive season being identified as risk factors. Whilst specific timeframes have not been identified within this study, likely due to the vast range of days between competitive starts, current best evidence would suggest to align the MOOCP with the FEI would be of benefit.

Recommendation 2: Reduce number of competitive starts within a year

Consideration should also be given to either a cap on the number of competitive starts, or the cumulative distance a horse can compete within a competitive season. As odds of elimination increased in the >10 category (Study 2b), consideration should be given to capping the number of starts to below ten in one competitive year.

Recommendation 3: Formalise back palpation scores

A significant link between back palpation scores and an increased likelihood of lameness has been identified within this thesis. Therefore, it is strongly recommended that the sport adopts the palpation grading system used within this thesis which has been shown to have high IRR. Further consideration should be given to the consequences of each palpation score.

Recommendation 4:

Research should centre around the management of endurance horses pre, peri and post competition. The research into training endurance horses specifically is sparse, with the main studies focussing on riders' descriptions of training (Webb *et al.*, 2019, 2020; Bolwell *et al.*, 2015). The physiological impact in terms of quantifying sub clinical damage occurring during training and prior to competition and whether competition is the catalyst for identification of the lameness has not been investigated. Research into training the endurance horse would of course be complicated due to the multifaceted demands and the evidence presented in this thesis demonstrates how the demands of the horse changes. Nevertheless, training of the horses should be a key focus for future work and educating competitors into the complexity and demand of training must also be a priority.

Recommendation 5: Increase knowledge and education of managing endurance horses during competition.

Management of horses during competition, should also be a focus of future work. The results presented here have demonstrated back pain to have a significant link with lameness during competition and asymmetrical palpation has been identified as a significant risk factor for lameness elimination, further work is required around this. During this study, no information surrounding the rider ability, fitness or weight was collected, no information on saddle type, design or frequency of fitting was collected and no information surrounding the normal management of the horses' musculoskeletal well-being pre, peri and post competition was collected. All of these factors would help provide a more robust picture to enable management strategies to be developed and recommended.

Recommendation 6: Increase the use of professionals within the sport

Specifically considering the findings of the epaxial muscle palpation study, it would certainly be of benefit to consider whether appropriate management techniques within the hold times in the vet gates has a beneficial impact. At international championships, the majority of teams will have a management team including a Chef d' Equipe, a licenced veterinarian, a farrier and a PET. However, frequently, only the Chef d'Equipe and veterinarian receive official accreditation at events. Whilst, it is impractical for each horse to have a full back up crew consisting of fully qualified personnel, by promoting the use of them at top level competition, it may encourage riders at lower levels to seek guidance from professionals regarding management strategies of the horses.

Recommendation 7: Capitalise and educate riders on the high inter-rater reliability of veterinarians

The sport should capitalise on the findings of high IRR of veterinarian in terms of lameness identification and back palpation, by promoting to riders that they should have confidence in the decision of the veterinary panel. Even if the riders themselves cannot see the lameness, the professionals have identified it and the riders' duty of care to the horse is to then ensure the horse receives a diagnosis for the lameness in order to manage it appropriately before returning to competition. Internationally, return to competition post repeated lameness has been considered and strategies have been employed to reduce risk by the extension of MOOCPs and the requirement for a specific veterinary inspection prior to return to competition (FEI, 2022b, 2022a). No such ruling exists at British national level and current legislation at national level means that repeated lameness' are not clearly highlighted to the veterinary panel at the time of competition, which perhaps, given lameness figures are not that dissimilar at higher levels to that of international competitors, they should be.

Recommendation 8: Continue with education to uphold the social licence to operate of the sport of endurance

As a result of this thesis, combined with EGB, steps have already been taken to enhance education of competitors and stakeholders within the sport to allowed more informed decision making surrounding the preparation and management of horses, pre, peri and post competition. Education of the demands of the sport to those that take part is key.

Whilst sport should always promote inclusivity, this should not be at the detriment of welfare, particularly when using animals. Perhaps, it is time to move away from endurance being seen as the sport anyone can do, to a sport that requires a huge investment to all that take part, in terms of investment of knowledge and skill. Riders should be seen as, and consider themselves as athletes and the horses, the ultimate athlete (Williams *et al.*, 2021). Perhaps, only when the complexity of the sport is acknowledged, can the management be truly optimised.

Recommendation 9: The governing body of the sport should improve on the data collection at competition.
This thesis demonstrates the complexity of identifying repeated eliminations and repeated lameness eliminations, which as discussed throughout are a red flag for equine welfare. Improving the data collection should be considered where by a repeated elimination is automatically flagged electronically, rather than relying solely on manual checks by stewards at the point of competition.

Recommendation 10: Future research evaluating the riders and saddle fit within competition should be considered as a priority.
Within this thesis it was demonstrated that back pain was a significant risk factor for elimination during competition. However, key factors (the riders and saddle fit) were not allowed to be considered. Analysing this information would provide an additional aspect which could be considered a modifiable risk factor in order to improve horse welfare. For example, if it was identified poorly fitting tack, or rider position impacted on back pain, education and change could be implemented to reduce the impact of this in future. Quantifying this would be of benefit to the sport and the welfare of the horses competing within the sport.

The results of this thesis, if considered by the governing body of the sport and are acted upon, could go some way to upholding the social licence of endurance within Britain. For this to happen the governing body, EGB must continue to support and increase the evidence-based research to underpin future development of the sport. Figure 18 shows the results and recommendations in the SLO framework.

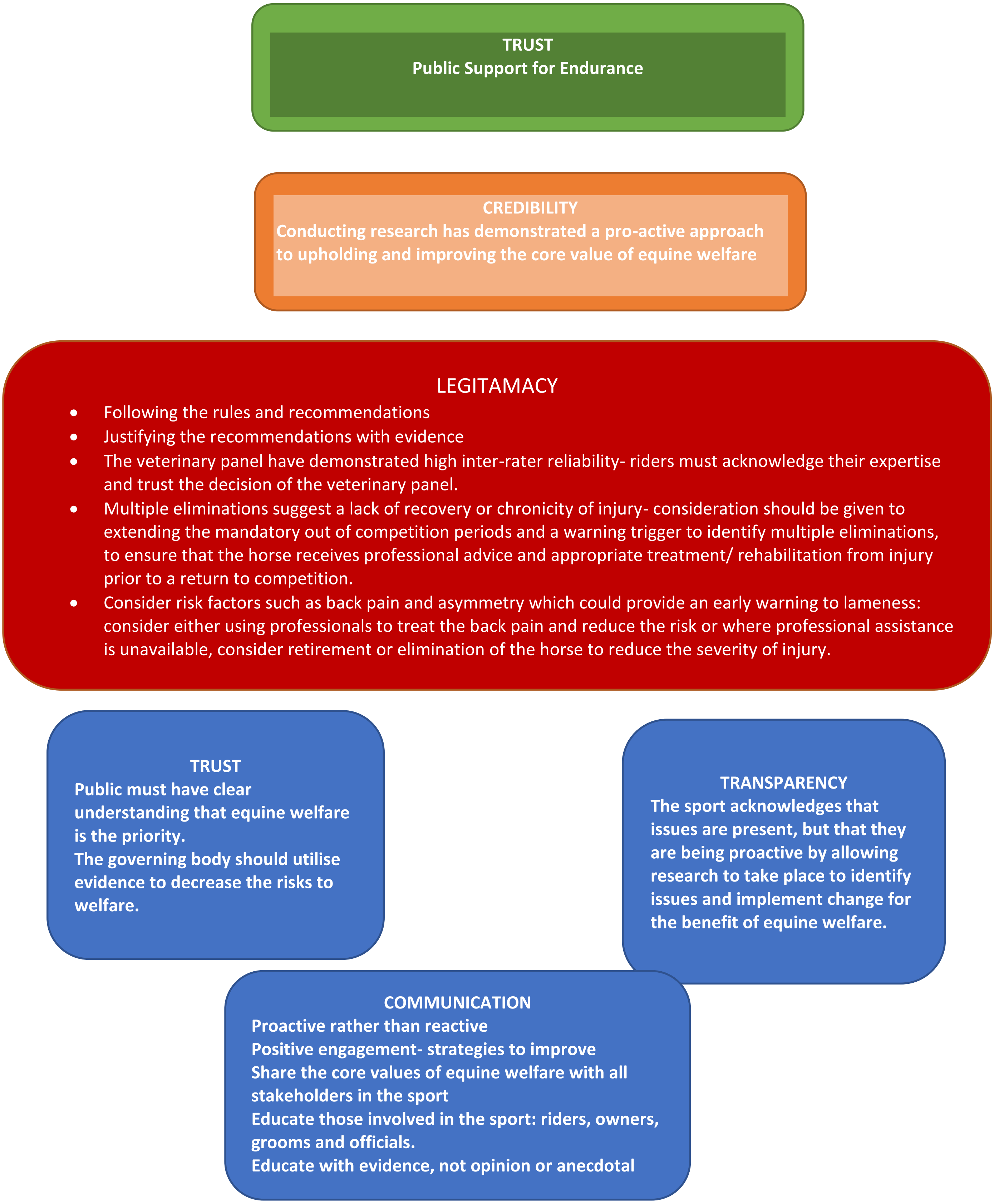

Figure 18: The results and recommendations in the Social License to Operate framework

Chapter 11

11.0 Conclusion

In conclusion, the results of this thesis have met the overarching aim to identify risk factors for elimination and more specifically lameness elimination from British national endurance competitions. It has furthered the knowledge and understanding of eliminations, and more specifically lameness eliminations in British national level endurance competitions. The aims have been met through a series of sequential studies, the results of each adding knowledge and value, but also informing the subsequent study development.

The findings of this thesis demonstrate that lameness is the leading cause of eliminations in British national endurance and consideration must be given to this, rather than continuing to view it as only a problem at FEI level. Throughout the thesis, multiple eliminations and lameness eliminations, have been identified as a red flag for equine welfare and considerations should be given by the sport's governing body for a more robust system to tackle this. Differences were found between risk factors at lower level single-loop competitions, to the more physiologically demanding, longer distanced multi-loop competitions.

A largely positive component of this thesis has identified that during competition, there is high IRR between examining veterinarians, which was found across lameness identification and thoracolumbar epaxial muscle palpation. This gives credibility to the veterinary panels' decision. It should also give confidence to riders that the veterinary decision is the correct one and provide positive affirmation to the public that welfare is fundamental to the sport.

For the first time, a standardised categorical scale was utilised to assess thoracolumbar epaxial musculature and its association with lameness eliminations during competition. The findings indicate that back palpation in horses competing within the sport should be considered as an important component of the veterinary examination. Further research surrounding this should be considered as beneficial to equine welfare within the sport.

The results of this thesis have been able identify issues and provide evidence informed recommendations to reduce risks to horses competing. The findings have allowed educational material to be developed and presented to stakeholders, including EGB board members and competitors within the sport and considerations for further work have been signposted. Each of these components are of benefit to the SLO of the sport of endurance and ultimately safeguard the welfare of the horse.

References

AAEP (2019) *LAMENESS EXAMS: Evaluating the Lame Horse | AAEP*2019 [online]. Available from: https://aaep.org/horsehealth/lameness-exams-evaluating-lame-horse [Accessed 12 November 2022].

Adamu, L., Adzahan, N.M., Rasedee, A. and Ahmad, B. (2014) Physical Parameters and Risk Factors Associated with the Elimination of Arabian and Crossed Arabian Endurance Horses during a 120-km Endurance Race. *Journal of Equine Veterinary Science*. [online]. 34 (4), pp.494–499. [Accessed 14 January 2021].

Adamu, L., Noraniza, M.A., Rasedee, A. and Bashir, A. (2013) Effect of age and performance on physical, haematological, and biochemical parameters in endurance horses. *Journal of Equine Veterinary Science*. [online]. 33 (6), pp.415–420. [Accessed 14 January 2021].

Al-Qudah, K.M. and Al-Majali, A.M. (2008) Higher lipid peroxidation indices in horses eliminated from endurance race because of synchronous diaphragmatic flutter (thumps). *Journal of Equine Veterinary Science*. [online]. 28 (10), pp.573–578. [Accessed 14 January 2021].

Altman, D.G. and Royston, P. (2006) The cost of dichotomising continuous variables. *BMJ*. [online]. 332 (7549), British Medical Journal Publishing Group, p.1080. [Accessed 10 December 2022]

Alvarez, C.B.G., Bobbert, M.F., Lamers, L., Johnston, C., Back, W. and Weeren, P.R. (2008) The effect of induced hindlimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Veterinary Journal*. [online]. 40 (2), pp.147–152. [Accessed 11 June 2022].

Annett, J. (2002) Subjective rating scales: science or art? *Ergonomics*. [online]. 45 (14), pp.966–987. [Accessed 8 April 2021].

Ashworth, B. (1964) Preliminary trial of carisoprodol in Multiple Sclerosis. *The Practitioner*. 192, pp.540–542.

Bailey, C.J., Reid, S.W., Hodgson, D.R., Suann, C.J. and Rose, R.J. (1997) Risk factors associated with musculoskeletal injuries in Australian thoroughbred racehorses. *Preventive Veterinary Medicine*. [online]. 32 (1–2), pp.47–55. [Accessed 8 December 2020].

Bandos, A.I., Rockette, H.E. and Gur, D. (2010) Use of likelihood ratios for comparisons of binary diagnostic tests: underlying ROC curves. *Medical Physics*. [online]. 37 (11), pp.5821–5830. [Accessed 17 September 2020].

Banse, H.E. and Andrews, F.M. (2019) Equine glandular gastric disease: prevalence, impact and management strategies. *Veterinary Medicine: Research and Reports*. [online]. Volume 10, pp.69–76. [Accessed 19 August 2022].

Bell, R., Kingston, J., Mogg, T. and Perkins, N. (2007) The prevalence of gastric ulceration in racehorses in New Zealand. *New Zealand Veterinary Journal*. [online]. 55 (1), pp.13–18. [Accessed 19 August 2022].

Belsley, D.A., Kuh, E. and Welsch, R.E. (1980*) Regression diagnostics: identifying influential data and sources of collinearity.* New York: John Wiley

Bendtsen, L., Jensen, R., Jensen, N. and Olesen, J. (1995) Pressure-controlled palpation: a new technique which increases the reliability of manual palpation. *Cephalalgia*. [online]. 15 (3), pp.205–210. [Accessed 15 January 2021].

Bennet, E.D., Cameron-Whytock, H. and Parkin, T.D.H. (2022) Fédération Equestre Internationale eventing: Risk factors for horse falls and unseated riders during the cross-country phase (2008-2018). *Equine Veterinary Journal*. [online]. 54 (5), pp.885–894. [Accessed 14 November 2022].

Bennet, E.D. and Parkin, T.D.H. (2018a) Fédération Equestre Internationale endurance events: Risk factors for failure to qualify outcomes at the level of the horse, ride and rider (2010–2015). *The Veterinary Journal*. [online]. 236, pp.44–48. [Accessed 7 January 2019].

Bennet, E.D. and Parkin, T.D.H. (2018b) Fédération Equestre Internationale (FEI) endurance events: Riding speeds as a risk factor for failure to qualify outcomes (2012–2015). *The Veterinary Journal*. [online]. 236, pp.37–43. [Accessed 7 January 2019].

Bennet, E.D. and Parkin, T.D.H. (2020) The impact of the mandatory rest period in Fédération Equestre Internationale endurance events. *Equine Veterinary Journal*. [online]. 52 (2), pp.268–272. [Accessed 5 January 2021].

Birch, H.L., McLaughlin, L., Smith, R.K.W. and Goodship, A.E. (1999) Treadmill exercise-induced tendon hypertrophy: assessment of tendons with different mechanical functions. *Equine Veterinary Journal.* [online]. 31 (S30), pp. 222-226. [Accessed 28 May 2023].
Blackstone, A. (2018) *Principles of Sociological Inquiry: Qualitative and Quantitative Methods* [online]. Saylor Academy Open Textbooks. Available from: https://openlibrary-repo.ecampusontario.ca/jspui/handle/123456789/296 [Accessed 3 September 2022].

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022a) A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019. *Comparative Exercise Physiology*. [online]. 18 (4), pp.329–338. [Accessed 3 December 2022].

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022b) Risk factors for lameness elimination in British endurance riding. *Equine Veterinary Journal*. [online]. p.evj.13875. [Accessed 3 December 2022].

Boden, L.A., Anderson, G.A., Charles, J.A., Morgan, K.L., Morton, J.M., Parkin, T.D.H., Clarke, A.F. and Slocombe, R.F. (2007) Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989–2004). *Equine Veterinary Journal*. [online]. 39 (5), pp.430–437. [Accessed 7 January 2019].

Bollinger, L., Bartel, A., Küper, A., Weber, C. and Gehlen, H. (2021) Age and hydration of competing horses influence the outcome of elite 160 km Endurance rides. *Frontiers in Veterinary Science*. [online]. 8, p.668650. [Accessed 19 January 2022].

Bolwell, C.F., Rogers, C.W., Rosanowski, S.M., Weston, J.F., Gee, E.K. and Gordon, S.J.G. (2015) Cross-sectional survey of the management and training practices of Endurance horses in New Zealand: A Pilot Study. *Journal of Equine Veterinary Science*. [online]. 35 (10), pp.801–806. [Accessed 19 January 2022].

Bondi, A., Norton, S., Pearman, L. and Dyson, S. (2020) Evaluating the suitability of an English saddle for a horse and rider combination. *Equine Veterinary Education*. [online]. 32 (S10), pp.162–172. [Accessed 14 June 2021].

Bookwala, A., Hussain, N. and Bhandari, M. (2011) The three-minute appraisal of a prospective cohort study. *Indian Journal of Orthopaedics*. [online]. 45 (4), pp.291–293. [Accessed 7 October 2022].

Boyde, A. and Firth, E.C. Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 8. Quantitative back-scattered electron scanning and electron microscopy and confocal fluorescence microscopy of the epiphysis of the third metacarpal bone. *New Zealand Veterinary Journal.* [online]. 53, pp. 123-132. [Accessed 8 June 2023].

British Dressage (2020) *BD youth horse care programme announced.* Available from: https://www.britishdressage.co.uk/news/bd-youth-horse-care-programme-announced/ [Accessed 18 October 2022].

British Eventing (2018) *Mark Todd bridging the gap scholarship applications open.* Available from: https://www.britishdressage.co.uk/news/bd-youth-horse-care-programme-announced/ [Accessed 18 October 2022].

Broeck, J.V. den, Cunningham, S.A., Eeckels, R. and Herbst, K. (2005) Data cleaning: detecting, diagnosing, and editing data abnormalities. *PLOS Medicine*. [online]. 2 (10), Public Library of Science, p.e267. [Accessed 8 December 2019].

Bruce, S.L., Rush, J.R., Torres, M.M. and Lipscomb, K.J. (2017) Test-retest and interrater reliability of core muscular endurance tests used for injury risk screening. *International Journal of Athletic Therapy and Training*. [online]. 22 (2), pp.14–20. [Accessed 17 January 2021].

Buchannan, C.I. and Marsh, R.L. (2002) Effects of exercise on the biomechanical, biochemical and structural properties of tendons. *Comparative Biochemistry and Physiology, Part A: Molecular and Integrative Physiology.* [online]. 133 (4), pp. 1101-1107. [Accessed 27 May 2023].

Burns, G., Dart, A. and Jeffcott, L. (2018) Clinical progress in the diagnosis of thoracolumbar problems in horses. *Equine Veterinary Education*. [online]. 30 (9), pp.477–485. [Accessed 17 January 2021].

Cameron-Whytock, H., Parkin, T.D.H., Hobbs, SJ., Brigden, C.V. and Bennet, E.D. (2023) Towards a safer sport: risk factors for cross-country falls at British Eventing competition. *Equine Veterinary Journal.* [online]. Available from: https://doi.org/10.1111/evj.13934 [Accessed 30 July 2023].

Cano, M.R., Vivo, J., MirÓ, F., Morales, J.L. and Galisteo, A.M. (2001) Kinematic characteristics of Andalusian, Arabian and Anglo-Arabian horses: a comparative study. *Research in Veterinary Science*. [online]. 71 (2), pp.147–153. [Accessed 8 December 2019].

Castejón, F., Rubio, D., Tovar, P., Vinuesa, M. and Riber, C. (1994) A comparative study of aerobic capacity and fitness in three different horse breeds (Andalusian, Arabian and Anglo-Arabian). *Journal of Veterinary Medicine Series A*. [online]. 41 (1–10), pp.645–652. [Accessed 8 December 2019].

Castejon-Riber, C., Riber, C., Rubio, M.D., Agüera, E. and Muñoz, A. (2017) Objectives, principles, and methods of strength training for horses. *Journal of Equine Veterinary Science*. [online]. 56, pp.93–103. [Accessed 8 December 2019].

Cherdchutham, W., Becker, C., Smith, R.K.W., Barneveld, A. and Van Weeren, P.R. (2010) Age-related changes and effect of exercise on the molecular composition of immature equine superficial digital flexor tendons. *Equine Veterinary Journal.* [online]. 31, pp. 86-94. [Accessed 28 May 2023].

Clansey, A.C., Hanlon, M., Wallace, E.S. and Lake, M.J. (2012) Effects of fatigue on running mechanics associated with tibial stress fracture risk. *Medicine & Science in Sports & Exercise*. [online]. 44 (10), pp.1917–1923. [Accessed 8 December 2019].

Clayton, HM (1991) *Conditioning sports horses* [online]. Mason MI: Sport Horse Publications. [Accessed 8 December 2019].

Coast, J.R., Blevins, J.S. and Wilson, B.A. (2004) Do gender differences in running performance disappear with distance? *Canadian Journal of Applied Physiology*. [online]. 29 (2), pp.139–145. [Accessed 8 December 2019].

Coggon, D., Barker, D. and Rose, G. (2009) *Epidemiology for the Uninitiated* [online]. John Wiley & Sons. [Accessed 15 January 2019].

Coombs, S.L. and Fisher, R.J. (2012) Endurance riding in 2012: Too far too fast? *The Veterinary Journal*. [online]. 194 (3), pp.270–271. [Accessed 15 January 2019].

Crawford, K.L., Finnane, A., Phillips, C.J.C., Greer, R.M., Woldeyohannes, S.M., Perkins, N.R., Kidd, L.J. and Ahern, B.J. (2021) The risk factors for musculoskeletal injuries in Thoroughbred Racehorses in Queensland, Australia: How these vary for two-year-old and older horses and with type of injury. *Animals*. [online]. 11 (2), p.270. [Accessed 7 June 2022].

Crook, T., Wilson, A. and Hodson-Tole, E. (2010) The effect of treadmill speed and gradient on equine hindlimb muscle activity. *Equine Veterinary Journal Supplement.* [online]. 38, pp. 412-416. [Accessed 29 May 2023].

Cuckson, P. (2020) UAE2020 Endurance: Business as usual in the killing fields. *Horse Sport*.10 January 2020 [online]. Available from: https://horsesport.com/cuckson-report-1/uae2020-endurance-business-as-asual-in-the-killing-fields/ [Accessed 15 November 2022].

Davidson, E.J. (2018) Lameness evaluation of the athletic horse. *Veterinary Clinics of North America: Equine Practice*. [online]. 34 (2), pp.181–191. [Accessed 7 June 2022].

De Heus, P., Van Oossanen, G., Van Dierendonck, M.C. and Back, W. (2010) A pressure algometer is a useful tool to objectively monitor the effect of diagnostic palpation by a physiotherapist in Warmblood horses. *Journal of Equine Veterinary Science*. [online]. 30 (6), pp.310–321. [Accessed 15 January 2021].

DeWeese, B.H., Hornsby, G., Stone, M. and Stone, M.H. (2015) The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science*. [online]. 4 (4), pp.308–317. [Accessed 8 December 2019].

Di Battista, C., Conte, M., Pepe, M., Petrizzi, L. and Beccati, F. (2019) Epidemiology and risk factors for eliminations from Fédération Equestre Internationale endurance rides between 2004–2015 in Italy. *Preventive Veterinary Medicine*. [online]. 170, p.104737. [Accessed 12 January 2021].

Dohoo, I.R., Ducrot, C., Fourichon, C., Donald, A. and Hurnik, D. (1997) An overview of techniques for dealing with large numbers of independent variables in epidemiologic studies. *Preventive Veterinary Medicine*. [online]. 29 (3), pp.221–239. [Accessed 15 January 2019].

Douglas, J., Owers, R. and Campbell, M.L.H. (2022) Social licence to operate: what can equestrian sports learn from other industries? *Animals*. [online]. 12 (15), p.1987. [Accessed 18 October 2022].

Dowling, B.A., and Dart, A.J. (2005) Functional properties of the equine superficial digital flexor tendon. *Veterinary Journal.* [online]. 170, pp. 184-192. [Accessed 28 May 2023].

Dressage Hub (2018) Guns, riots and death threats at the World Equestrian Games in Tryon2018 [online]. Available from: https://www.youtube.com/watch?v=9ZDvCmhxwSA.[Accessed 8 December 2019].

Duncan, E., Graham, R. and McManus, P. (2018) 'No one has even seen… smelt… or sensed a social licence': Animal geographies and social licence to operate. *Geoforum*. [online]. 96, pp.318–327. [Accessed 16 May 2022].

Dutto, D.J., Hoyt, D.F., Cogger, E.A. and Wickler, S.J. (2004) Ground reaction forces in horses trotting up an incline and on the level over a range of speeds. *Journal of Experimental Biology*. [online]. 207 (20), pp.3507–3514. [Accessed 14 June 2021].

Dyson, S. (2011) Can lameness be graded reliably? *Equine Veterinary Journal*. [online]. 43 (4), pp.379–382. [Accessed 14 June 2021].

Dyson, S., Carson, S. and Fisher, M. (2015) Saddle fitting, recognising an ill-fitting saddle and the consequences of an ill-fitting saddle to horse and rider. *Equine Veterinary Education*. [online]. 27 (10), pp.533–543. [Accessed 14 June 2021].

Dyson, S. and Greve, L. (2016) Subjective gait assessment of 57 sports horses in normal work: a comparison of the response to flexion tests, movement in hand, on the lunge, and ridden. *Journal of Equine Veterinary Science*. [online]. 38, pp.1–7. [Accessed 14 June 2021].

Dyson, S. and Pollard, D. (2020) Application of a ridden horse pain ethogram and Its relationship with gait in a convenience sample of 60 riding horses. *Animals*. [online]. 10 (6), p.1044. [Accessed 14 June 2021].

EGB (2022a) *Endurance GB Endurance GB Education Series*.2022 [online]. Available from: http://www.endurancegb.co.uk/Shop/Browse [Accessed 3 December 2022].

EGB (2022b) *Results Archive*2022 [online]. Available from: https://www.endurancegb.co.uk/Cms/Spaces/RA/Results+Archive [Accessed 3 December 2022].

EGB (2022c) *The 2022 Endurance GB rule book* [online]. Available from: https://www.endurancegb.co.uk/Client/Documents/2022_Handbook_v1.0.pdf.[Accessed 3 December 2022].

EGB (2023) *Endurance GB events calendar* [online]. Available from: https://www.endurancegb.co.uk/Events/Calendar?sortAscending=true&displayMode=map&filter=&pageSize=20&selectedDate=23%2F07%2F2023&pageOffset=0 [Accessed 30 May 2023].

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P. (2010) The effect of exercise regimens on racing performance in National Hunt racehorses. *Equine Veterinary Journal*. [online]. 42 (s38), pp.624–629.[Accessed 8 June 2019].

Entin, P. (2007) Do racehorses and Greyhound dogs exhibit a gender difference in running speed? *Equine and Comparative Exercise Physiology*. [online]. 4 (3–4), pp.135–140.[Accessed 8 May 2021].

Etikan, I., Musa, S.A. and Alkassim, R.S. (2016) Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*. [online]. 5 (1), p.1.[Accessed 15 January 2019].

Eugenio, B.D. and Glass, M. (2004) The kappa statistic: a second look. *Computational Linguistics*. [online]. 30 (1), pp.95–101.[Accessed 10 October 2020].

FEI (2018) *Cancellation of Endurance Competition at FEI World Equestrian Games™ Tryon 2018 FEI*.2018 [online]. Available from: https://inside.fei.org/media-updates/cancellation-endurance-competition-fei-world-equestrian-games%E2%84%A2-tryon-2018 [Accessed 21 November 2022].

FEI (2022a) *FEI 2022 Veterinary Regulations* [online]. Available from: https://inside.fei.org/sites/default/files/2022%20Veterinary%20Regulations%20_%20clean%20version%20with%20changes%20from%20Emergency%20Board%20Resolution%20-%208Sept22.pdf.[Accessed 21 November 2022].

FEI (2020) *FEI Endurance: 2019 Annual Report* [online]. Available from: https://inside.fei.org/sites/default/files/FEI_Endurance_Report_2019.final.pdf. [Accessed 21 November 2022].

FEI (2022b) *FEI Endurance Rules 11th Edition.* [online]. Available from: https://inside.fei.org/sites/default/files/FEI%20Endurance%20Rules%20-%201%20January%202022%20-%20CLEAN%20VERSION%20-%20Gender%20Neutral.pdf. [Accessed 21 November 2022].

Fiedler, J. and McGreevy, P. (2016) Reconciling horse welfare, worker safety, and public expectations: horse event incident management systems in Australia. *Animals*. [online]. 6 (3), p.16.[Accessed 16 May 2022].

Field, A. (2013) *Discovering Statistics Using IBM SPSS Statistics* SAGE.

Fielding, C.L., Meier, C.A., Balch, O.K. and Kass, P.H. (2011) Risk factors for the elimination of endurance horses from competition. *Journal of the American Veterinary Medical Association*. [online]. 239 (4), pp.493–498. [Accessed 15 January 2019].

Firth, E.C., Rogers, C.W., Doube, M. and Jopson, N.B. (2005). Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 6. Bone parameters in the third metacarpal and third metatarsal bones. *New Zealand Veterinary Journal.* [online]. 53 (2), pp.101-112. [Accessed 23 May 2023].

Foreman, J.H. (1998) The exhausted horse syndrome. *Veterinary Clinics of North America: Equine Practice*. [online]. 14 (1), pp.205–219. [Accessed 15 January 2019].

Foreman, J.H. and Lawrence, L.M. (1991) Lameness and heart rate elevation in the exercising horse. *Journal of Equine Veterinary Science*. [online]. 11 (6), pp.353–356. [Accessed 15 January 2019].

Fuller, C.J., Bladon, B.M., Driver, A.J. and Barr, A.R.S. (2006) The intra- and inter-assessor reliability of measurement of functional outcome by lameness scoring in horses. *The Veterinary Journal*. [online]. 171 (2), pp.281–286.[Accessed 14 June 2021].

Gabbett, T. (2016) The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine*. 50 (5), pp.273–280. [Accessed 8 December 2019].

Gardner, I.A. and Greiner, M. (2006) Receiver-operating characteristic curves and likelihood ratios: improvements over traditional methods for the evaluation and application of veterinary clinical pathology tests. *Veterinary Clinical Pathology*. [online]. 35 (1), pp.8–17. [Accessed 10 October 2020].

Georgopoulos, S.P. and Parkin, T.D.H. (2016) Risk factors associated with fatal injuries in Thoroughbred racehorses competing in flat racing in the United States and Canada. *Journal of the American Veterinary Medical Association*. [online]. 249 (8), pp.931–939. [Accessed 7 January 2019].

Ghasemi, A. and Zahediasl, S. (2012) Normality Tests for Statistical Analysis: A Guide for Non-Statisticians. *International Journal of Endocrinology and Metabolism*. [online]. 10 (2), pp.486–489. [Accessed 10 October 2020].

Grabe, M.E., Zhou, S. and Barnett, B. (2001) Explicating Sensationalism in Television News: Content and the Bells and Whistles of Form. *Journal of Broadcasting & Electronic Media*. [online]. 45 (4), pp.635–655. [Accessed 8 December 2019].

Greve, L. and Dyson, S. (2015) Saddle fit and management: An investigation of the association with equine thoracolumbar asymmetries, horse and rider health: Saddle fit and management. *Equine Veterinary Journal*. [online]. 47 (4), pp.415–421. [Accessed 14 June 2021].

Greve, L. and Dyson, S.J. (2013) An investigation of the relationship between hindlimb lameness and saddle slip: Saddle slip and lameness. *Equine Veterinary Journal*. [online]. 45 (5), pp.570–577. [Accessed 14 June 2021]

Greve, L., Murray, R. and Dyson, S. (2015) Subjective analysis of exercise-induced changes in back dimensions of the horse: The influence of saddle-fit, rider skill and work quality. *The Veterinary Journal*. [online]. 206 (1), pp.39–46. [Accessed 14 June 2021].

Gruyaert, M., Pollard, D. and Dyson, S.J. (2020) An investigation into the occurrence of, and risk factors for, concurrent suspensory ligament injuries in horses with hindlimb proximal suspensory desmopathy. *Equine Veterinary Education*. [online]. 32 (S10), pp.173–182. [Accessed 14 June 2021].

Gunnarsson, V., Stefánsdóttir, G.J., Jansson, A. and Roepstorff, L. (2017) The effect of rider weight and additional weight in Icelandic horses in tölt: part II. Stride parameters responses. *Animal*. [online]. 11 (9), pp.1567–1572. [Accessed 14 June 2021].

Gunst, S., Dittmann, M.T., Arpagaus, S., Roepstorff, C., Latif, S.N., Klaassen, B., Pauli, C.A., Bauer, C.M. and Weishaupt, M.A. (2019) Influence of functional rider and horse asymmetries on saddle force distribution during stance and in sitting trot. *Journal of Equine Veterinary Science*. [online]. 78, pp.20–28. [Accessed 14 June 2021].

Hammarberg, M., Egenvall, A., Pfau, T. and Rhodin, M. (2016) Rater agreement of visual lameness assessment in horses during lungeing. *Equine Veterinary Journal*. [online]. 48 (1), pp.78–82.[Accessed 17 May 2021].

Hampton, J.O., Jones, B. and McGreevy, P.D. (2020) Social License and Animal Welfare: Developments from the Past Decade in Australia. *Animals*. [online]. 10 (12), p.2237. [Accessed 16 May 2022].

Heleski, C., Stowe, C.J., Fiedler, J., Peterson, M.L., Brady, C., Wickens, C. and MacLeod, J.N. (2020) Thoroughbred racehorse welfare through the lens of ‘social license to operate—with an emphasis on a U.S. perspective. *Sustainability*. [online]. 12 (5), p.1706.[Accessed 16 May 2022].

Henley, W.E., Rogers, K., Harkins, L. and Wood, J.L.N. (2006) A comparison of survival models for assessing risk of racehorse fatality. *Preventive Veterinary Medicine*. [online]. 74 (1), pp.3–20. [Accessed 7 January 2019].

Hewetson, M., Christley, R.M., Hunt, I.D. and Voute, L.C. (2006) Investigations of the reliability of observational gait analysis for the assessment of lameness in horses. *Veterinary Record*. [online]. 158 (25), pp.852–858.[Accessed 18 June 2020].

Hicks, C. (2004) *Research methods for clinical therapists: applied project and design analysis.* 4th edition. Edinburgh, Churchill Livingstone.

Hitchens, P. L., Morrice-West, A. V., Stevenson, M. A., & Whitton, R. C. (2019). Meta-analysis of risk factors for racehorse catastrophic musculoskeletal injury in flat racing. *The Veterinary Journal*. [online]. 245, pp.29-40.[Accessed 28 May 2023].

Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L.M. and Fell, J. (2012) The association between jockey experience and race-day falls in flat racing in Australia. *Injury Prevention*. [online]. 18 (6), pp.385–391.[Accessed 18 January 2019].

Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L.M. and Fell, J.(2010) Predictors in race-day falls in flat racing in Australia. *Occupational and Environmental Medicine.*[online]. 67 (10), pp.693-698.[Accessed 17 May 2020].

Hobbs, S.J., Baxter, J., Broom, L., Rossell, L.-A., Sinclair, J. and Clayton, H.M. (2014) Posture, Flexibility and Grip Strength in Horse Riders. *Journal of Human Kinetics*. [online]. 42 (1), pp.113–125.[Accessed 9 December 2020].

Holtzhausen ,L..J; Schwellnus, M.P.; Jakeot, I.; Pretorius, A.L. (2007) The incidence and nature of injuries in South African rugby players in the rugby super 12 competition. *South African Medical Journal*. 96 (12), pp.1260–1265.[Accessed 14 October 2021].

Hosmer, D.W and Lemeshow, S. (2000) *Applied logistic regression.* 2nd edition. New York, USA, John Wiley and Sons Inc.

Hurcombe, S.D.A, Radcliffe, R.M, Cook, V.L. and Divers, T.J. (2022) The pathology of uncontrolled hemorrhage in horses. *Journal of Veterinary Emergency and Critical Care.* [online]. 32 (S1), pp. 63-71. [Accessed 25 May 2023].

Ii, H.C.S. *et al.* (2006) Changes in selected physiological and laboratory measurements in elite horses competing in a 160 km endurance ride. *Equine Veterinary Journal*. [online]. 38 (S36), pp.37–42.[Accessed 18 January 2019].

Jenkins, S.P. (2017) Beyond 'crude pragmatism' in sports coaching: Insights from C.S. Peirce, William James and John Dewey. *International Journal of Sports Science & Coaching*. [online]. 12 (1), pp.8–19.[Accessed 14 December 2021].

Jepsen, J.R., Laursen, L.H., Hagert, C.-G., Kreiner, S. and Larsen, A.I. (2006) Diagnostic accuracy of the neurological upper limb examination I: Inter-rater reproducibility of selected findings and patterns. *BMC Neurology*. [online]. 6 (1), p.8.[Accessed 19 June 2022].

Jones, Eleanor (2020) Record FEI ban for rider of 'nerve-blocked' horse who suffered horrific fracture *Horse and Hound*. [online]. Available from: https://www.horseandhound.co.uk/plus/news-plus/record-fei-ban-for-rider-of-nerve-blocked-horse-who-suffered-horrific-fracture-hh-plus-716845 [Accessed 10 October 2020].

Jones, Eleanor (2022) This is NOT endurance: calls for world to unite in condemnation after at least two horses die *Horse and Hound*. [online]. Available from: https://www.horseandhound.co.uk/news/this-is-not-endurance-calls-for-world-to-unite-in-condemnation-after-at-least-two-horses-die-773575 [Accessed 3 June 2022].

Kaneps, A.J. (2016) Practical rehabilitation and physical therapy for the general equine practitioner. *Veterinary Clinics of North America: Equine Practice*. [online]. 32 (1), pp.167–180.[Accessed 14 November 2021].

Karanicolas, P.J., Farrokhyar, F. and Bhandari, M. (2010) Blinding: Who, what, when, why, how? *Canadian Journal of Surgery*. 53 (5), pp.345–348.[Accessed 8 May 2022].

Keegan, K.G. *et al.* (1998) Evaluation of mild lameness in horses trotting on a treadmill by clinicians and interns or residents and correlation of their assessments with kinematic gait analysis. *American Journal of Veterinary Research*. 59 (11), pp.1370–1377.[Accessed 6 May 2021].

Keegan, K.G. (2007) Evidence-based lameness detection and quantification. *Veterinary Clinics of North America: Equine Practice*. [online]. 23 (2), pp.403–423.[Accessed 6 May 2021].

Keegan, K.G. *et al.* (2010) Repeatability of subjective evaluation of lameness in horses: Repeatability of subjective evaluation of lameness in horses. *Equine Veterinary Journal*. [online]. 42 (2), pp.92–97.[Accessed 6 May 2021].

Keegan, K.G., Kramer, J., Yonezawa, Y., Maki, H., Pai, P.F., Dent, E.V., Kellerman, T.E., Wilson, D.A. and Reed, S.K. (2011) Assessment of repeatability of a wireless, inertial sensor–based lameness evaluation system for horses. *American Journal of Veterinary Research*. [online]. 72 (9), pp.1156–1163.[Accessed 6 May 2021].

Keegan, K.G., Yonezawa, Y., Pai, P.F., Wilson, D.A. and Kramer, J. (2004) Evaluation of a sensor-based system of motion analysis for detection and quantification of forelimb and hind limb lameness in horses. *American Journal of Veterinary Research*. [online]. 65 (5), pp.665–670.[Accessed 6 May 2021].

Kellmann, M. (2010) Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring: Preventing overtraining. *Scandinavian Journal of Medicine & Science in Sports*. [online]. 20, pp.95–102.[Accessed 19 October 2021].

Kihlstrom, J.F. (2021) Ecological validity and “ecological validity”. *Perspectives on Psychological Science*. [online]. 16 (2), pp.466–471.[Accessed 11 October 2022].

Knechtle, B., Chlíbková, D., Papadopoulou, S., Mantzorou, M., Rosemann, T. and Nikolaidis, P.T. (2019) Exercise-associated hyponatremia in endurance and ultra-endurance performance–aspects of sex, race location, ambient temperature, sports discipline, and length of performance: a narrative review. *Medicina*. [online]. 55 (9), p.537.[Accessed 18 December 2021].

Krane, V. and Baird, S.M. (2005) Using ethnography in applied sport psychology. *Journal of Applied Sport Psychology*. [online]. 17 (2), pp.87–107.[Accessed 18 December 2021].

Lachin, J.M. (2004) The role of measurement reliability in clinical trials. *Clinical Trials*. [online]. 1 (6), pp.553–566. [Accessed 6 May 2021].

Lakoski, S.G., Barlow, C.E., Farrell, S.W., Berry, J.D., Morrow, J.R. and Haskell, W.L. (2011) Impact of body mass index, physical activity, and other clinical factors on cardiorespiratory fitness (from the Cooper Center Longitudinal Study). *The American Journal of Cardiology*. [online]. 108 (1), pp.34–39.[Accessed 14 December 2021].

Lam, K.K.H., Parkin, T.D.H., Riggs, C.M. and Morgan, K.L. (2007) Evaluation of detailed training data to identify risk factors for retirement because of tendon injuries in Thoroughbred racehorses. *American Journal of Veterinary Research*. [online]. 68 (11), pp.1188–1197.[Accessed 15 January 2019].

Landman, M.A.A.M., de Blaauw, J.A., Hofland, L.J. and van Weeren, P.R. (2004) Field study of the prevalence of lameness in horses with back problems. *Veterinary Record*. [online]. 155 (6), pp.165–168. [Accessed 11 December 2020].

Lawan, A., Noraniza, M.A, Rasedee, A., and Bashir, A. (2012) Prevalence of lameness and metabolic disorders in endurance horses. *Malaysian Journal of Veterinary Research*. 3 (1), pp.33–37.[Accessed 15 January 2019].

Legg, K.A., Weston, J.F., Gee, E.K., Bolwell, C.F., Bridges, J.P. and Rogers, C.W. (2019) Characteristics of endurance competitions and risk factors for elimination in New Zealand during six seasons of competition (2010/11–2015/16). *Animals*. [online]. 9 (9), Multidisciplinary Digital Publishing Institute, p.611.[Accessed 11 December 2020].

Lindinger, M.I. and Ecker, G.L. (2010) Ion and water losses from body fluids during a 163 km endurance ride. *Equine Veterinary Journal*. [online]. 27 (S18), pp.314–322.[Accessed 18 January 2019].

Lopes, M.A.F., Eleuterio, A. and Mira, M.C. (2018) Objective detection and quantification of irregular gait with a portable inertial sensor-based system in horses during an endurance race—a preliminary assessment. *Journal of Equine Veterinary Science*. [online]. 70, pp.123–129.[Accessed 18 January 2019].

Loughridge, A.B., Hess, A.M., Parkin, T.D. and Kawcak, C.E. (2017) Qualitative assessment of bone density at the distal articulating surface of the third metacarpal in Thoroughbred racehorses with and without condylar fracture. *Equine Veterinary Journal*. [online]. 49 (2), pp.172–177.[Accessed 15 December 2020].

MacKechnie-Guire, R., MacKechnie-Guire, E., Fairfax, V., Fisher, M., Hargreaves, S. and Pfau, T. (2020) The effect that induced rider asymmetry has on equine locomotion and the range of motion of the thoracolumbar spine when ridden in rising trot. *Journal of Equine Veterinary Science*. [online]. 88, p.102946. [Accessed 14 June 2021].

MacKinnon, M.C., Bonder, D., Boston, R.C. and Ross, M.W. (2015) Analysis of stress fractures associated with lameness in Thoroughbred flat racehorses training on different track surfaces undergoing nuclear scintigraphic examination. *Equine Veterinary Journal*. [online]. 47 (3), pp.296–301. [Accessed 15 December 2020].

Majeed, I. (2019) Understanding positivism in social research: a research paradigm of inductive logic of inquiry. *International Journal of Research in Social Sciences*. 9 (11), p.9.

Marlin, D. and Williams, J. (2018a) Equine endurance race pacing strategy and performance in 120-km single-day races. *Journal of Equine Veterinary Science*. [online]. 67, pp.87–90.[Accessed 12 October 2019].

Marlin, D. and Williams, J. (2018b) Equine endurance race pacing strategy differs between finishers and non-finishers in 120 km single-day races. *Comparative Exercise Physiology*. [online]. 14 (1), pp.11–18.[Accessed 12 October 2019].

Marshall, J.F., Lund, D.G. and Voute, L.C. (2012) Use of a wireless, inertial sensor-based system to objectively evaluate flexion tests in the horse: Sensor-based system to objectively evaluate flexion tests in horses. *Equine Veterinary Journal*. [online]. 44, pp.8–11.[Accessed 6 May 2021].

Martig, S., Chen, W., Lee, P.V.S. and Whitton, R.C. (2014) Bone fatigue and its implications for injuries in racehorses: Bone fatigue in racehorses. *Equine Veterinary Journal*. [online]. 46 (4), pp.408–415. [Accessed 12 October 2019].

Martig, S., Hitchens, P.L., Lee P.V.S. and Whitton, R.C. (2020) The relationship between microstructure, stiffness and compressive fatigue life of equine subchondral bone. *Journal of Mechanical Behavior of Biomedical Materials.* [online]. 101, 103439. [Accessed 23 May, 2023].

Martig, S., Lee, P.V.S., Anderson, G.A. and Whitton, R.C. (2013) Compressive fatigue life of subchondral bone of the metacarpal condyle in thoroughbred racehorses. *Bone.* [online]. 57 (2), pp. 392-398. [Accessed 28 May 2023].

Mayaki, A.M., Abdul Razak, I.S., Adzahan, N.M., Mazlan, M. and Rasedee, A. (2020) Clinical assessment and grading of back pain in horses. *Journal of Veterinary Science*. [online]. 21 (6), p.e82.[Accessed 14 June 2021].

McCracken, M.J., Kramer, J., Keegan, K.G., Lopes, M., Wilson, D.A., Reed, S.K., LaCarrubba, A. and Rasch, M. (2012) Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation: Comparison of inertial system with subjective lameness evaluation. *Equine Veterinary Journal*. [online]. 44 (6), pp.652–656.[Accessed 6 May 2021].

McLean, A.N. and McGreevy, P.D. (2010) Ethical equitation: Capping the price horses pay for human glory. *Journal of Veterinary Behavior*. [online]. 5 (4), pp.203–209.[Accessed 18 October 2022].

van Mechelen, W., Hlobil, H. and Kemper, H.C.G. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine*. [online]. 14 (2), pp.82–99.[Accessed 17 May 2020].

Merrifield-Jones, M., Tabor, G. and Williams, J. (2019) Inter- and intra-rater reliability of soft tissue palpation scoring in the equine thoracic epaxial region. *Journal of Equine Veterinary Science*. [online]. 83, p.102812.[Accessed 17 December 2020].

Met Office (2022) *A milestone in UK climate history Met Office*.2022 [online]. Available from: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/july-heat-review [Accessed 21 November 2022].

de Mira, M.C., Santos, C., Lopes, M.A. and Marlin, D.J. (2019) Challenges encountered by Federation Equestre Internationale (FEI) veterinarians in gait evaluation during FEI endurance competitions: an international survey. *Comparative Exercise Physiology*. [online]. 15 (5), pp.371–378.[Accessed 17 December 2020].

Misheff, M.M., Alexander, G.R. and Hirst, G.R. (2010) Management of fractures in endurance horses: Management of fractures in endurance horses. *Equine Veterinary Education*. [online]. 22 (12), pp.623–630.[Accessed 12 October 2019].

Mizobe, F., Takahashi, Y. and Kusano, K. (2021) Risk factors for jockey falls in Japanese Thoroughbred flat racing. *Journal of Equine Veterinary Science*. [online]. 106, p.103749.[Accessed 11 January 2022].

Montalvo, A.M., Shaefer, H., Rodriguez, B., Li, T., Epnere, K. and Myer, G.D. (2017) Retrospective injury epidemiology and risk factors for injury in CrossFit. *Journal of Sports Science & Medicine*. 16 (1), pp.53–59. [Accessed 11 January 2022].

Montejo, G. and Adriano, T. (2018) A critical discourse analysis of headlines in online news portals. *Journal of Advances in Humanities and Social Sciences*. 4 (2), pp.70–83.[Accessed 8 May 2021].

Moon, K. and Blackman, D. (2014) A guide to understanding social science research for natural scientists: social science for natural scientists. *Conservation Biology*. [online]. 28 (5), pp.1167–1177.[Accessed 8 May 2021].

Morrison, R. (2016) Pragmatist epistemology and Jane Addams: Fundamental concepts for the social paradigm of occupational therapy: Pragmatist epistemology and Jane Addams. *Occupational Therapy International*. [online]. 23 (4), pp.295–304.[Accessed 11 January 2022].

Mota, P., Pascoal, A.G., Sancho, F., Carita, A.I. and Bø, K. (2013) Reliability of the inter-rectus distance measured by palpation. Comparison of palpation and ultrasound measurements. *Manual Therapy*. [online]. 18 (4), pp.294–298. [Accessed 14 June 2021].

Mueller, M.J. and Maluf, K.S. (2002) Tissue adaptation to physical stress: a proposed 'physical stress theory' to guide physical therapist practice, education and research. *Physical Therapy.* [online] 82 (4), pp. 383-403. [Accessed 28 May 2023].

Mukai, K., Takahashi, T., Hada, T., Eto, D., Kusano, K., Yokota, S., Hiraga, A. and Ishida, N. (2003) Influence of gender and racing performance on heart rates during submaximal exercise in Thoroughbred racehorses. *Journal of Equine Science*. [online]. 14 (3), pp.93–96. [Accessed 17 May 2020].

Mukaka, M. (2012) A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal*. 24 (3), pp.69–71.[Accessed 11 November 2019].

Müller-Quirin, J., Dittmann, M.T., Roepstorff, C., Arpagaus, S., Latif, S.N. and Weishaupt, M.A. (2020) Riding soundness—comparison of subjective with objective lameness assessments of owner-sound horses at trot on a treadmill. *Journal of Equine Veterinary Science*. [online]. 95, p.103314.[Accessed 6 May 2021].

Munoz-Nates, F., Chateau, H., Pourcelot, P., Camus, M., Ravary-Plumioen, B., Denoix, J.m. and Crevier-Denoix, N. (2017) Ground reaction force and impulses of fore and hindlimbs in horses at trot on an asphalt track: effects of an inclined (uphill) compared to a flat surface. *Computer Methods in Biomechanics and Biomedical Engineering.* [online]. 20 (1), pp. S143-S144. [Accessed 30 May 2023].

Muñoz, A., Riber, C., Trigo, P., Castejón-Riber, C. and Castejón, F.M. (2010) Dehydration, electrolyte imbalances and renin-angiotensin-aldosterone-vasopressin axis in successful and unsuccessful endurance horses: RAAV in horses. *Equine Veterinary Journal*. [online]. 42, pp.83–90.[Accessed 15 January 2019].

Munsters, C.C.B.M., Kingma, B.R.M., van den Broek, J. and Sloet van Oldruitenborgh-Oosterbaan, M.M. (2020) A prospective cohort study on the acute: chronic workload ratio in relation to injuries in high level eventing horses: A comprehensive 3-year study. *Preventive Veterinary Medicine*. [online]. 179, p.105010.[Accessed 11 December 2020].

Murray, J.K., Singer, E.R., Morgan, K.L., Proudman, C.J. and French, N.P. (2005) Risk factors for cross-country horse falls at one-day events and at two-/three-day events. *The Veterinary Journal*. [online]. 170 (3), pp.318–324.[Accessed 18 January 2019].

Murray, R., Guire, R., Fisher, M. and Fairfax, V. (2017) Reducing peak pressures under the saddle panel at the level of the 10th to 13th thoracic vertebrae may be associated with improved gait features, even when saddles are fitted to published guidelines. *Journal of Equine Veterinary Science*. [online]. 54, pp.60–69.[Accessed 14 June 2021].

Murray, R.C., Dyson, S.J., Tranquille, C. and Adams, V. (2006) Association of type of sport and performance level with anatomical site of orthopaedic injury diagnosis. *Equine Veterinary Journal*. [online]. 38 (S36), pp.411–416.[Accessed 18 January 2019].

Murray, R.C., Walters, J.M., Snart, H., Dyson, S.J. and Parkin, T.D.H. (2010) Identification of risk factors for lameness in dressage horses. *The Veterinary Journal*. [online]. 184 (1), pp.27–36. [Accessed 18 January 2019].

Nagy, A., Dyson, S.J. and Murray, J.K. (2012) A veterinary review of endurance riding as an international competitive sport. *The Veterinary Journal*. [online]. 194 (3), pp.288–293.[Accessed 15 January 2019].

Nagy, A., Dyson, S.J. and Murray, J.K. (2017) Veterinary problems of endurance horses in England and Wales. *Preventive Veterinary Medicine*. [online]. 140, pp.45–52. [Accessed 15 January 2019].

Nagy, A., Murray, J.K. and Dyson, S. (2010) Elimination from elite endurance rides in nine countries: A preliminary study: Elimination from endurance rides. *Equine Veterinary Journal*. [online]. 42, pp.637–643. [Accessed 15 January 2019].

Nagy, A., Murray, J.K. and Dyson, S.J. (2014a) Descriptive epidemiology and risk factors for eliminations from Fédération Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). *Equine Veterinary Journal*. [online]. 46 (1), pp.38–44. [Accessed 15 January 2019].

Nagy, A., Murray, J.K. and Dyson, S.J. (2014b) Horse-, rider-, venue- and environment-related risk factors for elimination from Fédération Equestre Internationale endurance rides due to lameness and metabolic reasons: Risk factors for elimination from endurance rides. *Equine Veterinary Journal*. [online]. 46 (3), pp.294–299. [Accessed 15 January 2019].

Nedkova-Ivanova, R. and Valev, Y. (2020) Short-term training program for the preparation period in the endurance discipline of equestrian sport. *Journal of Applied Sports Science.* [online]. 2, pp.69-79. [Accessed 08 June 2023].

Nylund, L.E., Sinclair, P.J., McLean, A.N. and Cobley, S. (2021) Development of a video analysis protocol and assessment of fall characteristics in equestrian cross-country eventing. *Scandinavian Journal of Medicine & Science in Sports*. [online]. 31 (12), pp.2187–2197. [Accessed 6 May 2021].

Ortved, K.F. (2018) Regenerative medicine and rehabilitation for tendinous and ligamentous injuries in sports horses. *Veterinary Clinics: Equine Practice.* [online]. 34 (2), pp.359-373. [Accessed 28 May 2023].

Owen, K.R., Singer, E.R., Clegg, P.D., Ireland, J.L. and Pinchbeck, G.L. (2011) Identification of risk factors for traumatic injury in the general horse population of north-west England, Midlands and north Wales. *Equine veterinary Journal.* [online]. 44 (2), pp. 144-148. [Accessed 01 June 2023].

Paris, A., Beccati, F. and Pepe, M. (2021) Type, prevalence, and risk factors for the development of orthopedic injuries in endurance horses during training and competition. *Journal of the American Veterinary Medical Association*. [online]. 258 (10), pp.1109–1118.[Accessed 12 January 2022].

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2010a) Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal*. [online]. 36 (6), pp.521–526.[Accessed 18 January 2019].

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004) Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal*. [online]. 36 (6), pp.521–526. [Accessed 18 January 2019].

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2010b) Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. *Equine Veterinary Journal*. [online]. 37 (3), pp.192–199.[Accessed 12 October 2019].

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2005) Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. *Equine Veterinary Journal*. [online]. 37 (3), pp.192–199. [Accessed 12 October 2019].

Patterson-Kane, J.C. and Firth, E.C. (2014) Tendon, ligament, bone and cartilage: Anatomy, physiology and adaptations to exercise and training: The Athletic Horse: Principles and Practice of Equine Sports Medicine. [online]. 2nd edition. Elsevier; Amsterdam, The Netherlands 2014. pp. 202-242. [Accessed 29 May 2023].

Peham, C., Licka, T., Schobesberger, H. and Meschan, E. (2004) Influence of the rider on the variability of the equine gait. *Human Movement Science*. [online]. 23 (5), pp.663–671.[Accessed 17 May 2020].

Perkins, N., Reid, S. and Morris, R. (2005) Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *New Zealand Veterinary Journal*. [online]. 53 (3), Taylor & Francis, pp.171–183.[Accessed 18 January 2019].

Pfau, T. (2019) Sensor-based equine gait analysis: more than meets the eye? *UK-Vet Equine*. [online]. 3 (3), pp.102–112.[Accessed 6 May 2021].

Pinchbeck, G.L., Clegg, P.D., Boyde, A., Barr, E.D. and Riggs, C.M. (2013) Horse-, training- and race-level risk factors for palmar/plantar osteochondral disease in the racing Thoroughbred. *Equine Veterinary Journal*. [online]. 45 (5), pp.582–586.[Accessed 12 October 2019].

Pinchbeck, G.L., Clegg, P.D., Proudman, C.J., Morgan, K.L., Wood, J.L.N. and French, N.P. (2002) Risk factors and sources of variation in horse falls in steeplechase racing in the UK. *Preventive Veterinary Medicine*. [online]. 55 (3), pp.179–192.[Accessed 18 January 2019].

Powell, A., Levy, E., Heneghan, N.R. and Horsley, I. (2021) Intra-rater reliability, inter-rater reliability and minimal detectable change of the posterior shoulder endurance test in elite athletes. *Physical Therapy in Sport*. [online]. 49, pp.62–67.[Accessed 24 July 2022].

Pryor, P. and Tibary, A. (2005) Management of estrus in the performance mare. *Clinical Techniques in Equine Practice*. [online]. 4 (3), pp.197–209.[Accessed 17 May 2020].

Randle, H., Steenbergen, M., Roberts, K. and Hemmings, A. (2017)'The use of the technology in equitation science: A panacea or abductive science?' *Applied Animal Behaviour Science*. *Special Issue on Equitation Science in Practice* [online]. 190, pp.57–73.[Accessed 6 May 2021].

Ravara, B., Gobbo, V., Carraro, U., Gelbmann, L., Pribyl, J. and Schils, S. (2015) Functional electrical stimulation as a safe and effective treatment for equine epaxial muscle spasms: Clinical evaluations and histochemical morphometry of mitochondria in muscle biopsies. *European Journal of Translational Myology*. [online]. 25 (2), p.109.[Accessed 14 June 2021].

Rhodin, M., Egenvall, A., Haubro Andersen, P. and Pfau, T. (2017) Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. Loor, J.J. (ed.) *PLOS ONE*. [online]. 12 (4), p.e0176253.[Accessed 9 May 2021].

Ricard, A. and Touvais, M. (2007) Genetic parameters of performance traits in horse endurance races. *Livestock Science*. [online]. 110 (1–2), pp.118–125. [Accessed 18 January 2019.

Riggs, C.M. and Boyde, A. (1999) Effect of exercise on bone density in distal regions of the equine third metacarpal bone in 2-year-old Thoroughbreds. *Equine Veterinary Journal.* [online]. 30, pp.555-560. [Accessed 24 May 2023].

Riggs, C.M, Whitehouse, G.H. and Boyde, A. (1999) Pathology of the distal condyle of the third metacarpal and metatarsal bones of the horse. *Equine Veterinary Journal.* [online]. 31, pp.140-148. [Accessed 22 May 2023].

Rich, T. and Patterson-Kane, J.C. Science-in-brief: what is needed to prevent tendon injury in equine athletes? A conversation between researchers and industry stakeholders. *Equine Veterinary Journal.* [online]. 46, pp.393-398. [Accessed 28 May 2023].
Robert, C., Valette, J.P. and Denoix, J.M. (2010) The effects of treadmill inclination and speed on the activity of two hindlimb muscles in the trotting horse. *Equine Veterinary Journal.* [online]. 32 (4), pp. 312-317. [Accessed 29 May 2023].

Rogers, C.W., Bolwell, C.F. and Gee, E.K. (2012) Proactive management of the equine athlete. *Animals*. [online]. 2 (4), Multidisciplinary Digital Publishing Institute, pp.640–655.[Accessed 14 March 2022].

Roly Owers (2017) *Equestrian sport and the concept of a social licence* [online]. FEI General Assembly. Available from:

https://inside.fei.org/system/files/GA17_World_Horse_Welfare_PPT.pdf.[Accessed 17 February 2022].

Romani, W.A., Gieck, J.H., Perrin, D.H., Saliba, E.N. and Kahler, D.M. (2002) Mechanisms and management of stress fractures in physically active persons. *Journal of Athletic Training*. 37 (3), pp.306–314. [Accessed 12 October 2019].

Rubio-Martinez, Cruz, A.M., Gordon, K. and Hurtig, M.B. (2008) Mechanical properties of subchondral bone in the distal aspect of the third metacarpal bones from Thoroughbred racehorses. *American Journal of Veterinary Research.* [online] 69 (11), pp. 1423-1433. [Accessed 28 May 2023].

Rungsri, P.K., Staecker, W., Leelamankong, P., Estrada, R.J., Schulze, T. and Lischer, C.J. (2014) Use of body-mounted inertial sensors to objectively evaluate the response to perineural analgesia of the distal limb and intra-articular analgesia of the distal interphalangeal joint in horses with forelimb lameness. *Journal of Equine Veterinary Science*. [online]. 34 (8), pp.972–977.[Accessed 6 May 2021].

Samol, M.A., Uzal, F.A., Blanchard, P.C., Arthur, R.M. and Stover, S.M. (2021) Sudden death caused by spinal cord injury associated with vertebral fractures and fetlock failure in a Thoroughbred racehorse. *Journal of Veterinary Diagnostic Investigation*. [online]. 33 (4), pp.788–791.[Accessed 14 March 2022].

Schmuckler, M.A. (2001) What Is ecological validity? A dimensional analysis. *Infancy*. [online]. 2 (4), pp.419–436.[Accessed 13 April 2022].

Schober, P., Boer, C. and Schwarte, L.A. (2018) Correlation coefficients: appropriate use and interpretation. *Anesthesia & Analgesia*. [online]. 126 (5), pp.1763–1768.[Accessed 14 June 2020].

Schroter, R.C. and Marlin, D.J. (2010) An index of the environmental thermal load imposed on exercising horses and riders by hot weather conditions. *Equine Veterinary Journal*. [online]. 27 (S20), pp.16–22.[Accessed 17 May 2020].

Sepulveda Caviedes, M.F., Forbes, B.S. and Pfau, T. (2018) Repeatability of gait analysis measurements in Thoroughbreds in training. *Equine Veterinary Journal*. [online]. 50 (4), pp.513–518.[Accessed 6 May 2021].

Shakeshaft, A. and Tabor, G. (2020) The effect of a physiotherapy intervention on thoracolumbar posture in horses. *Animals*. [online]. 10 (11), p.1977.[Accessed 14 June 2021].

Sim, J. and Wright, C.C. (2005) The Kappa Statistic in Reliability Studies: Use, Interpretation, and Sample Size Requirements. *Physical Therapy*. [online]. 85 (3), pp.257–268.[Accessed 14 March 2020].

Singer, E.R., Saxby, F. and French, N.P. (2010) A retrospective case-control study of horse falls in the sport of horse trials and three-day eventing. *Equine Veterinary Journal*. [online]. 35 (2), pp.139–145.[Accessed 18 January 2019].

Smith, D.J. (2003) A framework for understanding the training process leading to elite performance. *Sports Medicine*. [online]. 33 (15), pp.1103–1126. [Accessed 9 February 2022].

Smith, R.K., Birch, H., Patterson-Kane, J., Firth, E.C., Williams, L., Cherdchutham, W., Van Weeren, W.R. and Goodship, A.E. (1999) Should equine athletes commence training during skeletal development? Changes in tendon matrix associated with development, ageing, function and exercise. *Equine Veterinary Journal.* [online]. 30, pp. 201-209. [Accessed 28 May 2023].

Smith, L.J., Tabor, G. and Williams, J. (2018) A retrospective case control study to investigate race level risk factors associated with horse falls in Irish point-to-point races. *Comparative Exercise Physiology*. [online]. 14 (2), pp.127–134.[Accessed 18 January 2019].

Soligard, T. *et al.* (2016) How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*. [online]. 50 (17), pp.1030–1041. [Accessed 14 March 2022].

Starke, S.D., Raistrick, K.J., May, S.A. and Pfau, T. (2013) The effect of trotting speed on the evaluation of subtle lameness in horses. *The Veterinary Journal*. [online]. 197 (2), pp.245–252.[Accessed 6 May 2021].

Steinskog, D.J., Tjøstheim, D.B. and Kvamstø, N.G. (2007) A cautionary note on the use of the Kolmogorov–Smirnov test for normality. *Monthly Weather Review*. [online]. 135 (3), American Meteorological Society, pp.1151–1157.[Accessed 17 November 2021].

Symes, D. and Ellis, R. (2009) A preliminary study into rider asymmetry within equitation. *The Veterinary Journal*. [online]. 181 (1), pp.34–37.[Accessed 14 June 2021].

Tabor, G., Nankervis, K., Fernandes, J. and Williams, J. (2020) Generation of domains for the equine musculoskeletal rehabilitation outcome score: development by expert consensus. *Animals*. [online]. 10 (2), p.203.[Accessed 11 January 2022].

Tabor, G. and Williams, J. (2020) Objective measurement in equine physiotherapy. *Comparative Exercise Physiology*. [online]. 16 (1), pp.21–28. [Accessed 11 January 2022].

Tabor, G. and Williams, J. (2018) The use of outcome measures in equine rehabilitation. *The Veterinary Nurse*. [online]. 9 (9), pp.497–500. [Accessed 11 January 2022].

Takahashi, Y., Mukai, K., Ohmura, H. and Takahashi, T. (2021) Changes in muscle activity with exercise-induced fatigue in Thoroughbred horses. *Comparative Exercise Physiology*. [online]. 17 (1), pp.25–34.[Accessed 16 October 2020].

Talari, K. and Goyal, M. (2020) Retrospective studies – utility and caveats. *Journal of the Royal College of Physicians of Edinburgh*. [online]. 50 (4), pp.398–402.[Accessed 3 August 2022].

Tamzali, Y., Marguet, C., Priymenko, N. and Lyazrhi, F. (2011) Prevalence of gastric ulcer syndrome in high-level endurance horses: EGUS prevalence is high in elite endurance horses. *Equine Veterinary Journal*. [online]. 43 (2), pp.141–144. [Accessed 4 April 2021].

Teichtahl, A.J, Wluka, A.E., Wijethilake, P., Wang, Y., Ghasem-Zadeh, A. and Cicuttini, F.M. (2015) Wolff's law in action a mechanism for early knee osteoarthritis. *Arthritis Research and Therapy.* 17 (207). pp.1-9.

Teitelbaum, S.L. (2000) Bone Resorption by Osteoclasts. *Science*. [online]. 289 (5484), pp.1504–1508.[Accessed 15 January 2019].

Teixeira, P.J., Carraça, E.V., Markland, D., Silva, M.N. and Ryan, R.M. (2012) Exercise, physical activity, and self-determination theory: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*. [online]. 9 (1), p.78 [Accessed 14 September 2021].

Thorpe, C.T., Clegg, P.D. and Birch, H.L. (2010) A review of tendon injury: why is the equine superficial digital flexor tendon most at risk? *Equine Veterinary Journal.* [online]. 42 (2), pp. 174-180.

Treiber, K.H., Hess, T.M., Kronfeld, D.S., Boston, R.C., Geor, R.J., Friere, M., Silva, A.M.G.B. and Harris, P.A. (2006) Glucose dynamics during exercise: dietary energy sources affect minimal model parameters in trained Arabian geldings during endurance exercise. *Equine Veterinary Journal*. [online]. 38 (S36), pp.631–636.[Accessed 11 April 2022].

Trigo, P., Castejon, F., Riber, C. and Muñoz, A. (2010) Use of biochemical parameters to predict metabolic elimination in endurance rides: Predicting metabolic elimination in endurance races. *Equine Veterinary Journal*. [online]. 42, pp.142–146. [Accessed 15 January 2019].

Varcoe-Cocks, K., Sagar, K.N., Jeffcott, L.B. and McGowan, C.M. (2006) Pressure algometry to quantify muscle pain in racehorses with suspected sacroiliac dysfunction. *Equine Veterinary Journal*. [online]. 38 (6), pp.558–562.[Accessed 20 May 2021].

Viry, S., De Graaf, J.B., Frances, J.-P., Berton, E., Laurent, M. and Nicol, C. (2015) Combined influence of expertise and fatigue on riding strategy and horse-rider coupling during the time course of endurance races: Horse-rider coupling during endurance races. *Equine Veterinary Journal*. [online]. 47 (1), pp.78–82. [Accessed 15 January 2019].

Viry, S., Sleimen-Malkoun, R., Temprado, J.-J., Frances, J.-P., Berton, E., Laurent, M. and Nicol, C. (2013) Patterns of horse-rider coordination during endurance race: a dynamical system approach. *PLoS ONE*. [online]. 8 (8), p.e71804.[Accessed 15 January 2019].

Walker, V.A., Tranquille, C.A., Dyson, S.J., Spear, J. and Murray, R.C. (2016) Association of a subjective muscle score with increased angles of flexion during sitting trot in dressage horses. *Journal of Equine Veterinary Science*. [online]. 40, pp.6–15. [Accessed 18 May 2022].

Watson, T. (2022) Soft tissue repair and healing review [online]. Available from https://www.electrotherapy.org/_files/ugd/9d8e61_fc7eb78278d045f2bb06b5bab36185c3.pdf [Accessed 28 May 2023].

Webb, H.J., Weston, J.F., Norman, E.J., Cogger, N., Bolwell, C.F. and Rogers, C.W. (2020) A descriptive study of training methods for Fédération Equestre Internationale Endurance horses in New Zealand. *Journal of Equine Veterinary Science*. [online]. 92, p.103155.[Accessed 11 December 2021].

Webb, H.J., Weston, J.F., Norman, E.J., Cogger, N.D. and Rogers, C.W. (2019) Experience, riding practices and training methods of Fédération Equestre Internationale (FEI: 80-160 km) level endurance horse rider-owner-trainers in New Zealand. *Comparative Exercise Physiology*. [online]. 15 (2), pp.137–145. [Accessed 11 December 2021].

Weeren, P.R., Pfau, T., Rhodin, M., Roepstorff, L., Serra Bragança, F. and Weishaupt, M.A. (2018) What is lameness and what (or who) is the gold standard to detect it? *Equine Veterinary Journal*. [online]. 50 (5), pp.549–551.[Accessed 11 December 2021].

Whaley, D.E. and Krane, V. (2011) Now that we all agree, let's talk epistemology: a commentary on the invited articles. *Qualitative Research in Sport, Exercise and Health*. [online]. 3 (3), pp.394–403.[Accessed 18 June 2022].

Whitaker, T.C., Olusola, O. and Redwin, L. (2008) The influence of horse gender on eventing competition performance. *Comparative Exercise Physiology*. [online]. 5 (02), p.67. [Accessed 15 January 2019].

Whitton, R.C., Ayodele, B.A., Hitchens, P.L. and Mackie, E.J. (2018) Subchondral bone microdamage accumulation in distal metacarpus of Thoroughbred racehorses. *Equine Veterinary Journal*. [online]. 50 (6), pp.766–773.[Accessed 12 October 2019].

Whitton, R.C., Trope, G.D., Ghasem-Zadeh, A., Anderson, G.A., Parkin, T.D.H., Mackie, E.J. and Seeman, E. (2010) Third metacarpal condylar fatigue fractures in equine athletes occur within previously modelled subchondral bone. *Bone*. [online]. 47 (4), pp.826–831.[Accessed 12 October 2019].

Wickler, S.J., Greene, H.M., Egan, K., Astudillo, A., Dutto, D.J. and Hoyt, D.F. (2006) Stride parameters and hindlimb length in horses fatigued on a treadmill and at an endurance ride. *Equine Veterinary Journal*. [online]. 38 (S36), pp.60–64.[Accessed 15 May 2020].

Wilberger, M.S., McKenzie, E.C., Payton, M.E., Rigas, J.D. and Valberg, S.J. (2015) Prevalence of exertional rhabdomyolysis in endurance horses in the Pacific Northwestern United States: Rhabdomyolysis in endurance horses. *Equine Veterinary Journal*. [online]. 47 (2), pp.165–170.[Accessed 15 January 2019].

Wilkins, C.A., Nankervis, K., Protheroe, L. and Draper, S.B. (2020) Static pelvic posture is not related to dynamic pelvic tilt or competition level in dressage riders. *Sports Biomechanics*. [online]. pp.1–13.[Accessed 18 December 2021].

Williams, J. and Marlin, D. (2020) Foreword – Emerging issues in equestrian practice. *Comparative Exercise Physiology*. [online]. 16 (1), pp.1–4.[Accessed 18 December 2021].

Williams, J. and Tabor, G. (2017) Rider impacts on equitation. *Applied Animal Behaviour Science*. [online]. 190, pp.28–42.[Accessed 18 December 2021].

Williams, J.M., Douglas, J., Davies, E., Bloom, F. and Castejon-Riber, C. (2021) Performance demands in the endurance rider. *Comparative Exercise Physiology*. [online]. 17 (3), pp.199–217.[Accessed 11 December 2021].

Williams, J.M., Marlin, D.M., Langley, N., Parkin, T.D. and Randle, H. (2013) The Grand National: a review of factors associated with non-completion and horse-falls, 1990 to 2012. *Comparative Exercise Physiology*. [online]. 9 (3–4), pp.131–146. [Accessed 15 January 2019].

Wong, A. S., Morrice-West, A. V., Whitton, R. C., & Hitchens, P. L. (2023) Changes in Thoroughbred speed and stride characteristics over successive race starts and their association with musculoskeletal injury. *Equine Veterinary Journal*, 55(2), pp.194-204 [Accessed 2 June 2023].

Wyn-Jones, G. (1988) *Equine Lameness.* Oxford, Blackwell Scientific Publishing.

Younes, M., Barrey, E., Cottin, F. and Robert, C. (2016) Elimination in long-distance endurance rides: insights from the analysis of 7,032 starts in 80 to 160 km competitions. *Comparative Exercise Physiology*. [online]. 12 (4), pp.157–167. [Accessed 15 January 2019].

Younes, M., Robert, C., Cottin, F. and Barrey, E. (2015) Speed and cardiac recovery variables predict the probability of elimination in equine endurance events. *PLOS ONE*. [online]. 10 (8), p.e0137013.[Accessed 15 January 2019].

Zaryski, C. and Smith, D.J. (2005) Training principles and issues for ultra-endurance athletes. *Current Sports Medicine Reports*. [online]. 4 (3), pp.165–170.[Accessed 15 May 2021].

Zuffa, T., Bennet, E.D. and Parkin, T.D.H. (2022) Factors associated with completion of Fédération Équestre Internationale endurance rides (2012–2019): Modelling success to promote welfare-oriented decisions in the equestrian sport of endurance. *Preventive Veterinary Medicine*. [online]. 198, p.105534.[Accessed 19 September 2022].

Appendix 1

Veterinary inspection details, accepted parameters and qualification pathways

Metabolic Inspection

Examination	FEI	EGB CER	EGB GER
Heart Rate	Using a stethoscope or FEI-approved electronic heart rate monitor. Taken on left side. If a stethoscope is used, a stopwatch must be used. The Heart rate must be taken for a minimum of 15 seconds, if when multiplied by 4, it is below the required parameter by 5 beats, it can be recorded, however if it is within 4 beats of the maximum heart rate, it must be taken for a full minute before the result can be recorded. If the first heart rate is above the required parameter, there is the opportunity to re-present the horse, if there is sufficient time left in the competitors 'time to vet' except at the final vetting. Maximum heart rate 64bpm within 15 minutes of crossing the end of the line of each loop, except the final loop where the maximum heart rate is 64bpm in 20 minutes. At the first vet gate, after the halfway point on course, or at the third vet gate (whichever comes first), horses that initially present with a heart rate of 68bpm or above must pass a heart rate re-inspection and a compulsory re-inspection before being permitted to start the next loop		Taken for 60 seconds with a stethoscope. Maximum heart rate of 64bpm within 20 minutes in a vet gate, with one opportunity to represent. Maximum heart rate at the finish 64bpm within 30 minutes of finishing. No opportunity to represent.
Cardiac Recovery Index	The heart rate is recorded following the procedure above, the horse then	Recorded as per FEI- used at the	Not recorded as standard

	completes the gait assessment. At the end of the gait assessment the veterinarian starts the stopwatch for one minute. After one minute, the heart rate is recorded again. The cardiac recovery index is the difference between the first and second heart rate.	discretion of the veterinarian.	
Respiration	Visual inspection, any abnormal, or laboured breathing may result in elimination	As per FEI	Observed but not documented
Muscle Tone	Graded A-D. Defined categories and standardisation not available. Predominantly palpation of the back musculature and hind limb musculature.	As per FEI	Assessed, non-standardised process- not documented
Mucous Membrane	Colour of the mucous membranes of the lower mucous membrane of the eye. Graded A-D. Defined categories and accepted parameters not available.	As per FEI	Not assessed
Capillary Refill	Tested by observing the gums, and applying finger pressure, time taken to return to return to normal colour when pressure applied is recorded in seconds. Defined categories and accepted parameters not available.	As per FEI	Not assessed
Jugular Refill	Pressure is applied to the jugular vein and time taken to return to normal is recorded in seconds. Defined parameters are not available.	As per FEI	Not assessed
Dehydration	Tested using a neck skin pinch, the time taken for the skin to return to normal is recorded in seconds. Accepted parameters not available.	As per FEI	As per FEI
Gut sounds	Graded A-D. Defined categories not available. Both sides of the horse’s gut are	As per FEI	Not assessed

	listened to with a stethoscope.		

FEI- Fédération Equestre Internationale
EGB CER- Endurance GB Competitive Endurance Rides
EGB GER- Endurance GB Graded Endurance Rides

For examinations where defined categories are not available, anecdotally, if an examination that is graded A-D results in a C or below, the horse is likely to be asked to return for a reassessment or, if in conjunction with more than one C, or other poor metabolic scores, is likely to be eliminated.

For examinations where categories are recorded in seconds, anecdotally if the result is 3 or more seconds the horse will either be asked to return for reassessment or, if in conjunction with additional poor metabolic scores may result in elimination.
Ultimately, if the veterinarians feel that the horse's welfare is compromised, they have the authority to stop the horse continuing.

Endurance GB Pleasure rides do not undergo a metabolic assessment.

Gait Assessment

In all categories of competition, the horse is trotted away from the veterinarian and back towards them, in hand, without a saddle and is observed by a single veterinarian.
If there is doubt about the horse's gait pattern, a second trot will be requested. In FEI rides and CER rides if a second or re-trot is requested, three veterinarians will observe the trot and vote as to whether they think the horse should pass or fail the gait assessment. The voting is completed without discussion and documented on a voting slip which is handed to the ground jury. The ground jury gives the majority verdict to the rider as to whether the horse has passed or failed the assessment. In a GER, only two veterinarians are required for the second trot, if they have differing opinions, if a third

veterinarian is available, they will observe a third trot. If there is no third veterinarian available, then another official such as the farrier or the technical steward may cast a vote. At FEI level, after the second trot, if there is any doubt, the veterinarians may ask for one additional trot, if they are unable to decide after this point the horse is eliminated. At EGB rides, if the veterinarians request a third trot and are unable to decide, then the horse is given the benefit of the doubt and passes the ride.

Qualification requirements for International Endurance competitions

Ride Level	Horse	Rider
1* 100-119km in one day	Minimum age: 6 years old Must have completed two national novice rides of 40-79 km and two national rides of 80-100km (either as two single day events or one single day and one multi-day) at a maximum speed of 16 kmh^{-1}. Qualification rides must be completed within two years. May not compete in 1* competition any earlier than one year from successful completion of their first novice qualification.	Young rider competitions minimum weight 60kg Senior competitions minimum weight 70kg Must have completed two national novice rides of 40-79 km and two national rides of 80-100km (either as two single day events or one single day and one multi-day) at a maximum speed of 16 kmh^{-1}. Qualification rides must be completed within two years. May not compete in 1* competition any earlier than six months from successful completion of their first novice qualification.
2* 120-139km in one day, or 70-89km per day over two days	Minimum age: 7 years old Able to compete at 2* when they have completed 2 out of 3 consecutive 1* competitions within a two-year period.	Young rider competitions minimum weight 60kg Senior competitions minimum weight 70kg Able to compete at 2* when they have completed 2 out of 3 consecutive 1* competitions within a two-year period.
3* 140-160km in one day, or 90-100km per day over two days, or 70-80km per day over three days or more.	Minimum age: 8 years old Able to compete at 3* when they have successfully completed 2 out of 3 consecutive 2* competitions and one 2* competition must be as a combination with the rider who wishes to compete the horse in the 3 * competition within a two-year period. (**elite athletes exempt)	Minimum weight 75 kg Able to compete at 3* when they have successfully completed 2 out of 3 consecutive 2* competitions and one 2* competition must be as a combination with the horse that they are to compete in the 3* competition within a two-year period (**elite athletes exempt)

**Elite athletes- successfully completed ten 3* competitions and must successfully complete a 3* competition every successive two years to maintain their elite status.

National qualifications required to compete at and progress through FEI levels of endurance competitions (FEI rules, 2022).

Endurance GB qualification levels

Novice GERs must be ridden at 8-15 km h^{-1} over distances of between 20-50km. In order to progress to the next level, which is 'open level', novice riders must complete five novice rides of 30-50km, and novice horses must complete three novice rides of 30-45km. Open and advanced level GERs are 30-160km in distance and must be completed at 9-18km h^{-1} Open level horses and riders must complete at least two open level GER's of 60-80km (at least one must be 80km in one day) before they are eligible to take part in advanced level competitions.

Appendix 2

Key Differences between Fédération Equestre International (FEI) and Endurance GB (EGB)

Speed:

FEI speed: can be dictated by the ground jury dependant on the competition, usually 10/ 12kmh^{-1}. No maximum speed but additional mandatory out of competition periods if rides are completed over 20 kmh^{-1}.

EGB speed differs between levels. Novice horses must complete rides 8-15 kmh^{-1}. Open level horses must complete 9-18 kmh^{-1}. Advanced level horses must complete graded rides at 9-18 kmh^{-1}. Horses competing in competitive endurance rides must complete at a minimum speed of 10 kmh^{-1}, there is no upper speed limit or increased rest period if horses compete over 20 kmh^{-1}, unless the horse is registered with the FEI and then must follow their rulings.

Veterinary inspections: see appendix 1.

Weight:

FEI: FEI rides have a minimum weight limit of the rider. Young rider/ junior rider competitions and championships, minimum weight: 60kg. At senior level Concours de Raid d' Endurance International* (CEI) and CEI**, the minimum weight is 70kg. At CEI*** and championships the minimum weight is 75kg.

EGB: No minimum weight requirement.

Mandatory Out of Competition Periods

After each competition, horses are not allowed to compete in another competition within the specified mandatory out of competition periods, the differences between the FEI and EGB are detailed in the table below.

Standard Mandatory Out of Competition Periods

Distance	FEI (MOOCP) rules	Distance	EGB (MOOCP) rules
From crossing the start line to 54km	5 days	From crossing the start line until 77km	No MOOCP
Over 54-106km	12 days	78-95 km	12 days
Over 106-126km	19 days	96-125km	19 days
Over 126- 146km	26 days	126-145 km	26 days
Over 146 km	33 days	Over 146km	33 days

EGB further specifies MOOCP for multi day rides. Multi-day rides of 96-125km require 12 days MOOCP, those of 126-145km require 19 days MOOCP and those of 146km+ require 26 days.

Additional MOOCP:

On occasions, additional to the above table, further days can be added, the differences are shown in the table below. EGB adds 8 days for any lameness or metabolic incident, this does not alter regardless of how many incidents/ consecutive eliminations the horse has, although if this is observed at the time of declaring the horse by the technical steward, additional rest periods of 30 days may be added if the senior veterinarian believes this appropriate.

Additional Mandatory Out of Competition Period: Differences between Endurance GB and Fédération Equestre Internationale

Incident	FEI Additional MOOCP	EGB Additional MOOCP
Average speed of over $20kmh^{-1}$.	7 days	N/a
Second metabolic elimination in a rolling year	14 days	N/a
Third (or subsequent) metabolic elimination in a rolling year	60 days (can be further extended)	N/a
Third (or subsequent) gait elimination in a rolling year	180 days and horse must undergo a specific veterinary examination protocol prior to competing in any national or FEI events	N/a
Serious musculoskeletal injury	180 days (can be extended)	N/a. Although if brushing lesions or girth galls present 14 days can be added.
Serious metabolic incident	60 days (can be extended)	30 days may be added, but only at the discretion of the senior vet and technical steward.
Disqualification for hyposensitivity	28 days	N/a
Failure by the person responsible for the horse to provide a copy of the veterinary report from a designated/ approved referral centre to the FEI Veterinary department	180 days, plus unable to compete until certificate is shown.	N/a

Appendix 3

Ethical approval:

Study 2 & 3:

HARTPURY UNIVERSITY

Research and Knowledge Exchange Ethics Sub Committee

Ethics reference *(to be issued by Ethics Committee)*	ETHICS2018-48

N. B: if proposal relates to your own research please indicate N/A in boxes

Name of Applicant	Fiona Bloom		
Type of Project (UG, PGT, PGR)	PGR	**Field**	Equine
Title of Project	Lameness eliminations in endurance horses		
Supervisor	Jane Williams		
Professional body consulted	n/a		

Assessor	**Comments/Queries**	**Recommended for Approval (Y/N)**
Alison Wills *(Chair)*		**Y**
For Applications approved via virtual meeting		
Approved by Chair (date)	**Staff notified (date)**	
Approved 17/05/2019	17/05/2019	
For Applications sent to Ethics sub committee for further discussion		
Approved by Chair (date)	**Staff notified (date)**	

Ethical approval Study 3

HARTPURY UNIVERSITY

Ethics Committee
Research ethics approval application form (staff and PGR)

Ethics reference *(to be issued by Ethics Committee)*	ETHICS2020-48

Assessor	**Comments/Queries**	**Outcome (Approve, Revise, Reject)**
Alison Wills *(Chair)*	No major concerns – just would like to see a copy of the text that competitors will be displayed at the start that gives them info about withdrawing – apologies if it was included, I couldn't see it in any of the documents. 11/05/21 - Thanks for supplying the additional information form	**Revise** **Approve**
James Swanson	11.05.21 Eloquent. For completeness would be good to see missing text in 4.0., the collaborator signature on the collaboration agreement (the image of the signature is too small and pixelated to see). One other comment about clarity. On risk assessment, be specific on covid controls. 12.05.21 Have now seen readable version of collaboration form so fine.	Approve with edits.

For Applications approved via virtual meeting	
Approved by Chair (date)	**Staff notified (date)**
For Applications sent to Ethics sub committee for further discussion	
Approved by Chair (date)	**Staff notified (date)**

Appendix 4

Published version of Study 1.

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022) Risk factors for lameness elimination in British endurance riding. *Equine Veterinary Journal.* DOI:10.1111/evj.13875

Author Contributions: F. Bloom, S. Draper, E. Bennet and J. Williams contributed to study design, study execution, data analysis and interpretation, preparation of the manuscript and final approval of the manuscript. D. Marlin contributed to study design, interpretation of the data, preparation of the manuscript and final approval of the manuscript. F. Bloom had access to all of the data and is responsible for data integrity and analysis.

Risk factors for lameness elimination in British Endurance riding

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KEY WORDS:
endurance, risk factor, elimination, lameness, horse welfare

Authors' declaration of interests:
No competing interests

Ethical animal research:
The ethics committee at Hartpury University approved this study. No external intervention was required by participants and all data were anonymised. Endurance GB board of directors gave consent for retrospective analysis of the raw data from the Endurance GB results database.

Source of funding:
No external funding was received for this research

Acknowledgements:
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Authorship:
F. Bloom, S. Draper, E. Bennet and J Williams contributed to study design, study execution, data analysis and interpretation, preparation of the manuscript and final approval of the manuscript. D. Marlin contributed to study design, interpretation of the data, preparation of the manuscript and final approval of the manuscript. F. Bloom had full access to all of the data in the study and is responsible for data integrity and accuracy of analysis.

Data availability statement
The data that supports the findings of this study are available from Endurance GB. Data are available from the authors with permission of Endurance GB.

Summary

Background: Horse welfare is a priority in the equine sport of endurance riding. Identification and reduction of risk factors associated with elimination and lameness has been the focus of research to date, however this has centred on international competition. National federations recognise there is a need to consider risk factors for elimination at a more local level.

Objectives: Determine current risk factors associated with horse eliminations, specifically lameness eliminations within British endurance.

Study design: Retrospective cohort study using the Endurance GB database, for open and advanced horses, competing in rides >64 km in the 2017 and 2018 competitive seasons.

Methods: Variables were analysed via univariable models which informed subsequent multivariable binary logistic regression modelling. Two models were completed, A: horse eliminated versus not eliminated and B: horse lame versus not lame.

Results: 1747 competitive starts were analysed; 542 horses were eliminated. Lameness accounted for 56.1 % (n = 304) of eliminations. Multivariable analysis identified decreased odds of lameness in graded rides compared with race rides (Adjusted Odds Ratio, OR 0.6; 95% Confidence Interval, CI 0.4-0.8). There were increased odds of elimination (OR 4.7, CI 3.5-6.5) and increased odds of lameness (OR 1.9, CI 1.2-3.06) when competing in FEI competitions of 2* and above, compared to rides run under national rules. Horses and riders who had not competed as a combination previously had increased odds of elimination (OR 2.2, CI 1.5-3.02).

Main Limitations: Variables which can influence performance such as speed, environmental and topographical conditions were not recorded in the data set. Only two seasons of data were analysed.

Conclusions: Competitive history of horses, including the number of previous starts, previous eliminations and the category of ride entered are significant in establishing the

likelihood of an elimination and more specifically a lameness elimination in British national endurance.

Introduction

Endurance is an internationally recognised equestrian sport in which horse and rider combinations compete up to 160km in one day [1,2]. Globally, endurance is governed by the Fédération Equestre Internationale (FEI), whilst in Great Britain, Endurance GB (EGB) governs the sport. Protecting the welfare of the horse is a key strategic priority for both the FEI and EGB. However, repeated incidences of horse injury and fatalities in high profile races have led to a negative public perception of the sport. This has resulted in calls for increased safeguarding of the welfare of the horses that participate within endurance, in order to reduce the risk not only to the horse, but to the sport of endurance and its social licence to operate [3-5].

To uphold welfare, prior to each endurance competition, the horse is examined by licenced veterinarians who check that horse is fit to compete by assessing its gait pattern and that it is metabolically fit. If any of these examinations are outside of accepted parameters, the horse is eliminated from the competition [1,2]. This process is repeated after each stage of the ride, which predominantly range from 20-40kms in length. The horse must also pass a veterinary inspection at the end of the ride before the result is confirmed. If the horse does not pass the veterinary inspection at any stage it is eliminated from the competition [1,2]. Previous epidemiological studies in the sport have focussed on FEI competitions and have identified risk factors for elimination, which include higher speeds, multiple competition starts with insufficient recovery periods and historic deleterious competition outcomes of the horse and rider [6-12]. Following identification of risk factors, positive changes were made to the sport at FEI level, including the duration of mandatory out of competition periods (MOOCP) between competitions being increased following an elimination, with additional days being added for multiple eliminations. This has been found to be successful in reducing eliminations in international competition, however EGB does not mirror the additional days added for multiple eliminations with only eight additional days added for an elimination, regardless of the number of failures. In contrast, FEI regulations require MOOCP increases to 180 days and a veterinary inspection prior to competition return if there have been 3 lameness eliminations within a year [1,2,13].The discrepancy between national and international rules on MOOCP may cause competitors confusion and the assumption, due to the reduced MOOCP within EGB rides that national level competition poses less of a welfare risk, which may in turn have a negative impact on horse welfare.

Lameness has been the leading cause of elimination in FEI rides with previous studies reporting 24->30% of all horses starting the competition being eliminated for lameness [6,11]. Eighty per cent of British endurance riders have reported their horses having at least one episode of lameness within their endurance career [14]. Despite this, there have been no studies identifying risk factors relating to British horses competing at national level and insufficient evidence currently exists to create an accurate profile of risk factors for eliminations and lameness within British Endurance. Therefore, this study aimed to identify risk factors associated with elimination and lameness within horses registered with EGB.

Methods:

Participants

Endurance GB provided the data for all rides with a veterinary inspection (rides of ≥64km) that had been recorded on their central database for the competitive seasons from March-October of 2017 and 2018. The majority of these data were publicly available. Horses which had a competitive history detailing that they were appropriately qualified in accordance with the EGB rules (had completed novice level and were at open or advanced level) to compete in rides of 64Km and above were included within the study. No external intervention was required by participants and all data were anonymised.

A total of 1747 single day ride entries were recorded, representing 512 unique horses and 385 unique riders, all were appropriate for inclusion. Frequency analysis of risk factors was completed. As all the data met non-parametric assumptions the data are reported as median± interquartile range unless otherwise stated.

For each ride entry, the database had eight possible outcomes, (1) Completion (C), the horse successfully completed and passed the final veterinary inspection; (2) Eliminated, the horse did not successfully complete the competition; this was split further into (a) eliminated due to lameness, (b) eliminated for metabolic reasons (MET), (c) retired (RET), the horse successfully passed the veterinary inspection but was subsequently withdrawn by the rider, (d) disqualified (DSQ), a breach of the rules resulted in disqualification, (e) out of time (OOT), the course was not completed within the maximum-minimum time requirements, (f) withdrawn (WDN), the horse was entered but was not presented to the initial veterinary inspection [1,2].

Risk factors

Previous literature findings and anecdotal experience within EGB competitions were used to identify potential risk factors to be considered at horse, rider and ride-level that were included in the initial stage of modelling [6-8, 10-12]. Fifty-eight factors were identified including the level of ride (FEI or national), competitive history such as the number of times a horse had been eliminated and whether the horse and rider combination had competed together previously. All factors are provided as supplementary material (Supplementary file 1).

Data collection and analysis

The data were publicly available, however EGB provided the raw data from their full database. The database provided the competition details and outcome, for every competition entered within the horse/ rider career. All analyses were completed using

Statistical Product and Service Solutions software (Version 26, IBM, United Kingdom Limited, Portsmouth, Hampshire, UK) .

Whilst the study cohort contained horse starts in only the 2017 and 2018 competitive seasons, the data for the entirety of the horse career were available from the archive history of EGB. However, in multiple cases, the reason for historic elimination was not specified and only listed as 'Fail' or 'Eliminated'.

A series of Spearman's rank correlations ($p<0.05$) examined the relationship between the number of times a horse had been eliminated in their entire career and the following variables: age of horse, career length (years), number of rides attempted, number of rides completed, distance attempted, and distance completed. A separate series of correlations examined the relationship between the same variables and the number of times a horse had been eliminated due to lameness in the entire career.

The data were translated to binary or categorical data where required, prior to coding (Supplementary file: Table S1).

Univariable and multivariable analysis

Binary logistic regression modelling was used to identify risk factors [16]. Two deleterious outcomes were considered: A) Eliminated (any reason) and B) Eliminated due to lameness. For each of the two outcomes, univariable analysis of each of the risk factors was completed. Risk factors with a P value $\leq$0.1 were included in the final multivariable models [16]. Additional variables which did not meet the significance level for inclusion but were considered biologically plausible based on previous research were also included. Multivariable logistic regression models were constructed using a backwards-stepwise process, with an Omnibus test of model coefficients applied at each step. The Hosmer-Lemeshow goodness-of-fit test was used to assess at each stage of the models [17].

The predictive ability of the models were assessed using receiver operating characteristic (ROC) curve analysis [18,19]. Risk factors with P value ≤0.05 in the final multivariable models were considered significant [6-8, 10-12].

Results:

Descriptive Statistics

Of the 1747 competitive horse starts, 91.5% of riders were female (n = 1598) and the majority of riders, (n = 1625; 93.0%) were in the senior age (over 21 years old) category. Median horse age was 11±4 years. Most of the entrants to the rides (n = 1571; 89.9%) had ridden as a horse and rider combination previously within the 2017-2018 competitive season. The experience of the horses ranged from horses being in their first competitive season to having competed for 15 years. The number of previous competitive starts ranged from 2-112 (median 19±19). The number of previous eliminations ranged from 0-16 (median 2.1±2); 23% of horses (n = 404) had never been eliminated and 31% (n = 547) had never had a lameness elimination outcome. The number of previous lameness eliminations ranged from 0-14 (median 1±3).

A significant positive correlation was found between the distance a horse attempted within its career and the number of times it had been eliminated (r = 0.73, p<0.001, n = 1747). The number of rides attempted in the horses career had a significant positive correlation with the number of times the horse had been eliminated (r = 0.67, p<0.001, n = 1747) as did the distance completed in the horses career (r = 0.62, p<0.001, n = 1747) the number of years the horse had been competing (r = 0.64, p<0.001, n = 1747). Weaker correlations were found between the number of eliminations in a horses career and the number of rides completed in the horses career (r = 0.57, p<0.001, n = 1747), and the age of the horse and the number of times it had been eliminated (r = 0.47, p<0.001, n = 1747).

A significant, positive correlation was found between the number of lameness eliminations in a horses career and the distance it had attempted within its career (r = 0.72, p<0.001, n = 1747). The number of lameness eliminations were also significantly associated with the rides attempted within the horses career (r = 0.66, p<0.001, n = 1747) the length of the horses career (years) (r = 0.63, p<0.001, n = 1747) the distance the horse had completed in its career (r = 0.62, p<0.001, n = 1747) the number of rides the horse had completed in its career (r = 0.57, p<0.001, n = 1747) and to a lesser extent the age of the horse (r = 0.46, p<0.00, n = 1747).

The data for each of the horse starts and the subsequent outcomes for the 2017-2018 rides are shown in Table 1.

Table 1: Number of horse starts and outcomes in 2017-2018 competitions

Category	**Entrants**	**Successful Completion N (%)**	**Eliminated Any reason N (%)**	**Eliminated Lame N (%)**
Year				
2017	937	663 (70.8)	274 (29.2)	152 (16.2)
2018	810	542 (66.9)	268 (33.1)	152 (18.8)
Ride Category				
GER	999	757 (75.8)	242 (24.2)	115 (11.5)
CER (EGB)	193	141 (73.1)	52 (26.9)	38 (19.7)
FEI	555	307 (55.3)	248 (44.7)	151 (27.2)
FEI Ride				
No	1192	898 (75.3)	294 (24.7)	153 (12.8)
Yes	555	307 (55.3)	248 (44.7)	151 (27.2)
FEI Level				
Not FEI	1192	898 (75.3)	294 (24.7)	153 (12.8)
1 star	328	212 (64.6)	116 (35.4)	77 (23.5)
2star+	227	95 (41.9)	132 (58.1)	74 (32.6)
Distance (km)				
64-79	612	473 (77.3)	139 (22.7)	69 (11.3)
80-119	906	635 (70.1)	271 (29.9)	161 (17.8)
120+	229	97 (42.4)	132 (57.6)	74 (32.3)

GER, graded endurance ride (capped speed), CER, competitive endurance ride (no capped speed) EGB, Endurance GB, FEI, Fédération Equestre Internationale

The number of horse starts and the outcomes for horses registered with Endurance GB, competing in rides of >64km, during the competitive seasons of 2017-2018. Data from Endurance GB's database.

Across the sample, 69% (n = 1205) of horse and rider combinations successfully completed the competitions they entered. The remaining 31% were eliminated. The most common reason for elimination was due to lameness with (n=304). The reasons for elimination are shown in figure 1.

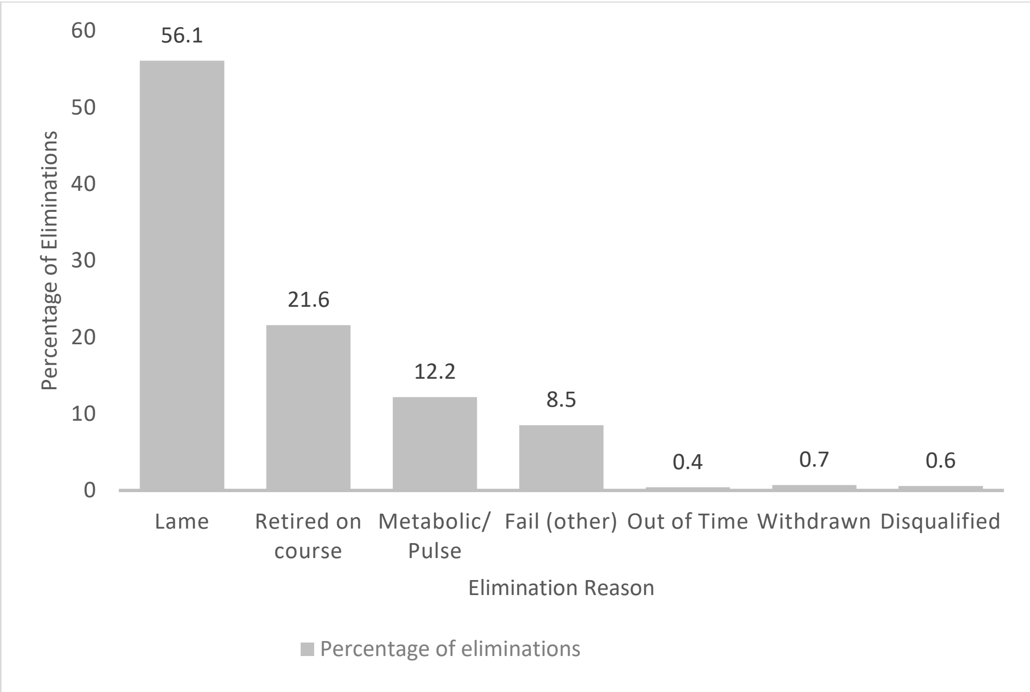

Figure 1: The reasons horses registered with Endurance GB were eliminated from competitions of >64km, during the 2017-2018 competitive seasons. Displayed as percentages of eliminated horses. Data from Endurance GB's database.

Model A: Elimination outcomes

A total of 42 variables from the univariable analysis were significant at $p \leq 0.1$ and were taken forward to multivariable analysis, additionally all previous distance attempted and completed, and number of starts and completions were included as biologically plausible factors. Seven variables remained in the final model multivariable model with five demonstrating they were significantly associated with an elimination outcome (Table 2), the remaining two variables improved the model fit. Horse and rider combinations who had not competed together previously were at increased odds of elimination, compared with combinations who had competed together previously (Adjusted Odds Ratio, OR 2.2, 95% confidence interval, CI: 1.5-3.02). Compared with rides which were run under EGB rules, those competing in FEI 1* competitions had increased odds of an elimination outcome (OR 1.7, CI 1.3-.2.3) and those in FEI 2* and above had increased odds of elimination compared to those competing under EGB rules (OR 4.7, CI: 3.5-6.5). Horses that had two competitive starts within the previous 60 days were at increased odds of elimination compared to those who had not competed in the last 60 days (OR 1.8 CI: 1.3-2.5). Previous elimination results impacted on the odds of an elimination outcome, with horses having more than one elimination within the last 365 days having increased odds (OR 2.2, CI: 1.3-3.7) compared with horses who had no elimination results in the previous 365 days.

Table 2
Model A: Multivariable model results showing the significant risk factors impacting on ride entries for 2017-2018, for all Elimination reasons.

Risk Factor	Cases: Eliminated n (%)	Controls: Pass n (%)	Adjusted OR	95% CI	P value
Returning Combination					
Yes	467 (29.7)	1104(70.3)	Reference	-	<0.001
No	75 (42.6)	101 (57.4)	2.15	1.53-3.02	<0.001
FEI Level					
Not FEI	294 (24.7)	898 (75.3)	Reference	-	<0.001
1*	116 (35.4)	212 (64.6)	1.71	1.31-2.25	<0.001
2 *+	132 (58.1)	95 (41.9)	4.74	3.48-6.46	<0.001
Distance attempted in 365 days					
0-100km	47 (29.7)	111 (70.3)	Reference	-	0.05
101-200km	121(31.2)	267 (68.8)	1.12	0.73-1.72	0.6
201-300km	150 (32.7)	309 (67.3)	1.11	0.73-1.71	0.6
301-400km	117 (30.3)	269 (69.7)	0.88	0.56-1.38	0.6
401-500km	69 (27.6)	181 (72.4)	0.63	0.38-1.04	0.07
>500km	38 (35.8)	68 (64.2)	0.75	0.40-1.38	0.4
Number of starts in 60 days					
0	121 (27.9)	313 (72.1)	Reference		0.002
1	253 (30.9)	567 (69.1)	1.15	0.87-1.52	0.3
2	139 (37.7)	230 (62.3)	1.78	1.28-2.47	0.001
3+	29(23.4)	95 (73.4)	1.01	0.61-1.67	>0.9
Eliminated last 60 days					
No	466 (29.5)	1114(70.5)	Reference	-	-
Yes	76 (45.5)	91 (54.5)	1.33	0.90-1.96	0.2
Eliminated last 365 days					
0	282 (27.0)	764 (73.0)	Reference	-	0.02
1	175 (33.0)	355 (67.0)	1.31	0.88-1.92	0.2
2+	85 (44.5)	106 (55.5)	2.15	1.25-3.68	0.005

Eliminated lame last 365 days					
No	340 (28.0)	876 (72.0)	Reference	-	-
Yes	202 (38.0)	329(62.0)	1.03	0.70-1.52	0.9

OR, adjusted odds ratio, 95% CI, 95 % confidence interval. Model fit was good: Omnibus p<0.001, Hosmer-Lemeshow p=0.43. ROC =0.68
FEI, Fédération Equestre Internationale.
Risk factors associated with elimination for horses registered with Endurance GB, competing in rides of >64km during the 2017-2018 competitive seasons. Data from Endurance GB's database.

Model B: Failure to qualify due to lameness outcomes

A total of 40 variables related to horse starts were significantly associated with an elimination due to lameness outcome at univariable level at p≤0.1, all variables relating to distance attempted and completed and the number of rides started and completed were included in the model as biologically plausible, regardless of whether they met the significance level. Nine variables remained in the final multivariable model with 4 being significantly associated with a lameness outcome, the remaining 5 remained as they improved the model fit (Table 3). Riders and horses who had not competed as a combination before were at a higher likelihood (OR 2.3, CI: 1.5-3.4) of being eliminated with a lameness outcome than those who had competed together. Rides categorised as GER were associated with reduced odds of lameness compared to CER rides (OR -0.6, CI: 0.4-0.8). Horses competing at FEI 2* and above had an increased likelihood of lameness (OR 1.9, CI: 1.2-3.06) when compared to horses competing under EGB rules. Weak collinearity was found between the risk factors 'distance completed in 365 days and 'eliminated lame in previous 365 days'.

Significant associations were found between the outcome of elimination due to lameness and previous lameness eliminations, with horse's being 0.5 times less likely to be eliminated lame if their previous lameness was 91-365 days ago, compared with horses that had a lameness elimination within the last 45 days. There was a decreased likelihood of a lameness elimination outcome (OR 0.4, CI: 0.3-0.8) when the horses previous lameness was over a year ago and a decreased likelihood of a lameness elimination if the horse had never been eliminated for lameness (OR 0.3, CI 0.2-0.6) when compared with horses who had a lameness elimination in the past 45 days. Weak collinearity was found between the risk factors ‘starts in 60 days’ and ‘starts in 90 days’.

Biologically plausible interactions terms were tested in both the final models. No statistically significant interactions terms were found.

Table 3 Model B: Results of the multivariable model for all horse starts for the Elimination due to lameness outcome only.

Risk Factor	Cases: Lame n-per category (%)	Controls: Not Lame n-per category (%)	Adjusted OR	95% CI	P value
Returning Combination					
Yes	261 (16.6)	1310 (83.4)	Reference	-	<0.001
No	43 (24.4)	133 (75.6)	2.26	1.52-3.37	<0.001
Class Code					
CER	189 (25.3)	559 (74.7)	Reference	-	<0.001
GER	115 (11.5)	884 (88.5)	-0.54	0.35-0.81	0.003
FEI Level					
Not FEI	153 (12.8)	1039 (87.2)	Reference	-	0.02
1star	77 (23.5)	251 (76.5)	1.21	0.76-1.91	0.4
2 stars+	74 (32.6)	153 (67.4)	1.90	1.18-3.06	0.008
Distance attempted last 30 days (km)					
0	167 (16.9)	824 (83.1)	Reference	-	0.6
1-55	54 (15.4)	296 (84.6)	0.93	0.62-1.38	0.7
56-79	31 (17.7)	144 (82.3)	1.12	0.69-1.84	0.6
80-100	41 (22.4)	142 (77.6)	1.23	0.78-1.92	0.4
>100	11 (22.9)	37 (77.1)	1.71	0.76-3.87	0.2
Distance change from previous ride					
Distance decrease	39 (13.3)	254 (86.7)	Reference	-	0.2
Equal distance	60 (22.7)	204 (77.3)	1.56	0.98-2.50	0.1
Increase ≤ 55km	205 (17.2)	985 (82.8)	1.22	0.80-1.88	0.4
Rides completed previous 180 days					
0	33 (13.3)	216 (86.7)	Reference	-	0.4
1	83 (17.4)	395 (82.6)	1.00	0.55-1.81	>0.9
2	83 (19.2)	349 (80.8)	1.25	0.66-2.37	0.5
3+	105 (17.9)	483 (82.1)	1.44	0.73-2.81	0.3
Starts last 60 days	83 (17.4)	395 (82.6)			
0	83 (19.2)	349 (80.8)	Reference	-	0.04
1	105 (17.9)	483 (82.1)	1.05	0.64-1.71	0.9
2	79 (19.9)	290 (73.2)	1.61	0.83-3.15	0.2
3+	16 (12.9)	108 (87.1)	0.74	0.29-1.89	0.5
Starts last 90 days					
0	31 (10.8)	256 (89.2)	Reference	-	0.03
1	114 (19.6)	468 (80.4)	1.64	0.81-3.30	0.2
2	92 (17.2)	442 (82.8)	0.92	0.40-2.14	0.9
3	116 (28.1)	297 (71.9)	1.03	0.39-2.72	>0.9
Days since previous Lameness					
Within 45 days	25 (34.2)	48 (65.8)	Reference	-	<0.001
46-90	31 (34.1)	60 (65.9)	1.15	0.57-2.30	0.7
91-365	70 (19.4)	291 (80.6)	-0.51	0.28-0.92	0.03
>365	109 (16.4)	554 (83.6)	-0.44	0.25-0.78	0.005
No previous lameness	69 (12.5)	484 (87.5)	-0.33	0.18-0.59	<0.001

OR, adjusted odds ratio, 95% CI, 95% confidence interval. Model fit was good: Omnibus p<0.001 Hosmer- Lemeshow p=0.24. ROC=0.72 GER, graded endurance ride (capped speed), CER, competitive endurance ride (no capped speed) FEI, Fédération Equestre Internationale

Risk factors associated with lameness eliminations for horses registered with Endurance GB, competing in rides of >64km during the 2017-2018 competitive seasons. Data from Endurance GB's database.

Discussion:

The results of this study demonstrate that the competitive history of a horse, the combined competitive experience of the horse and rider and ride specific factors such as whether a competition is classified as a CER or GER, are specific risk factors for horses to elimination and more specifically elimination due to lameness within British endurance rides.

Returning combinations

Horses ridden by a rider that they had never previously competed with were more than twice as likely to be eliminated and be eliminated due to lameness compared to horses ridden by a rider that they had previously been partnered with in competition. Therefore, it could be assumed that riders who had previously partnered with the horse would be more likely to adapt their riding strategy as necessary throughout the competition, compared to an individual who had not ridden the horse previously. The partnership between horse and rider has been discussed from a biomechanical perspective with previous studies identifying that a horse adapts to the riders positioning which can impact on gait [20-23]. Riders respond to the horses movement and adopt their individual postural strategies and responses differently to other riders [21-24]. Therefore, if a horse has been trained, or is normally competed by one individual and then ridden in the next competition by another individual the horse would have to adapt its movement patterning to compensate for the change in each riders' position. Over the course of the long distance and time frame within endurance riding it is possible that the horse may adopt compensatory muscle patterning which may result in altered biomechanics, abnormal loading and increased fatigue, which could potentially manifest as gait abnormalities resulting in the increased elimination and lameness outcomes observed in new combinations [23,25].

From a welfare perspective the horse and rider relationship within competition, should also be considered. If the rider has an awareness of the typical movement behaviour and physiological responses of the horse, it is likely that they would be more competent to recognise fatigue or changes to the gait pattern and implement strategic changes such as changing pace, change of tactics, or where necessary considering retiring the horse before it requires additional veterinary attention [26].The individual experience of the horse and rider may be considered as a contributing factor in the ability to adapt in ride tactics throughout the competition, as has been found in racing, where less falls were associated with more experienced jockeys [27,28]. However, as limited information was available surrounding the riders, this study limited inclusion to horses and riders who had successfully completed their novice qualifications and therefore were deemed eligible to attempt rides of 64km and above and had some experience within the sport. Further research could consider novice horses and riders, to identify whether there is a difference in eliminations and specifically lameness eliminations in lower levels, which could impact the success and welfare of the horse as it progresses through the distances.

Rider age and gender

This study did not find a significant difference between rider age and elimination/ lameness elimination or between rider gender and elimination/ lameness elimination in the final modelling. Rider age had no significance at univariable analysis stage, which is in contrast to previous research which identified young riders were less likely to be eliminated as lame, however, this was only at univariable level and should not be over interpreted [6]. Previous research at international level competition has identified male riders are more likely to have a horse which is eliminated for metabolic compromise [11]. This study did not look specifically at metabolic eliminations, however, at univariable analysis, male riders were significantly more likely to be eliminated overall but were less likely to be eliminated for lameness. This did not carry significance in the final multivariable models and cannot be overinterpreted.

Class Categories

While speed data were not available, horses competing in CER classes with no upper speed limit were more likely to be eliminated than horses in GER where a defined upper speed limit is enforced. This pattern was repeated for horses competing in FEI rides with no upper speed limit compared to national rides, where the majority (83.8%) had speed restrictions in place. Concerns within the sport regarding increasing speeds and the increased likelihood of a negative outcome have been documented by veterinarians who have officiated at the highest level [29] . Additionally, other studies have found that increased speeds in the initial phases of the race, or sudden changes within the pace have been found to increase the likelihood of a deleterious outcome [10-12, 30] This information was not available in the data set analysed however, anecdotally, a change in pace is more likely within a CER competition where the riders are racing another combination and are perhaps more likely to push the horses physiological capabilities, compared to a GER where other horses competing have no impact on their final result. This highlights the complexity of the sport and consideration should be given to tactical riding including pacing strategies and awareness of the negative impact speed may have. Maximum speed limits have been introduced for FEI qualifications; however, these are not echoed for riders who have no desire to compete at international level [1,2]. Tactical training and race management strategies are anecdotally shared with riders who have aspirations to compete at an international level during team training days, however it is not given to riders competing at national level. Further consideration should be given to increased education for riders changing from GER’s to CER’s such as pacing strategies and care of the horse within the vet hold, with perhaps an upper speed limit imposed for their first attempts at CER’s.

A higher incidence and increased odds of elimination and lameness were identified in FEI rides, whilst this could be associated with international competitors perhaps riding at a higher speed, it is also plausible that the veterinary scrutiny may differ between rides run under EGB rules and those run under FEI rules. The veterinary parameters remain the same for both EGB and FEI, but different veterinarians, with differing levels of experience, particularly experience within the sport specifically, may account for some of the higher incidence of eliminations within the FEI category rides. Additionally, a horse can be eliminated with two veterinarians viewing the trot for a EGB GER, whereas three are required to view any questionable trot ups in EGB CERs and all FEI rides. It should be noted however, the incidence of elimination and lameness elimination in British FEI rides was slightly less in this study (44.7% and 27.2%), compared to previous findings (49.8% and 39.4%) [6].

Number of competitions

Multiple rides within the previous 60 days were found to increase the odds of an elimination; this potentially could be linked to a lack of recovery time between competitions. The benefit of longer rest periods between competition has been demonstrated at international level, where an analysis of competition starts from 2010-2017 found 2.3% of eliminations could have been prevented if the mandatory rest period rule instated in 2014 had been implemented in 2008 [13]. By extending the mandatory rest period by seven days, and a further seven days if the horse was ridden over 20kmph, 10.7% of eliminations could be prevented [13]. Research in racehorses has associated accumulative repetitive loading combined with insufficient recovery from micro trauma with a higher incidence of lameness and catastrophic injuries [31-33]. The significant positive correlation between the distance attempted in the horses competitive career and the number of eliminations as well as the number of eliminations due to lameness in the horses career, would indicate that endurance horses also experience the impact of repetitive microtrauma. The correlation identified between the increased number of rides attempted and the number of eliminations and eliminations in the horses career supports this theory. Endurance horses undergo similar physical loading patterns, although work/exercise occurs predominately at lower speeds the repetition of strides will be increased, not only in competition, but in training. It is plausible that horses competing may have a subclinical issue which is not apparent until exposed by the increased physical demands of competition. The details surrounding the training of the horses in the data set were not available, however research into training of endurance horses and subsequent impact on competitive success or failure needs to be considered in greater detail and may be advantageous in reducing injuries [33,34].

Previous eliminations

Endurance GB requires horses to have MOOCP based on the distance completed and an additional eight days are added if the horse is eliminated by the veterinary panel regardless of the number of previous eliminations. As this study has identified that horses are at a decreased likelihood of lameness eliminations if there is >90 days since their previous lameness elimination, consideration should be given to extending these rest periods within national competition dependent on the elimination reason. Adopting this approach has been successful in decreasing the likelihood of elimination in FEI competitions [13].

Recommendations

Equestrian sport is recognised in the literature to have inherent risks, but within the context of social licence to operate, there is a need to define a framework to limit risks, reduce injury and optimise the welfare of competing horses [3]. The results of this study demonstrate reasons for lameness may be multifactorial and therefore complex to remove entirely from endurance. Veterinarians within the sport also report identification of lameness within competition is challenging and is considered a clinical sign rather than a diagnosis [35]. The findings of this study demonstrate that following a lameness elimination, there is a higher likelihood of another lameness elimination, however, little is known about the causality, diagnosis and rehabilitation prior to return to competition post lameness elimination. In order to manage endurance horses effectively, it would be beneficial to have greater details of lameness such as which limb(s) and at what stage of the competition lameness and elimination is occurring, to be able to determine prophylactic management strategies. The current data do not indicate which limb(s) of the horse(s) are considered to be the lame limb and therefore it is not possible to evaluate whether the horse(s) with repeated lameness elimination results are being eliminated with the same limb each time, which would be indicative of return to competition prior to full recovery. Identification of reoccurring injuries and/or compensatory patterns which may be detrimental to the welfare of the horse would allow stakeholders to act upon it, to improve the welfare and ultimately performance outcomes. Increasing the mandatory rest periods between competition and education for riders surrounding the importance of appropriate and maximal recovery could improve equine welfare and increase the longevity of the horse’s career. . It may also be of benefit to restrict the number of competitive starts within one competitive season to reduce the possible impact of microtrauma from cumulative distance.

Limitations

This study highlights gaps in the current data recorded at ride level, such as the terrain and ground conditions of the ride, the weather conditions, the speeds, point of elimination, and if lame, the limb(s) which were identified as lame which would enable further information surrounding lameness eliminations to be considered for the improvement of welfare within the sport. Some eliminations (8.5%) on the database were documented only as elimination without further classification, which may explain the lower percentage of lameness eliminations in comparison to other studies. It is assumed that some of these eliminations without further classification, may indeed have been lameness eliminations, but of course could not be considered as, which will have some impact on the accuracy of the results. This also prevented detailed modelling on other elimination reasons such as metabolic eliminations which have identified different risk factors from lameness [6-13]. Additionally, 21.6% of eliminations were a result of riders retiring their horses on course, further information as to the reasons behind their retirement were not available . Whilst FEI rides and EGB use the same vetting parameters, it is plausible that there may be a differing level of veterinary scrutiny across competitions, which may impact on results. It is also acknowledged that weak collinearity between variables in the final models were found and are recognised as a limitation but are inevitable in studies of this nature.

Conclusion:

This study of British endurance horses has shown that multiple competitive starts, previous veterinary eliminations and ride categories are significant risk factors associated with elimination from competition. Additionally, it demonstrated that horses and riders who had not previously competed as a combination were significantly more likely to be eliminated from competition.

Supplementary files:
Table S1: Potential risk factors identified from Endurance GB database

References

1.Endurance GB website: https://egb.myclubhouse.co.uk/Cms/Spaes/NEWS/Ness/2020+Endurance+GB+Rules+Ride+Information. Last accessed: 06/05/2021.

2. Fédération Equestre Internationale website: https://inside.fei.org/fei/disc/endurance/rules. Last accessed: 04/03/2021.

3. Owers, R. (2017) Equestrian sport and the concept of a social licence: presentation to the 2017 FEI General Assembly.

Available from: https://inside.fei.org/system/files/GA17_World_Horse_Welfare_PPT.pdf
Last accessed: 06/01/202.

4. Fiedler, J, Ames, K. and Thomas, M. (2018) Sports horse welfare and social license to operate: informing communication strategies.
Available from:
https://www.researchgate.net/publication/340756198_Sport_Horse_Welfare_and_Social_Licence_to_Operate Last accessed 07/12/2020.

5. Fédération Equestre Internationale website:
https://inside.fei.org/sites/default/files/FEI_Endurance_Report_2019.final.pdf Last accessed: 06/12/2020.

6. Nagy, A, Murray, J and Dyson, S (2010) Elimination from elite endurance rides in nine countries: a preliminary study. *Equine Vet. J.* **42***,* Suppl. 38, 637-643.

7. Fielding, C.L, Meier, C.A., Balch, O.K., and Kass, P.H. (2011) Risk factors for the elimination of endurance horses from competition. *J. Am. Vet. Med. Assoc.* **239**, 493-498.

8. Nagy, A, Murray, J.K. and Dyson, S.J. (2014) Descriptive epidemiology and risk factors for elimination from Federation Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). *Equine Vet. J.* **46**, 38-44.

9. Nagy, A, Murray, J.K. and Dyson, S.J. (2014) Horse-, rider-, venue- and environment-related risk factor for elimination from Fédération Equestre Internationale endurance rides due to lameness and metabolic reasons. *Equine Vet. J.* **46**, 294-299.

10. Younes, M., Barrey, E., Cottin, F. and Robert, C. (2016) Elimination in long-distance endurance rides: insights from the analysis of 7032 starts in 80-160km competitions. *Comp. Exerc. Physiol.* **12**, 157-167.

11. Bennet, E.D, and Parkin, T.D.H. (2018) Fédération Equestre Internationale endurance events: risk factors for failure to qualify outcomes at the level of the horse, ride, and rider (2010-2015). *Vet. J.* **236**, 44-48.

12. Bennet, E.D, and Parkin, T.D.H. (2018) Fédération Equestre Internationale endurance events: riding speeds as a risk factor for elimination (2012-2015). *Vet. J.* **236**, 37-43.

13. Bennet, E.D. and Parkin, T.D.H. (2020) The impact of the mandatory rest period in Fédération Equestre Internationle endurance events. *Equine Vet. J.* **52**, 268-272.14. Nagy, A., Dyson, S.J. and Murray, J.K. (2017) Veterinary problems of endurance horses in England and Wales. *J. Prev. Vet. Med.* **140**, 45-52.

14. Nagy, A., Dyson, S.J. and Murray, J.K. (2017) Veterinary problems of endurance horses in England and Wales. *J. Prev. Vet. Mede.* **140**, 45-52.

15. Schober, P., Boer, C. and Schwarte, L. (2018) Correlation coefficients: appropriate use and interpretation. *Anesthesia & Analgesia* **126,** 1763-1768.

16. Dahoo, I., Ducrot, C., Fouricho, C., Donald, A. and Hurnik, D. (1996). An overview of techniques for dealing with large numbers of independent variables in epidemiological studies. *J. Prev. Vet. Mede.* **29**, 221-239.

17. Hosmer, D.W. and Lemeshow, S., (2000) Applied logistic regression 2nd edn., Ed: John Wiley and Sons Inc., New York, USA. pp143-202.

18. Gardner, I.A. and Greiner, M (2006). Receiver-operating characteristic curves and likelihood ratios: improvements over traditional methods for the evaluation and application of veterinary clinical pathology tests. *Vet. Clin. Path.* **35**, 8-17.

19. Bandos, A.I., Rockette, H.E. and Gur, D. (2010) Use of likelihood ratios for comparisons of binary diagnostic tests: underlying ROC curves. *J. Med. Phys.* **37**, 5821-30.

20. Peham C., Licka T., Schobesberg H. and Meschan E. (2004) Influence of the rider on the variability of the equine gait. *Hum. Move. Sci.* **23**, 663-671.

21. Viry, S., Sleimen-Malkoun, R., Temprado, J.J, Frances, J.P, Beron, E., Laurent, M. and Nicol, C. (2013) Patterns of horse-rider coordination during endurance race: a dynamic system approach. *Plos one* [online]. 8 e71804. doi.org/10.1371/journal.pone.0071804 Last accessed: 15/06/2020.

22. Viry, S., De Graff, J.B., Frances, J.P., Berton, E., Laurent, M. and Nicol, C. (2015) Combined influence of expertise and fatigue on riding strategy and horse-rider coupling during the time course of endurance races. *Equine Vet. J.* **47**, 78-82.

23. Mackechnie-Guire, R., Mackechnie-Guire, E, Fairfax, V. Fisher, M., Hargreaves, S and Pfau, T. (2020) The effect that induced rider asymmetry has on equine locomotion and the range of motion of the thoracolumbar spine when ridden in rising trot. *J. Equine Vet. Sci.*[online] 88:102946. doi:10.1016/j.jevs.2020.102946.
Last accessed:06/08/2021

24. Wilkins, C., Nankervis, K., Protheroe, L. and Draper, S. (2020) Static pelvic posture is not related to dynamic pelvic tilt or competition level in dressage riders. *Sports Biomech.* [online] doi.org/10.1080/14763141.2020.1797150 Last accessed: 18/03/ 2021.

25. Foreman, J.H (1998) The exhausted horse syndrome. *Vet. Clin. North Am. Equine Pract.* **14**, 205-220.

26. Clayton, H.M and Hobbs, SJ (2017) The role of biomechanical analysis of horse and rider in equitation science. *Appl. Anim. Behav. Sci.* **190**, 123-132.

27. Hitchens, P.L., Blizzard, C.L., Jones, G., Day, L.M., and Fell, J. (2012) The association between jockey experience and race-day falls in flat racing in Australia. *Inj. Prev.* **18**, 385-391.

28. Williams, J.M., Marlin, D., Langley, N., Parkin, T. and Randle, H. (2013) The Grand National: a review of factors associated with non-completion and horse-falls, 1990 to 2012. *Comp. Exerc. Physiol*. **9**, 131-146.

29. Coombs S.L., and Fisher, R.J. (2012) Endurance riding in 2012: too far too fast? *Vet J*. **194**, 270-271.

30. Marlin, D. and Williams, J. (2018) Equine endurance pacing strategy differs between finishers and non-finishers in 120km single day races. *Comp. Exerc. Physiol.* **14**, 11-18.

31. Williams, R.B., Harkins, L.S., Hammond, C.J. and Wood, J.L.N. (2001). Racehorse injuries, clinical problems and fatalities recorded on British racecourses from flat racing and National Hunt racing during 1996, 1997 and 1998. *Equine Vet. J.* **33**, 478-486.

32. Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M.,Singer, E.R., Webbon, P.M. and Morgan, K.L. (2005) Risk factors for fatal lateral condylar fracture of the third metacarpus/ metatarsus in UK racing. *Equine Vet. J.* **37**, 192-199.

33. Martig, S., Chen, W., Lee, P.V.S., Whitton, R.C. (2014) Bone fatigue and its implications for injuries in racehorses. *Equine Vet. J*. **46**, 408-415.

34. Parkin, T.D.H., Clegg, P.D., French, N.P, Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004) Horse-level risk factors for fatal distal limb fracture in racing thoroughbreds in the UK. *Equine Vet. J.* 3**6**, 513-519.

35. De Mira, M., Santos, C., Lopes, M.A. and Marlin, D. (2019) Challenges encountered by Federation Equestre Internationale (FEI) veterinarians in gait evaluation during FEI endurance competitions: an international survey. *Comp. Exerc. Physiol.* **15**, 371-378.

Table S1: Potential risk factors identified from Endurance GB database

Potential risk factor	Categorisation	Description
Horse gender	Binary	Male/ Female
Horse age	Categorical	Horse age on day of ride,

Horse breed	Binary	'Arabian bloodlines' and 'Non-Arabians
Returning combination	Binary	Had the horse and rider competed as a combination previously
Rider gender	Binary	Male/ Female
Rider age	Binary	Senior rider over 21 years of age or not
Class Code	Binary	Graded Endurance Ride or Competitive Endurance Ride
Distance	Categorical	Ride distances of 64-160km
Level if Fédération Equestre Internationale	Categorical	Categories correspond to Fédération Equestre Internationale categories
Year of competition	Binary	2017 or 2018
Days since previous competition	Categorical	Number of days since previous competitive start
Career length of horse (years)	Categorical	How many years of competitive history did the horse have recorded on the database
Career length of horse (days)	Categorical	How many days of competitive history did the horse have recorded on the database
Career rides attempted	Categorical	Number of rides attempted in the career of the horse
Career rides completed	Categorical	Number of rides completed in career of the horse
Career distance attempted	Categorical	Distance (km) attempted in the career of the horse
Career distance completed	Categorical	Distance (km) attempted in the career of the horse
Outcome of previous ride	Categorical	Pass, Retired on course, Eliminated Lame, Eliminated-including all other reasons for failure
Number of eliminations in career	Categorical	The total number of times the horse was eliminated in its competitive career
Number of lameness eliminations in career	Categorical	The total number of times the horse was eliminated due to lameness in its competitive career
Days since previous elimination	Categorical	The number of days since the previous elimination of the horse

Days since previous lameness elimination	Categorical	The number of days since the horse previously was eliminated due to lameness
Distance attempted last 30 days	Categorical	Competitive distance horse attempted in last 30 days
Distance attempted last 60 days	Categorical	Competitive distance horse attempted in last 60 days
Distance attempted last 90 days	Categorical	Competitive distance horse attempted in last 90 days
Distance attempted last 180 days	Categorical	Competitive distance horse attempted in last 180 days
Distance attempted last 365 days	Categorical	Competitive distance horse attempted in last 365 days
Distance completed last 30 days	Categorical	Competitive distance horse completed in last 30 days
Distance completed last 60 days	Categorical	Competitive distance horse completed in last 60 days
Distance completed last 90 days	Categorical	Competitive distance horse completed in last 90 days
Distance completed last 180 days	Categorical	Competitive distance horse completed in last 180 days
Distance completed last 365 days	Categorical	Competitive distance horse completed in last 365 days
Distance change since previous ride(km)	Categorical	Did the horse compete at a higher, lower or same distance compared to its previous ride
Distance change since previous ride(percentage)	Categorical	How much did the distance increase or decrease by percentage compared to the previous ride
Number of competitive starts in last 30 days	Categorical	Number of competitions horse started in last 30 days
Number of competitive starts in last 60 days	Categorical	Number of competitions horse started in last 60 days

Number of competitive starts in last 90 days	Categorical	Number of competitions horse started in last 90 days
Number of competitive starts in last 180 days	Categorical	Number of competitions horse started in last 180 days
Number of competitive starts in last 365 days	Categorical	Number of competitions horse started in last 365 days
Number of successful completions in last 30 days	Categorical	Number of competitions horse successfully completed in last 30 days
Number of successful completions in last 60 days	Categorical	Number of competitions horse successfully completed in last 60 days
Number of successful completions in last 90 days	Categorical	Number of competitions horse successfully completed in last 90 days
Number of successful completions in last 180 days	Categorical	Number of competitions horse successfully completed in last 180 days
Number of successful completions in last 365 days	Categorical	Number of competitions horse successfully completed in last 365 days
Eliminated last 30 days	Binary	Was the horse eliminated in the last 30 days?
Eliminated last 60 days	Binary	Was the horse eliminated in the last 60 days?
Eliminated last 90 days	Binary	Was the horse eliminated in the last 90 days?
Eliminated last 180 days	Categorical	Number of times the horse was eliminated in last 180 days
Eliminated last 365 days	Categorical	Number of times the horse was eliminated in last 365 days
Eliminated lame last 30 days	Binary	Was the horse eliminated lame in the last 30 days?
Eliminated lame last 60 days	Binary	Was the horse eliminated lame in the last 60 days?
Eliminated lame last 90 days	Binary	Was the horse eliminated lame in the last 90 days?

Eliminated lame last 180 days	Binary	Was the horse eliminated lame in the last 180 days?
Eliminated lame last 365 days	Binary	Was the horse eliminated lame in the last 365 days?
Rider previous eliminations	Categorical	Number of times rider recorded an elimination outcome in their career
Rider previous lameness eliminations	Categorical	Number of times rider has recorded a lameness elimination outcome in their career
Combination previous eliminated	Binary	Had the horse and rider combination previously recorded an elimination outcome
Combination previous eliminated lame	Binary	Had the horse and rider combination previously recorded a lameness elimination outcome

Appendix 5

Published version of Study 2a.

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022) A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019. *Comparative Exercise Physiology.* 18 (4), pp. 329-338. DOI:10.3920/CEP220003

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A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019

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Abstract:

Veterinary eliminations within the equestrian sport of endurance have predominantly been evaluated based on data from international competitions. However, in order to take part in international competition, each horse and rider must qualify by completing rides under their national federation. The aim of this study was to analyse the competitive data and veterinary eliminations, specifically lameness, from competitions run by the British governing body of endurance: Endurance GB, during the 2019 competitive season. Competitive results for 765 ride starts from seven different ride venues were evaluated; 81.6% (n = 624) horses successfully completed the rides, with the remaining 18.4% (n = 141) failing to complete the ride. The majority of horses that were unsuccessful were eliminated for lameness at veterinary inspections (n = 83; 58.9%). Horses competing in single loop rides (up to 55km rides) had a success rate of 88.6% (n = 624), in contrast, horses competing in rides of three loops or more (>80km rides) reported a decreased success rate of 61.8% (n=81). Hind limb lameness was identified more frequently (n = 50; 60.2%) compared with forelimb lameness (n=33; 39.8%). Further consideration should be given to the differences between single loop rides, where a higher percentage are presented to the veterinary panel as lame prior to the start, and multi loop rides, where a higher percentage of horses are eliminated lame during the ride and potential risk factors for the increased prevalence of hind limb lameness observed.

Key words: endurance racing, equine welfare, lameness, horse,

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Introduction:

The governing body of endurance riding within the UK, Endurance GB (EGB) schedules over 100 competitions between March-October each year. Single day competitions range from 20-160km rides and are categorised as graded endurance rides (GER) or competitive endurance rides (CER). Horses and riders compete through a series of GER before being eligible to compete in CER. Riders or horses do not necessarily have to qualify as a consistent combination but can qualify as an individual (Endurance GB, 2020). Graded endurance rides must be completed within a set range of speeds, the minimum and maximum speeds are dependent on the qualification level of the horse and rider (8-15kmph for novices and 9-18kmph for open and advanced level). A summary of qualification levels and progression requirements are shown in Appendix A.

If horses do not complete the ride within the required time frame, they fail to qualify (FTQ) and are eliminated for being out of time (OOT). Advanced level horses are eligible to compete in competitive endurance rides (CER). These are race rides, with a minimum speed of 10kmph, where the first horse past the finish line, who successfully passes the vetting, is declared the winner. Each competition regardless of distance has a veterinary inspection at the start and finish, with distances over 55km also requiring veterinary inspections at intervals of 30-40 km during the ride. The horse must successfully pass all the veterinary inspections in order to complete the ride (Endurance GB, 2020).

The veterinary inspection consists of a metabolic inspection, where the heart rate must be below 64 bpm, within 20 minutes during the ride and within 30 minutes at the end of the ride. The veterinarian also listens to gut sound, checks the hydration levels of the horse and ensures its muscle tone and general demeanour indicate that it can continue the next phase of the competition. If they are not satisfied that the horse is able to continue on metabolic grounds it is eliminated and fails to qualify for metabolic reasons (FTQME). The horse must also be trotted, without tack 30m in a straight line, away from and towards the examining veterinarian. If they assess the horse to be lame, or have an un-even gait pattern, the horse is asked to re-trot. During the re-trot, additional members of the veterinary team will observe the horse trotting. During a GER, this may only be one additional member. During a CER, there will be a panel of three veterinarians. Each veterinarian marks on a voting slip if they consider the horse to 'pass' or 'fail'. The voting takes place without discussion and individual outcomes are passed to the ground jury who gives the majority decision as to whether the horse has passed or failed to qualify due to lameness (FTQLA). If a horse passes a veterinary inspection, but the rider feels it is not in the best interest of the horse to continue, then they can 'retire on course' (ROC) (Endurance GB, 2020).

Previous studies in Endurance and international statistics have identified that the most common reason for elimination is lameness (Bennet and Parkin, 2018; Fédération Equestre Internationale, 2019; Fédération Equestre Internationale, 2020; Fielding *et al.,* 2011; Nagy *et al.*, 2010; Nagy *et al.,* 2012; Nagy *et al.,* 2014; Younes *et al.,* 2016). Most studies have focussed on international competitions where competitors, (horses and riders) are experienced. These studies have identified that horses are at increased odds of lameness in rides over longer distances or when they have been ridden at faster speeds (Bennet and Parkin, 2018b). However, this by no means implies that the risk of lameness at shorter distances and slower speeds is negligible.

At national level, Nagy *et al.,* 2017, surveyed the membership of EGB to identify the most common issues their horses faced and 80% confirmed that their horse(s) had had an episode of lameness within their competitive career. Additionally, anecdotally, the most common reason EGB for elimination is considered to be lameness. There is a need to identify if this perception is accurate, to facilitate proactive risk management to improve the welfare and increase the competitive longevity of the horses competing within the sport at a national level.

Within EGB endurance competitions while records are kept for horses that have been eliminated for lameness, details surrounding the lameness are not specified/recorded. Ordinarily, outside of competition, when a veterinarian is examining a horse for lameness, a series of diagnostic tests, such as nerve blocks and/or appropriate imagery may be performed to identify the source of the lameness (American Association of Equine Practitioners, 2019). Whilst it is recognised that the veterinary examinations during competition are not diagnostic, and lameness is often multifactorial, further information could be gathered. Additionally, the current options for veterinary eliminations are usually for 'lameness' or 'metabolic' despite the case that some metabolically compromised horses also present lame and vice versa. A greater depth of information surrounding lameness at the point of elimination is required, such as which limb(s) are most commonly affected, the severity of lameness' and whether this changes dependent on the competition level and distance. This would facilitate a more accurate evaluation of risk factors which would potentially allow more in-depth awareness and enable preventative strategies to be considered and implemented.

Risk factors for FTQ and FTQLA have been documented at international level and include multiple competitive starts, insufficient rest periods between competitions, high speeds (> 20kmph) and previous FTQ and FTQLA in a horse's competitive history (Bennet and Parkin 2018a, 2018b; Fielding *et al*., 2011; Nagy *et al.,* 2010; Nagy *et al.,* 2014, Younes *et al.,* 2016; Zuffa *et al*., 2021). However, no studies to date have examined the risk factors associated with FTQ and FTQLA at British national level. This information is important in order to establish whether risk factors differ between national and international competition, to ensure that appropriate education and proactive risk mitigation strategies can be implemented across all levels of the sport to improve equine welfare and public perception of the sport.

Therefore, this study aimed to consider lameness eliminations in more detail than previously studied, by identifying the most commonly affected limb(s), understanding the severity of lameness presented, and if changes found were dependent on the stage or level of competition. Subsequent relationships between risk factors and lameness across national level British endurance are reported elsewhere (Bloom *et al.,* unpublished data).

Methods:

Participants

Following agreement from EGB, seven national rides were attended between June-October 2019, totalling thirteen days of competition. Prior to each ride, an information sheet was sent via email to the ride organisers, technical stewards, ground jury and attending veterinarians detailing the study and the data that would be requested. Horses competing across all distances in rides run under EGB rules, with full veterinary examinations were included in the study. Horses competing in FEI rides were excluded, as were horses competing in pleasure ride classes as these are run under different rules. Ethical approval was granted by the Hartpury University ethics board prior to data collection.

Measures

At the rides attended, information collected by EGB as standard was obtained by taking copies of the official results, including, the start and finish time for each loop and the duration of the ride, time taken to present to the veterinarian (multi-loop rides only) and the official heart rate of the horse at the veterinary inspections during the ride and at the finish. In addition, the subjective steepness of the ride, based on the route description documented on the ride entry (e.g. serious hills or flat forest tracks) and trot up surface were documented. The air temperature and relative humidity were recorded using a calibrated digital temperature and humidity meter (Peak-Meter PM6508). These measurements were taken hourly at the venue from the time the first horse(s) started the competition, until the final horse completed the ride.

During the veterinary inspection, at each of the rides attended, if a horse was asked to re-trot within any of the veterinary inspections throughout the ride, each member of the veterinary panel (VP) watching the horse trot was asked to note whether they believed the horse to be lame/not lame. If they considered the horse to be lame, they were then asked to identify which limb(s) they considered the horse to be lame on, and to assess the severity of lameness using the American Association of Equine Practitioners (AAEP) 6-point scale, shown in Table 1.

Table 1: American Association of Equine Practitioners Lameness Scale*

Grade	Description
0	Lameness not perceptible under any circumstances
1	Lameness is difficult to observe and is not consistently apparent, regardless of circumstances (e.g. under saddle, circling, inclines, hard surfaces etc)
2	Lameness is difficult to observe at walk or wen trotting in a straight line but consistent under certain circumstances (e.g. weight-carrying, circling, inclines, hard surface etc)
3	Lameness is consistently observable at trot under all circumstances
4	Lameness is obvious at a walk
5	Lameness produces minimal weightbearing in motion and/or rest or a complete inability to move

*Table from American Association Equine Practitioners, 2019

Voting slips were handed to the ground-jury member to give the decision to the rider as to whether the horse had passed or failed the veterinary inspection. The ground jury then handed the slips to the researcher to analyse. No external intervention was required or placed upon participants and all data were anonymised. The only addition to the standard vetting procedure was the notation of limb(s) and grade, there were no changes to the physical veterinary examination.

Horse demographics such as age, sex and breed were collected and historical information for each horse taking part was downloaded from the Endurance GB website. This information included: the number of years the horse had been competing, the number of successful and unsuccessful rides, the cumulative distance attempted over the horse's career, the number of previous FTQ and FTQLA occurrences for the horse and how long prior to the ride currently being attended these negative outcomes occurred. The length of time between the ride attended and the previous competition, the previous FTQ and the previous FTQLA was also calculated.

Data Analysis

Frequency analysis of factors was completed. Historical data met non-parametric assumptions and are reported as median± interquartile range unless otherwise stated. A series of Spearman's Rank Correlations ($p<0.05$) examined the relationship between the number of times a horse FTQ in their career, or FTQLA in their career and the age of the horse, the length of their competitive career (years) the number of rides the horse had attempted in their career and successfully completed in their career, the distance (km) the horse had attempted in their career and the distance (km) the horse had successfully completed in their career. The correlation coefficient was identified as either positive or negative, with the strength of the association being determined by its proximity to either +1 or -1. The closer to 1 (positive or negative), the stronger the association between the ranks (Schober *et al.,* 2018). Correlation coefficients of 0.0-0.30 were considered negligible, values of 0.31-0.50 were considered low, 0.51-0.70 moderate, 0.71-0.90 high and 0.91-1 very high (Mukaka, 2012). All analyses were completed using Statistical Product and Service Solutions software (Version 26.0 IBM, Portsmouth). Multivariable modelling evaluated risk factors associated with FTQ and FTQLA; these results are presented separately (Bloom *et al.,* unpublished data*).*

Results:

Competitive results from 765 entries were collected and evaluated. Results were obtained from rides ranging from a single loop ride (22-48km), to six loop rides over two or three days, with a maximum distance of 174km. The longest single day ride consisted of four loops and a total of 101km. Only one ride had the veterinary inspection on hard ground (concrete), whilst the other six were on grass. The majority of the grass trot up lanes were not mown or specialised areas, but the flattest area of the venue fields. One ride was considered 'steep', with the ride information detailing 'serious hills', the other rides were considered to have 'minimal climbs'. Temperature ranged from 8.4-29.8°Celcius. Relative humidity ranged from 39.1% to 100%, with bright sunshine to heavy rain. Table 2 shows the conditions for each ride.

Table 2: Environmental, climatic and topographical conditions at each ride

Ride	1	2	3	4	5	6	7
Month	June	July	July	Sept	Sept	Oct	Oct
Temperature °Celcius	14.3-20.1	21.6-29.8	16.3-24.6	12.4-26.2	15.7-18.2	13.2-16.6	8.4-10.0
Relative Humidity %	49.3-83.2	40.8-52.8	44.4-78.5	39.1-68.8	62.4-100	61.3-74.6	77.0-87.6
Weather	Sunshine, light breeze	Bright sunshine, minimal breeze	Cloudy with sunny spells	Bright sunshine, minimal breeze	Heavy Rain	Cloudy with sunny spells some rain showers	Rain most of the day

Route Description	Grassy downland tracks, undulating	Forest, heath and farmland, fast sandy tracks, gently undulating	Bridleways, private tracks in park. Very little roadwork	Good going on field margins, across grassland and bridleways, minimal roadwork	Private tracks and field headlands.	Grass and heather on rolling plateaux with some serious hills	Grass tracks, bridleways, flat, clay soil.

The greatest number of entries were in single loop rides n=526 (68.7%). Single loop rides were all categorised as GER with a completion speed of 11.7± 1.9kmph. Two-loop rides (GER's), 64-80km accounted for 14.1% of entries (n=108) with a completion speed of 12.5± 1.6kmph. Rides of three loops and above, which ranged from 80-174km accounted for 17.1% of entries (n=131), within these rides 64.1% (n=84) were categorised as CER with a completion speed of 12.5± 2.9kmph and the remaining 35.9% were GER with a completion speed of 12.0± 1.1kmph.

Table 4 shows the number of horse starts dependent on how many loops the ride consisted of and the outcomes of the competitions. The highest number of entries were in single loop rides (n = 526, 68.8%) with a success rate of 88.6% (n = 466) this decreased to 71.3% (n = 77) in rides of 2 loops and 61.8% (n = 81) for rides of 3 loops or more as shown in Figure 1.

Lameness accounted for 83.3% of FTQ's in rides of six loops, but only 55% of FTQ's in single loop rides. The overall prevalence of lameness was 10.8%, however in rides of three loops or more, 26.0 % of horses that started the competitions were eliminated for lameness.

Table 3: Ride entries and results per number of loops

Number of loops	**1**	**2**	**3**	**4**	**5**	**6**	**All rides**
Entries (n)	526	108	105	7	2	17	765
Entries %	68.76	14.12	13.72	0.92	0.26	2.22	100
Completions (n)	466	77	65	4	1	11	624
Completions %	88.59	71.30	61.90	57.14	50.00	64.71	81.57
FTQ (n)	60	31	40	3	1	6	141
FTQ %	11.41	28.70	38.10	42.86	50.00	35.29	18.43
Lame (n)	33	16	27	2	0	5	83

Lame % of FTQ	55.00	51.61	67.50	66.67	0	83.33	58.87
FL Lame (n)	15	4	12	1	0	1	33
FL Lame % of Lame	45.45	25.00	44.44	50.00	0	20.00	39.76
HL Lame (n)	18	12	15	1	0	4	50
HL Lame % of Lame	54.55	75.00	55.56	50.00	0	80.00	60.24
Met (n)	5	3	2	0	0	0	10
Met % of FTQ	8.33	9.68	5.00	0	0	0	7.09
Ret (n)	11	12	8	0	1	1	33
Ret % of FTQ	18.33	38.48	20.00	0	100.00	16.67	23.40
FTQ other (n)	11	0	3	1	0	0	15
FTQ other % of FTQ	18.33	0	5.00	33.33	0	0	10.64
FTQ Start (n)	5	4	1	0	0	0	10
FTQ Start % of FTQ	8.33	12.90	2.50	0	0	0	7.10
FTQ During ride (n)	4	20	30	2	1	6	63
FTQ During Ride % of FTQ	6.67	64.52	75.00	66.67	100.00	100.00	44.68
FTQ End (n)	51	7	9	1	0	0	68
FTQ End % of FTQ	85.00	22.58	22.50	33.33	0	0	48.23

*Percentages not exact due to rounding. Forelimb (FL), Hindlimb (HL), Fail to Qualify (FTQ)

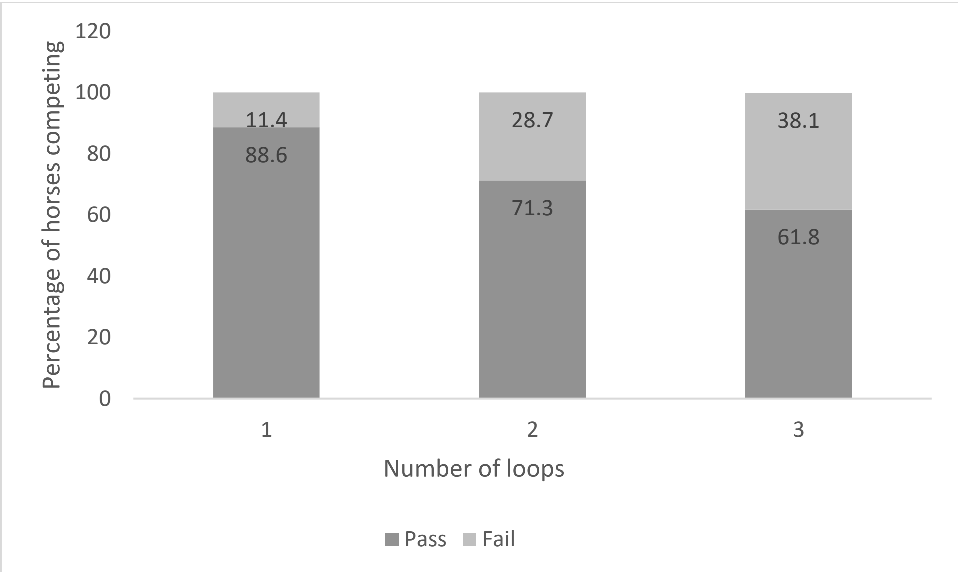

Figure 1. The percentage of horses that passed or failed the competition for single loop rides, two loop rides and rides of 3 or more loops.

The percentage of horses that passed or failed the competition, calculated from data collected at Endurance GB competitions in 2019, presented for single loop rides (up to 55km), two loop rides (56-79km), and three or more loops (80km and above).

Metabolic eliminations (n=10) accounted for 7.1% of eliminations, 23.4% of eliminations (n=33) were due to the rider retiring the horse from the competition and 10.6% of eliminations (n=15) were due to other reasons; one of these was due to a sore back, one was due to a wound and the others were due to course errors or failure to meet the minimum speed requirements (Fig. 2).

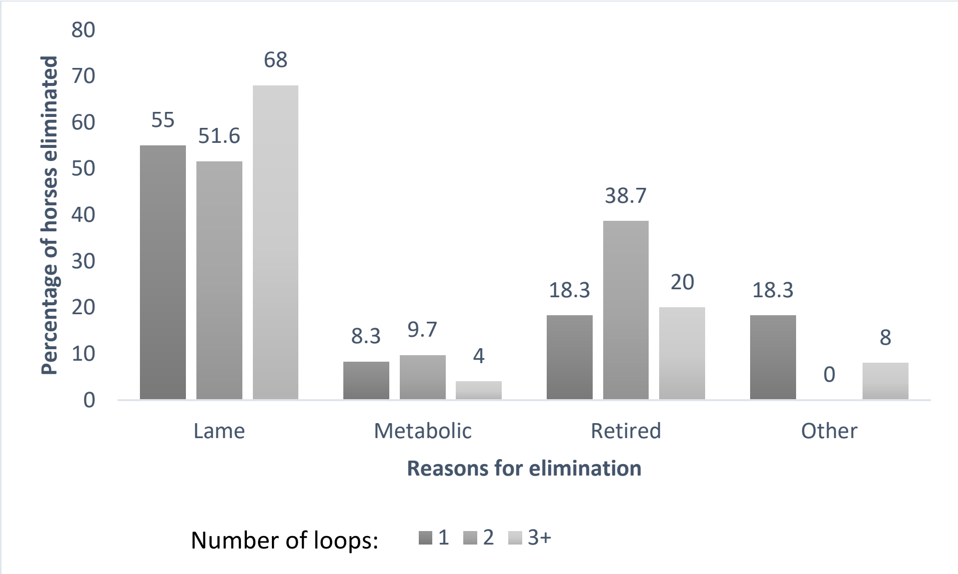

Figure 2. For horses that failed to qualify, the percentage of the failures in one loop, two loop and three+ loop rides and the reasons for their elimination from competition.
The reasons for eliminations in single loop (up to 55Km), two loop (56-79km) and three or more loop rides (>80km) calculated as a percentage from data collected at Endurance GB rides in 2019.

Of horses that FTQ, the highest percentage, 58.9% (n=83) were eliminated for lameness. In single loop rides 55% (n=33) of all FTQ were FTQLA. Lameness eliminations accounted for 51.6% (n=16) in two-loop rides and 68% (n=34) in rides of three loops and above. Hind limb lameness accounted for 60.2% (n=50) of all lameness eliminations. Fig.3 demonstrates the split between single loop and multi-loop rides.

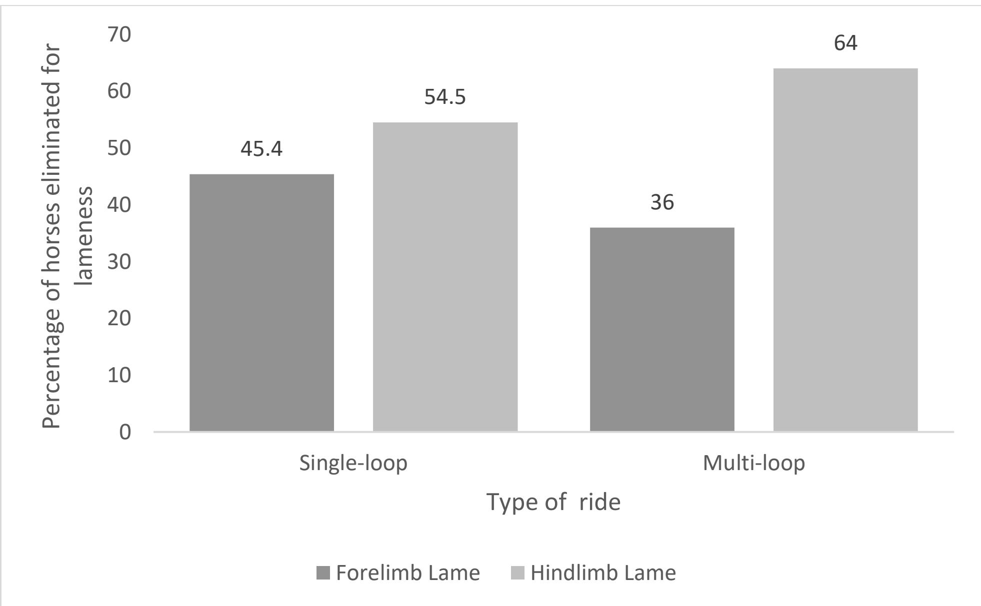

Figure 3. Percentage of lame horses eliminated for forelimb or hind limb lameness for single loop rides and multi-loop rides.
Horses eliminated as lame from competition from single loop rides (up to 55km) and multi-loop rides (>55km) categorised as forelimb or hindlimb lame, determined by the veterinarians at the time of elimination and calculated as a percentage, from data collected at Endurance GB rides in 2019.

Excluding single loop rides, where there is only a veterinary examination at the start and the finish, the majority of horses that FTQ did so during the ride 72.8% (n = 59). Of those that FTQ, 21% (n = 17) did so at the end of the ride. The remaining 6.2% (n = 5) of FTQ's were declared lame at the pre-ride veterinary inspection. No horses were declared lame at the start in rides consisting of four loops and above.

Examining veterinarians agreed on which limb was lame in 100% of cases where two veterinarians observed the re-trot. Agreement was only slightly less (83%) when three veterinarians observed the re-trot. The highest grade of lameness was a grade four. This occurred in three cases. One was a forelimb lameness at the penultimate ride of the competitive season, and the other two cases were hind limb lameness's at the final ride of the season. The median lameness grade was 2±1.

Historical Horse Data:

The competitive history and demographics for the horses competing varied considerably with some horses having competed in lower distances the previous day, and others having not competed for several years. Table 4 shows the background information on the horses competing. The median age of the horses was similar across all distances, with the upper range of horses competing going into their twenties. The cumulative competitive distances had a vast range, particularly in the single loop categories where some horses had not competed before and others having attempted over ten thousand kilometres.

Historical Correlations:

Across all distances, significant positive correlations were found between all historical parameters investigated, and the number of competitive rides horses had previously been eliminated from for all FTQ reasons (Table 5) and for FTQLA only (Table 6).

Table 4: Historical data for horses competing

Variable	Single Loop Median± IRQ (Range)	2 loops Median± IRQ (Range)	3+ loops Median± IRQ (Range)
Age	11± 5 (5-29)	12 ±6 (6-24)	11± 4 (6-24)
Number of Years Competing	2± 5 (0-19)	3 ± 4 (0-17)	4 ± 5 (1-14)
Days since previous ride	34±50 (1-1980)	27± 22 (6-3314)	34± 35 (5-757)
Distance previous ride	40± 10 (16-160)	44±28 (16-144)	80± 38 (31-143)
Days since previous FTQ	223± 441 (6-3716)	265.5± 286.75 (7-2618)	294± 405 (2-2944)
Days since previous FTQLA	371.5± 711.25 (14-3710)	307± 558.75 (21-2652)	395± 612.75 (20-3591)
FTQ 2019	0 ± 1 (0-4)	0 ± 1 (0-3)	0± 1 (0-5)
FTQ Career	1±3 (0-21)	2± 5 (0-21)	3± 5 (0-18)
FTQLA 2019	0 ± 0 (0-3)	0 ± 1 (0-3)	0± 1 (0-3)
FTQLA Career	0±1 (0-15)	1± 3 (0-10)	1± 3 (0-10)
Rides attempted 2019	3 ± 5 (0-15)	4± 2 (0-12)	4± 3 (0-11)
Rides completed 2019	3± 4 (0-14)	3± 4 (0-11)	3± 3 (0-9)
Rides attempted in career	10.5± 23 (0-200)	29± 31.75 (3-90)	23± 30 (2-98)
Rides completed in career	9 ± 20 (0-180)	26± 25 (3-83)	18± 28 (1-87)
km attempted 2019	114 ± 195 (0-694)	178.5 ± 156.5 (0-822)	216± 238 (0-898)
km completed 2019	105±171 (0-694)	155 ± 147.25 (0-622)	189± 178 (0-698)
km attempted career	364± 1057 (0-10924)	1090± 2029.5 (110-5628)	1357± 1835 (104-6904)
km completed career	327.5± 877 (0-9364)	931± 1382	1106± 1500

	(110-5161)	(80-5746)

Table 5 Correlations between horse factors and total number of Failed to Qualify results within horse career

Correlation Variables	Spearman's Rank
All Rides	
km attempted in career	R=0.797 N=765 p<0.001
Rides attempted in career	R=0.777 N=765 p<0.001
Years competing	R=0.744 N=765 p<0.001
km completed in career	R=0.736 N=765p<0.001
Rides completed in career	R= 0.717 N=765 p<0.001
Age	R=0.474 N=765 p<0.001
Single Loop Rides	
km attempted in career	R=0.765 N=526 p<0.001
Rides attempted in career	R=0.753 N=526 p<0.001
Years competing	R=0.721 N=526 p<0.001
km completed in career	R=0.709 N=526 p<0.001
Rides completed in career	R=0.697 N=526 p<0.001
Age	R=0.456 N=526 p<0.001
2 Loop Rides	
km attempted in career	R=0.756 N=108 p<0.001
Rides attempted in career	R=0.753 N=108 p<0.001
km completed in career	R=0.673 N=108 p<0.001
Rides completed in career	R=0.671 N=108 p<0.001
Years competing	R=0.670 N=108 p<0.001

Age	R=0.452 N=108 p<0.001
3+ Loop Rides	
km attempted in career	R=0.798 N=131 p<0.001
Rides attempted in career	R=0.781 N=131 p<0.001
Years competing	R=0.754 N=131 p<0.001
km completed in career	R=0.707 N=131 p<0.001
Rides completed in career	R=0.684 N=131 p<0.001
Age	R=0.601 N=131 p<0.001

Table 6 Correlations between horse factors and total number of Failed to Qualify due to Lameness within horse career

Correlation Variables	Spearman's Rank
All Rides	
km attempted in career	R=0.739 N=765 p<0.001
Rides attempted in career	R=0.712 N=765 p<0.001
km completed in career	R=0.686 N=765 p<0.001
Years competing	R=0.676 N=765 p<0.001
Rides completed in career	R=0.662 N=765 p<0.001
Age	R=0.457 N=765 p<0.001
Single Loop Rides	
km attempted in career	R=0.691 N=526 p<0.001
Rides attempted in career	R=0.677 N=526 p<0.001
km completed in career	R=0.643 N=526 p<0.001
Rides completed in career	R=0.631 N=526 p<0.001
Years competing	R=0.631 N=526 p<0.001
Age	R=0.420 N=526 p<0.001
2 Loop Rides	

km attempted in career	R=0.683 N=108 p<0.001
Rides attempted in career	R=0.652 N=108 p<0.001
Years competing	R=0.613 N=108 p<0.001
km completed in career	R=0.611 N=108 p<0.001
Rides completed in career	R=0.575 N=108 p<0.001
Age	R=0.397 N=108 p<0.001
3+ Loop Rides	
km attempted in career	R=0.787 N=131 p<0.001
Years competing	R=0.764 N=131 p<0.001
Rides attempted in career	R=0.755 N=131 p<0.001
km completed in career	R=0.709 N=131 p<0.001
Rides completed in career	R=0.688 N=131 p<0.001
Age	R=0.652 N=131 p<0.001

Discussion:

This study confirms that lameness is the most frequent cause of elimination in British national endurance competitions. This result is in agreement with previous studies (Bennet and Parkin, 2018; Fielding *et al.,* 2011; Nagy *et al.,* 2010; Nagy *et al.,* 2012; Nagy *et al.,* 2014; Nagy *et al.,*2017; Younes *et al.,* 2016) and statistics from international endurance rides (Fédération Equestre Internationale, 2019; Fédération Equestre Internationale, 2020).

The results have also identified that lameness is the leading cause of elimination throughout all distances, from single loop to multi-loop rides in EGB competitions. The majority of studies to date have focussed on rides of above 80km and not at entry level competition (Bennet and Parkin, 2018; Fielding *et al.,* 2011; Nagy *et al.,* 2010; Nagy *et al.,* 2012; Nagy *et al.,* 2014; Younes *et al.,* 2016). Further work to increase understanding of risk factors for lameness across all levels of the sport, that can inform management and competition strategies, to reduce the incidence and reoccurrence of lameness, are required to safeguard equine welfare and the future sustainability of the sport.

A higher frequency of hindlimb lameness was identified in comparison to forelimb lameness across all race distances, but this was amplified in multi-loop rides. An increased incidence of hindlimb (tarsal injuries) has previously been reported in endurance horses presenting at a veterinary clinic (Murray *et al.,* 2006). Additionally, a small study of 22 horses competing in endurance had their gait pattern objectively analysed at the time of competition with portable inertial sensor-based systems. The highest percentage of irregular gait pattern (41.7%) was attributed to the hindlimb(s) (Lopes *et al.,* 2018). Further research as to why hindlimb lameness is more apparent than forelimb lameness needs to be conducted in order to develop and implement preventative and risk management strategies to increase the competitive longevity of the horses without compromising on their welfare.

Despite the finding of this study that the number of FTQ's and number of FTQLA's increase with the number of rides attempted, there is no information available, nor any current requirement as to whether riders seek veterinary advice post elimination prior to returning to competition. Nagy *et al.* (2017) found that only 52% of riders had their horses' lameness eliminations followed up with veterinary examination and advice, with many riders, anecdotally calling lameness eliminations 'bad luck', or suggesting 'the horse was not lame in the first place'. This is an issue described by veterinarians when asked about challenges faced when examining horses in endurance competitions (Mira *et al*., 2019). Although riders may consider eliminations to be ‘bad luck’ objective analysis identified 21 out of 22 horses to have an irregular gait pattern at the time of competition (Lopes *et al.,* 2018). These combined findings suggest that more horses would benefit from veterinary follow up post lameness elimination to identify the cause and to enable specific diagnosis. Riders, trainers and owners must take responsibility for seeking appropriate professional advice post elimination, for diagnosis and appropriate phased return to work and competition. Repeated images or reports of lame horses within the sport will negatively impact on the public perception of endurance, therefore it must be emphasised that strategies are in place to prevent lameness’, but when they do occur, aftercare and return to sport must be appropriately and professionally managed. Consideration should perhaps be given to implementing the rule of the FEI that three lameness eliminations within a rolling year require a lameness investigation prior to returning to competition (Fédération Equestre Internationale, 2020).

The competitive history of the horse, particularly the cumulative distance attempted was strongly correlated with the number of FTQ and FTQLA outcomes, particularly as race distances increased (>80 km) in rides of three loops and above. Across human and equine endurance sports, the cumulative impact of repeated competition, which may be indicative of microtrauma, is associated with an increased risk of injury (Bennet and Parkin, 2018; Burns *et al.,* 2003; Fielding *et al.,* 2011; Henley *et al.,* 2006; Martig *et al.,* 2014; Parkin *et al.,* 2005.) This may well occur during training but is then exacerbated by competition when physiological demands are increased. As the horses begin to fatigue, the low grades of lameness which may be too subtle for the average rider to identify, are evident to the expert veterinarians, who are in place to safeguard the welfare of the horse and remove them from competition prior to a more severe injury occurring. Additional rest periods have been found to reduce the likelihood of a negative outcome and may allow for micro trauma to heal (Bennet and Parkin, 2020). Extended mandatory out of competition periods have been implemented at FEI level, particularly in the case of consecutive FTQ and FTQLA where three consecutive FTQLA results in a 180-day mandatory out of competition period and requires a veterinary inspection prior to being allowed to compete again (Bennet and Parkin, 2020; Fédération Equestre Internationale, 2020). Current EGB rules state an additional eight days mandatory rest are added for FTQLA or FTQME outcomes which is clearly much less than the FEI specified rest periods (Endurance GB, 2020). However, the descriptive profiling of EGB horses shows a median of >300 days across each distance since the horses were last FTQLA which would indicate the majority of British endurance horse owners are resting post lameness. Perhaps the return to competition is the more important aspect in risk reduction and greater consideration should be given to the training and rehabilitation post injury of endurance horses. There is currently no specific evidence to suggest the optimal way to train endurance horses, but evidence in human sports suggest that the majority of non-contact sporting injuries are due to incorrect training-loads and a sudden increase in demand (Gabbett, 2016). This would be similar to an endurance horse who may train on flat ground, being asked to attend and compete in the ride described as having 'serious hills', with the rider unaware that training on the flat ground may not prepare the horse sufficiently for hills and vice versa. However, the evidence also suggests the majority of these injuries which are predominantly soft tissue in nature, are preventable with appropriate training, rehabilitation and preparation for competition (Gabbett, 2016). Therefore, further focus should be placed on the training of endurance horses and ensuring that riders utilise appropriate professionals to advise them accordingly based on their individual horses and aspirations.

Differences between distances

Across the differing number of loops of rides, age only had a correlation coefficient >0.5 for both FTQ and FTQLA, when the rides were of three loops or more. Previous epidemiological studies, focussing on rides of 80km and above, have identified an increase in age of the horse as a significant risk factor in deleterious outcomes (Adamu *et al.,* 2014; Bennet and Parkin, 2018). This is unsurprising, given the physiological changes and joint degeneration that occur during aging. Additionally, older horses, who have been competing for longer, are also likely to have a greater risk of increased cumulative micro trauma which may be exacerbated by an increased length of time exposed to risk and an increased demand on the musculoskeletal system over the longer distances.

Lower distances were found to have a reduced incidence of FTQ and FTQLA perhaps because they are thought to be less competitive and therefore riders may not demand as much of the horses physiologically in the lower distances. Moreover, there is a maximum and minimum speed, in the lower distances whereas in the higher distances which include CER there is not a maximum speed limit. Speed has been clearly linked to an increased risk of deleterious outcomes in endurance and a higher risk of injury in racehorses and whilst the speeds identified in this study are not high in comparison to the average >20km/h seen at international rides, perhaps a speed limit for horses competing in their first CER may be of benefit (Adamu *et al.,* 2014; Bennet and Parkin, 2018; Coombs and Fisher, 2012; Marlin and Williams, 2018; Nagy *et al.,* 2012; Parkin *et al.,* 2004; Younes *et al.,* 2016).

The highest percentage of ROC and FTQME occurred in two loop rides. Horses who are ROC must still be presented to the veterinarians at the ride and must pass the veterinary examination to ensure the outcome given is ROC. If they fail the veterinary examination the outcome will be given as either FTQLA or FTQME and the horse would be subjected to the MOOCP (Endurance GB, 2020). There is however no limit on the number of times a horse can be ROC and this should be monitored more closely. The first progression level from novice level to open level is a change from single loop to two-loop rides and the finding that two-loop rides have the highest percentage of ROC and FTQME could perhaps be explained by a lack of rider experience when 'stepping up' a level, or a lack of knowledge on how to manage a horse during a ride, such as utilising pacing strategies which have been found to be beneficial in successful ride outcomes (Marlin and Williams, 2018). Whilst riders have to complete five novice level rides and horses three novice level rides to qualify for open level, there are no clear support systems to support novice riders progressing, or to confirm that novice horses are ready to progress. Further research into the lower levels of competition would be of benefit to enable better education at grass roots level, and to secure a strong foundation prior to progressing on to higher levels of competition. In turn, this is likely to be of benefit to the sport of endurance as success at lower levels is more likely to encourage participants to continue and progress within the sport, rather than having a pessimistic perception, based on negative experiences and outcomes (Teixeira et al., 2012). Above all, the sport of endurance is complex and the rider, as the responsible athlete for the horse, must have the appropriate knowledge and understanding in multiple aspects of training, fitness and the principles of training in order to appropriately meet their duty of care to their horse and ultimately optimise their competitive performance.

Recommendations:

Future work to further elucidate why hindlimb lameness occurs more than forelimb lameness at all levels of the sport, but more so as the distance increases, is required to support the development and implementation of evidence-informed management strategies that can reduce injury risk, enable successful return to competition and fundamentally optimise horse welfare and performance.

Training endurance horses is currently either based on anecdotal or extrapolated evidence., More specific evidence-informed training, progression and management strategies tailored to the level of competition would be of benefit for riders and their horses. Whilst riders must take responsibility, Endurance GB as the governing body should work in partnership with professionals to develop and provide training and guidance to continue to promote horse welfare at all times.

The results of this study also support increasing the length of MOOCP at national level, which should allow any potential micro trauma to heal. This may be of benefit in reducing negative outcomes at all levels of British Endurance and has been successfully demonstrated at FEI level (Bennet and Parkin, 2020).

Multiple lameness eliminations of the same horse should be closely monitored and consideration be given to adopting the FEI requirement that three lameness eliminations within a rolling year necessitates a veterinary review, prior to returning to competition.

Conclusion:

This study demonstrates that lameness is the most common cause of eliminations from endurance competitions in the U.K. across all distances. In addition, this study identified a higher frequency of hindlimb lameness, compared to forelimb lameness, the reasons for this should be explored further to allow early intervention and appropriate management and rehabilitation to maximise welfare and performance. Notable differences in eliminations exist between the distances where single loop riders have the highest success, but the step-up to two loop rides increases the incidence of FTQME and ROC eliminations and the highest percentage of lameness eliminations occurring in rides of three-loops or more. The incidence of hind limb lameness also increases from single to multi-loop rides, which may be associated with the increased distance between single loop and multi-loop rides. The reasons for these differences warrant further exploration to develop specific education, training and risk mitigation strategies, appropriate to the level of competition which can improve the welfare and competitive success of the endurance horse.

References:

Adamu, L, Adzahan, N.M, Rasedee, A and Ahmad, B (2014) Physical parameters and risk factors associated with the elimination of Arabian and crossed Arabian endurance horses during a 120km endurance race. Journal of Equine Veterinary Science 34: 494-499. https://doi.org/10.1016/j.jevs.2013.10.175

American Association of Equine Practitioners (2019) Lameness exams: evaluating the lame horse. Available at:
https://aaep.org/horsehealth/lameness-exams-evaluating-lame-horse
Accessed: 10 February 2019.

Bennet, E.D, and Parkin, T.D.H. (2018) Fédération Equestre Internationale endurance events: risk factors for failure to qualify outcomes at the level of the horse, ride, and rider (2010-2015) The Veterinary Journal 236:44-48. https://doi.org/10.1016/j.tvjl.2018.04.011

Bennet, E.D, and Parkin, T.D.H. (2018) Fédération Equestre Internationale endurance events: riding speeds as a risk factor for elimination (2012-2015). The Veterinary Journal. 236: 37-43. https://doi.org/ 10.1016/j.tvjl.2018.04.012

Bennet, E.D. and Parkin, T.D.H. (2020) The impact of the mandatory rest period in Fédération Equestre Internationle endurance events. Equine Veterinary Journal 52: 268-272. https://doi.org/10.1111/evj.13148

Burns, J, Keenan, A, and Redmond A.C (2003) Factors associated with triathlon-related overuse injuries. Journal of Orthopaedic & Sports Physical therapy 33 (4): 177-184. https://www.jospt.org/doi/10.2519/jospt.2003.33.4.177

Endurance GB (2020) The rules and recommendations of Endurance GB.
Available at:
https://egb.myclubhouse.co.uk/Client/Cms/Attachments/2/2020%20Endurance%20GB%20Rule%20Book%20v4.pdf
Accessed: 08 November 2020.

Fédération Equeste Internationale (2019) FEI endurance 2019 annual report.
Available at:

https://inside.fei.org/sites/default/files/FEI_Endurance_Report_2019.final.pdf
Accessed 06 December 2020.

Fédération Equestre Internationale (2020). FEI endurance rules 2020.
Available at:
https://inside.fei.org/fei/disc/endurance/rules
Accessed 06 December 2020.

Fielding, C.L, Meier, C.A., Balch, O.K., and Kass, P.H. (2011) Risk factors for the elimination of endurance horses from competition. Journal of the American Veterinary Medical Association 239 (4): 493-498. https://doi.org/10.2460/jama.239.4.493

Gabbett, T (2016) The training-injury prevention paradox: should athletes be training smarter and harder? British Journal of Sports Medicine 50: 273-280. http://doi.org/10.1136/bjsports-2015-095788.

Henley. W.E., Rogers, K., Harkins, L. and Wood, J.L.N. (2006). A comparison of survival models for assessing risk of racehorse fatality. Preventative Veterinary Medicine 74 (1): 3-20. https://doi.org/ 10.1016/j.prevetmed.2006.01.003

Lopes, M.A., Eleuterio, A., Mira, M., Health, E and Lopes, M. (2018). Objective detection and quantification of irregular gait with a portable inertial sensor-based system in horses during an endurance race- a preliminary assessment. Journal of Equine Veterinary Science 70: 123-129.
https://doi.org/ 10.1016/j.jevs.2018.08.008

Marlin, D. and Williams, J. (2018) Equine endurance pacing strategy differs between finishers and non-finishers in 120km single day races. Comparative Exercise Physiology 14 (1):11-18. https://doi.org/10.3920/CEP170027

Martig, S., Chen, W., Lee, P.V.S., Whitton, R.C. (2014) Bone fatigue and its implications for injuries in racehorses. Equine Veterinary Journal 46: 408-415.
https://doi.org/10.111/evj.12241

Mira, M., Santos, C., Lopes, M.A. and Marlin, D. (2019) Challenges encountered by Fédération Equestre Internationale (FEI) veterinarians in gait evaluation during FEI endurance competitions: an international survey. Comparative Exercise Physiology 15 (5):1-8._https://doi.org/10.3920/CEP180058

Mukaka, M.M (2012) A guide to appropriate use of correlation coefficient in medical research. Malawi Medical Journal 24 (3): 69-71.

Murray, R.C., Dyson, S.J., Tranquille, C. and Adams, V. (2006). Association of type of sport and performance level with anatomical site of orthopaedic injury diagnosis. Equine Exercise Physiology: Equine Veterinary journal Supplement 36: 411-416.
https://doi.org/10.1111/j.2042-3306.2006.tb05578.x

Nagy, A, Murray, J and Dyson, S (2010) Elimination from elite endurance rides in nine countries: a preliminary study. Equine Veterinary Journal 38: 637-643.
https://doi.org/10.1111/j.2042-3306.2010.00220x

Nagy, A, Murray, J.K. and Dyson, S.J. (2014) Descriptive epidemiology and risk factors for elimination from Fédération Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). Equine Veterinary Journal 46: 38-44. https://doi.org/10.1111/evj.12069

Nagy, A., Dyson, S.J. and Murray, J.K. (2017) Veterinary problems of endurance horses in England and Wales. Preventative Veterinary Medicine 140: 45-52. https://doi.org/10.1016/j.prevetmed.2017.02.018

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M.,Singer, E.R., Webbon, P.M. and Morgan, K.L. (2005) Risk factors for fatal lateral condylar fracture of the third metacarpus/ metatarsus in UK racing. Equine Veterinary Journal 37: 192-199. https://doi.org/10.2746/0425164054530641

Teixeira, P.J., Carraça, E.V., Markland, D and Ryan, R.M. (2012) Exercise, physical activity, and self-determination theory: A systematic review. International Journal of Behavioural Nutrition and Physical Activity [online]. 9 (78) [Accessed: 12th June 2020]. https://doi.org/10.1186/1479-5868-9-78

Younes, M., Barrey, E., Cottin, F. and Robert, C. (2016) Elimination in long-distance endurance rides: insights from the analysis of 7032 starts in 80-160km competitions. Comparative Exercise Physiology 12 (4): 157-167. https://doi.org/10.3920/CEP160022

Zuffa, T., Bennet, E.D. and Parkin, T.D.H. (2021) Factors associated with completion of Fédération Équestre Internationale endurance rides (2012-2019): Modelling success to promote welfare-oriented decisions in the equestrian sport of endurance. *Preventative Veterinary Medicine* [online]. 198 [Accessed: 18th December 2021]. https://doi.org/10.1016/j.prevetmed.2021.105534

Study 2 a: Appendix A

Table 1: Competitive levels and progression requirements

Level	Rider	Horse
Novice	Rides of 20-50 km Speeds 8-15 kmph GER's only	Minimum age of 5, horses of 6 years old or over may complete novice & open levels in their first season. May not start more than 10 rides in first competitive season May not attempt more than 450km in first season Rides of 20-50 km Speeds 8-15 kmph GER's only
Number of loops:		
Requirements to progress from Novice to Open level	5 x successful completions of GER's 30-50 km	3 x successful completions of GER's 30-50 km
Open	Up to 90km in one day, or 130km over 2 days Speeds 10-18 kmph GER's only	Minimum age of 6 Up to 90km in one day, or 130km over 2 days Speeds 10-18 kmph GER's only
Requirements to progress from Open to Advanced level	2 x successful completions of GER's 60-90km, at least one must be 80 km in one day	2 x successful completions of GER's 60-90km, at least one must be 80 km in one day
Advanced level	May compete in GER's 10-18kmph and national CER's of any distance, no maximum speed, minimum declared by ground jury, usually 12 kmph	May compete GER's any distance 10-18 kmph Minimum age of 7 to compete in national CER's (any distance), no maximum speed, minimum declared by ground jury, usually 12 kmph

Appendix 6

Study 2b: Under review

Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019. *Comparative Exercise Physiology.* 18 (4), pp. 329-338. DOI:10.3920/CEP220003

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Eliminations in single loop and multi-loop British endurance rides in 2019

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KEY WORDS: Competition, Lameness, Elimination, Endurance, Welfare, Social license to operate

Authors' declaration of interests:
No competing interests

Ethical animal research:
The ethics committee at Hartpury University approved this study. No external intervention was required by participants and all data were anonymised. Endurance GB board of directors gave consent for analysis of the raw data from the Endurance GB results database and competitive data.

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Authorship:
F. Bloom, S. Draper, E. Bennet and J Williams contributed to study design, study execution, data analysis and interpretation, preparation of the manuscript and final approval of the manuscript. D. Marlin contributed to study design, interpretation of the data, preparation of the manuscript and final approval of the manuscript. F. Bloom had full access to all of the data in the study and is responsible for data integrity and accuracy of analysis.

Data availability statement
The data that supports the findings of this study are available from Endurance GB. Data are available from the authors with permission of Endurance GB.

Eliminations in single loop and multi-loop British endurance rides in 2019

Summary:

Background: Lameness in endurance competitions is the most common reason for elimination. Previous studies have focussed on international competition and have documented risk factors for elimination. Limb(s) which are most commonly lame at the point of elimination, have not been identified. This would evidence potential musculoskeletal structures most affected and inform future research for risk mitigation.

Objectives: To identify risk factors for elimination and specifically lameness eliminations within endurance at British national level, from grass routes (22km) through to a multi-day ride of 174km. Additionally, this study aimed to identify the limb(s) most frequently considered to be lame.

Study design: Prospective cohort study

Methods: A total of 765 competitive entries from 13 days of endurance competitions, across seven venues in Britain were collected and evaluated. Risk factors were identified from previous literature. Univariable models were used to inform multivariable binary logistic regression modelling. Models were completed for: a) horse eliminated vs horse not eliminated; b) horse lame vs horse not lame. Models were compiled separately for single loop rides and multi-loop rides. Veterinarians were asked to independently identify which limb they considered to be the lame limb.

Results: Risk factors significant at multivariable level ($P<0.05$) differed between single loop rides and multi-loop rides. In single loop rides horses were at increased odds of elimination in rides classified as "steep" ($P=0.04$; OR 2.0; CI 1.0-3.8). In multi-loop rides, previous career history, speed and final presentation heart rate were significant risk factors. Hindlimb lameness was identified in more cases than forelimb lameness. There was a statistically significant association between the lame limb and the number of loops, $X^2(1)=5.4$, p=0., p=0.02.

Main Limitations: Low levels of competitive starts.

Conclusions: Significant risk factors differed between single and multi-loop rides. Education surrounding risk factors and preventative strategies would be beneficial to all stakeholders.

Keywords: Competition, Lameness, Elimination, Endurance, Welfare, Social license to operate

Introduction:

The governing body of endurance riding within Britain, Endurance GB (EGB) stipulates that the aim of the organisation is to promote and uphold the highest standards of horse welfare.[1] Endurance has been criticised with regards to equine welfare with images of catastrophic injuries being widely circulated on social media. Despite this, endurance remains the only equestrian sport where horses are only allowed to compete at national level if they are declared fit to do so by a licensed veterinarian. If they do not pass the veterinary inspection at any stage of the competition, they are eliminated from the competition.[1,2] Possible reasons for elimination are shown in supplementary file 1.

The most common reason for a horse to be eliminated during endurance competition is due to lameness.[3-11] The majority of research to date has analysed retrospective competition data and been based on international competition run under the rules of the international governing body, the Fédération Equestre Internationale (FEI).[3,6,7,9,10] Retrospective analyses have provided valuable insight into risk factors associated with elimination and lameness eliminations, identifying increased speed, changes in speed, ride distance and competitive history of the horse as significant risk factors.[3,6,7,9,10]

Studies looking into risk factors of elimination and specifically lameness eliminations have previously considered distances of 80km and above, comprising of multiple loops and run under race conditions, despite entry level requirements for both horse and rider being a distance of ≤40km and comprising of a single loop, with a maximum speed limit imposed.[2,3,6,7,9,10] A review of veterinary problems within horses registered with EGB based on subjective owner feedback did conclude that lameness was the most common veterinary issue, with 80% having had an episode of lameness within their competitive career.[8] This high prevalence would strongly suggest that lameness is an issue not just in international endurance, but must be considered as a risk to endurance horse welfare at a national level.

Despite lameness being identified as the leading cause of elimination, there is little information surrounding the details of lameness at the point of elimination from competition. The reasons for this are multifactorial. Firstly, the gait examination is not a full clinical, diagnostic examination but to identify any concerns that may risk the horses' welfare if they were to continue within the competition, consequently details surrounding the lameness at the point of elimination are sparse. Additionally, a survey of FEI veterinarians concluded that even experienced veterinarians found the gait assessment during competition difficult handling, poor trot up area, muscular asymmetry and fatigue (of both horse and veterinarian) being cited as some of the challenges encountered, which limits the ability to provide robust information surrounding lameness at the time of elimination from competition.[12]

The purpose of this study was to identify risk factors associated with elimination outcomes and more specifically lameness outcomes within national rides run under EGB rules. In addition, the study aimed to identify which limb(s) were primarily affected by lameness at the time of elimination from competition. Identification of limb(s) most commonly impacted should provide evidence as to potential musculoskeletal structures impacted, to allow further investigation and appropriate management strategies to be implemented. This information should give valuable information to riders, trainers, veterinarians and all stakeholders within the sport to proactively manage and minimise risks of lameness, improve equine welfare within the sport and in turn increase competitive success.

Materials and Methods:

Participants:

Following agreement from EGB, national ride statistics were collected from seven competition venues, totalling 13 days (June-October) during the 2019 EGB competitive season. Prior to the ride event an information sheet was sent via email to the ride organisers, technical stewards, ground jury and attending veterinarians detailing the study and the data that would be requested. Data were collected from all classes and distances run under EGB national rules, requiring full veterinary inspection(s), from all horses that presented to the pre-ride veterinary inspection. A total of 765 competitive entries were collected and evaluated. The Ethics Committee at Hartpury University approved this study. No external intervention was required or placed upon participants, and all data were anonymised.

Measures:

Competition data:

Competition data ordinarily collected at each ride by EGB was documented by one of the authors in attendance at all of the rides (FB). For every horse this included: (1) the distance (km) entered; (2) the category of ride (Graded Endurance Ride (GER) which has a maximum and minimum speed to complete or Competitive Endurance Ride (CER) which is a race with only a minimum speed imposed); (3) the start and finish time of each loop;

(4) the speed (kmph) each loop and the average speed for the entire ride; (5) time taken to present to the vet (multi-loop rides only); (6) the heart rate of the horse as declared at each veterinary inspection.

In addition, the temperature and relative humidity was recorded using a calibrated digital temperature and humidity hygrometer thermometer (Peak-Meter PM6508) every hour and the average per loop and average for the duration of the competition was calculated.[13] The subjective steepness of the ride, based on the route description in the entry schedule, such as 'serious hills' or 'flat forest tracks' was documented. Whilst previous studies have evaluated steepness by asking the technical delegate, EGB does not have technical delegates and the information for the route is provided by ride organisers, who document the description in the entry schedules.[6] Each of the rides considered steep were declared to the researcher, by the ride organiser, or by the researcher examining the ordnance survey map provided to riders, to have more than one part of the route where the gradient changed by 10% or more within a kilometre of distance. The trot-up surface was also recorded.

Additional veterinary data:

At each of the rides attended, if a horse was asked to 're-trot' during the veterinary inspection, each of the members of the VP watching the second trot up were asked to note, without discussion with their colleagues, whether they believed the horse to be 'lame' or 'not lame'. The VP were also asked, if they considered the horse to be lame, which limb(s) they believed the horse to be lame on and the severity of the lameness based on the American Association of Equine Practitioners (AAEP) six-point scale.[14] The member(s) of the VP handed their voting slips to the official ground jury who gave the decision to the competitor as to whether the horse had passed the veterinary inspection. The ground jury passed the voting slips directly to the researcher.

Historical data:

Information on each of the entrants to the competitive rides was downloaded from the official EGB results database, which is publicly available, including horse demographics and competitive history. This information is presented in Supplementary file 2.

Statistical analysis:

All data were entered onto a Microsoft Excel spreadsheet and each horse start given a unique identifier prior to coding. Statistical analysis was undertaken using Statistical Product and Service Solutions (SPSS Version 26.0 IBM, Portsmouth). Inter-rater reliability of the veterinary surgeons was assessed using a calculation of Fleiss's Kappa (k) for limb(s) identified as lame and the grade of lameness. Where P= total agreement, including chance agreement and P_e = expected chance agreement.[15]

$$Kappa\ (k)=P-P_e/\ 1-P_e$$

Interpretation of strength of agreement based on the co-efficient was considered good at >0.60 and very good at >0.80.[15,16] All horses that presented to the initial vetting were included in this analysis. A chi-square test of independence was performed to examine the relationship between which limb(s) were lame (forelimb/ hindlimb) and the number of loops within the ride (single loop/ multi-loop).

Model building:

Prior to model building, horses which did not pass the initial veterinary inspection or did not complete the loop and therefore had no speed recorded were removed. Figure 1. Two deleterious outcomes were assessed: (1) Eliminated (any reason); and (2) Eliminated lame.

For each model, the initial stage was to fit univariable models for each of the potential risk factors. Risk factors were considered significant to take forward to multivariable analysis with a *P* value of ≤ 0.1.[17] Risk factors considered for univariable analysis, are provided as supplementary material (Supplementary file 2).

The multivariable logistic regression models were constructed using a backwards-stepwise process, with an omnibus test of model co-efficients applied at each step. The goodness-of-fit of each of the models were assessed using the Hosmer-Lemeshow test.[18] The predictive ability of the model(s) were assessed using the Receiver Operatic Characteristic (ROC) curve analysis, with the predictability considered good if the area under the curve was >0.7 and excellent if >0.9.[19,20] Risk factors with *P* values of <0.05 were considered significant in the final multivariable model(s).

For single loop rides, due to the low number of lameness eliminations, only univariable analysis was completed.

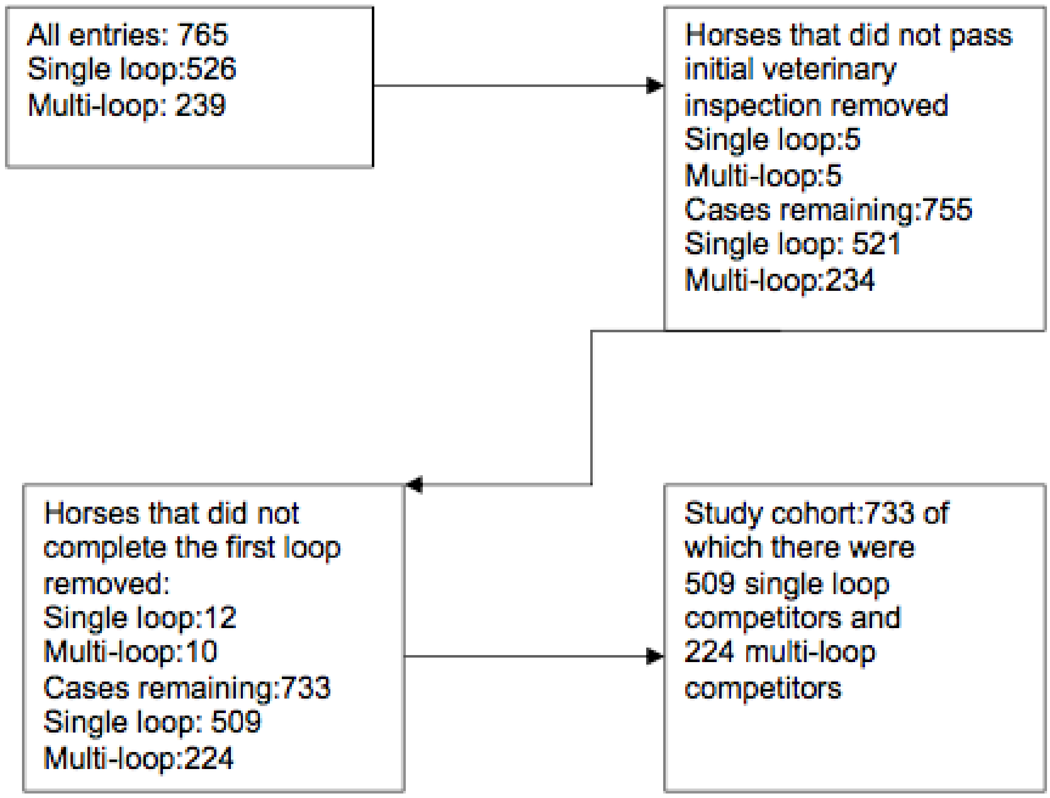

Figure 1. The process of achieving the final number of participants for consideration I model building from seven Endurance GB rides attended across Britain in 2019.

Results:

Descriptive statistics:

A total of 765 entries in rides run under EGB rules, from June-October 2019, across seven different venues were analysed. Results were taken from rides ranging from a single loop ride (22- 48 km), to six loop rides, over two or three days with a maximum distance of 174km. Only one ride had the veterinary inspection on hard ground (concrete), the other six were on grass. Temperature ranged from 9.1-27.4°C. Relative humidity ranged from 39% to 100%, with bright sunshine to heavy rain. The greatest number of entries were in single loop rides n = 526 (68.8%). Single loop ride distance ranged from 22-47 km and all were categorised as GER. Two-loop rides, 64-80 km, accounted for 14.1% of entries (n = 108) and were also all GER. Rides of three loops and above, 80-174 km, accounted for 17.1% of entries (n = 131), within these rides 64% (n = 84) were categorised as CER and the remaining 47 (36%) were GER. Ride success was high with 81.6% (n = 624) of all those that started completing the ride. The most common reason for failing to complete was lameness accounting for 59% (n = 83) of all eliminations. A full descriptive analysis is reported separately.[21]

Inter-rater reliability:

For horses that were eliminated lame which had two members of the VP observing the trot (n=51), there was total agreement as to which limb was lame (K=1, p<0.001, C.I.0.86-1.14). In this group of horses there was high agreement on the severity of lameness (K=0.85, p <0.001, C.I. 0.66-1.03).

For horses that were eliminated lame with three members of the VP observing the trot (n=32), there was a strong agreement in which was the lame limb (K=0.83, p<0.001, C.I.0.75-0.9). There was less agreement on the severity of lameness (K=0.53, p<0.001, C.I. 0.40-0.66).

Forelimb/ Hindlimb lameness

In single loop rides, 46% (n=15) of horses that were eliminated lame were forelimb lame, and 55% (n=18) were hindlimb lame. In multi-loop rides, 36% (n=18) were forelimb lame and 64% (n=32) were hindlimb lame. A chi-squared test of independence was conducted between the limb identified as lame (forelimb/ hindlimb) and the number of loops of the ride (single loop/ multi-loop). All expected cell frequencies were greater than five. There was a statistically significant association between the lame limb and the number of loops, $X^2(1)=5.4$, $p=0.02$.

Eliminations Single loop rides:

A total of 8 variables were significant at univariable analysis and were taken forward for multivariable analysis. Table 1 shows the significant ($P<0.05$) results of the multivariable model. Horses who had never completed a ride before were at increased odds of an elimination (Adjusted Odds Ratio, OR 3.07; 95% Confidence Interval, C.I. 1.10-8.51) compared to horses who had passed their previous competition. Horses who had attempted >10 rides in their competitive career at increased odds of elimination, compared to those who had attempted <10 rides (OR 3.88; C.I. 1.23-12.18). There was a small association between the number of kilometres attempted and the likelihood of an elimination outcome, with horses who had attempted >2500 km less likely to be eliminated compared to those who had attempted 500km or less (OR 0.13; C.I. 0.02-0.76). The steepness of the ride was also a significant factor in an elimination outcome with horses being 1.96 times more likely to be eliminated if the ride was steep (C.I. 1.02-3.77). The number of days since the horse previously displayed lameness in competition did not provide a significant result but was retained as it improved the model fit.

Table 1: Results of the multivariable model for single loop starts for any elimination outcome.

Risk Factor	Cases: ELIM Total n=44 n per category (%)	Controls: Passed ride Total n=465 n per category (%)	OR	95% C.I.	P value
Result Previous Ride					
Completed	34 (8.3)	377 (91.7)	Reference	-	0.077
Eliminated	3 (5.5)	52 (94.5)	0.63	0.16-2.42	0.449
No previous ride	7 (16.3)	36 (83.7)	3.07	1.10-8.51	0.032
Days since previous Lame					
≤180	4 (4.8)	79 (95.2)	Reference	-	0.099
>180	16 (12.3)	114 (87.7)	2.81	0.86-9.16	0.087
No previous Lameness Elimination	24 (8.1)	272.(91.9)	1.30	0.37-4.59	0.688
Rides Attempted Career					
≤10	19 (7.5)	234 (92.5)	Reference	-	0.020
>10	25 (9.8)	231 (90.2)	3.88	1.23-12.18	0.020
Distance (Km) Attempted Career					
≤500km	25 (9.0)	253 (91.0)	Reference	-	0.056
501-2500km	17(9.2)	167 (90.8)	0.35	0.12-1.06	0.064
>2500km	2 (4.3)	45 (95.7)	0.13	0.02-0.76	0.023
Steepness					
Minimal climbs	22 (6.3)	325 (93.7)	Reference	-	0.080
Steep	22 (13.6)	140 (86.4)	1.96	1.02-3.77	0.044

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.003, Hosmer and Lemeshow 0.38, ROC: 0.73
Final multivariable model showing elimination risk factors for horses competing in Endurance GB single loop rides (22-48km) from June-October 2019 at seven different venues.

Elimination due to lameness:

Due to the low numbers of lameness eliminations in single loop rides, only univariable analysis was completed; four risk factors were considered significant at p≤ 0.1and are shown in supplementary file 3.

Eliminations Multi- loop rides:

A total of 19 variables were significant at univariable analysis and taken forward for multivariable analysis. Table 2 shows the significant (P<0.05) results of the multivariable model for eliminations across multi-loop rides. The ride attended had small but significant association with an elimination, with a decreased odds of elimination at the third (OR 0.17, CI 0.05-0.57) and fifth ride (OR 0.13, CI 0.03-0.66) when compared with to the final ride of the competitive season. Horses were more than twice as likely (OR 2.25, CI 1.07-4.72) to be eliminated in competitions of more than two loops when compared to two loop rides. A horse that completed the first loop at >14kmph had a small reduction of risk of elimination (OR 0.07, CI 0.02-0.26) compared to those that completed the first loop at less than 12kmph. However, horses that had a final average speed of >12kmph were at increased odds of elimination (OR 2.88, CI 1.15-7.24) compared with those that finished at less than 12kmph. Horses that had a final heart rate of 55 beats per minute (bpm), or more, (recorded from the vetting at which they were eliminated, or at the final vetting if they completed all the loops) were more than four times as likely to be eliminated (OR 4.23, CI 2.03-8.81) compared with those who had a final heart rate of less than 55bpm. Horses with a competitive history of 6 or more years were more than twice as likely to be eliminated (OR 2.39, CI 1.19-4.80) than those who had been competing for 5 years or less. If the outcome of the previous competition was elimination there was an increased risk (OR 2.26, CI 1.01-5.04) of elimination when compared to horses who successfully passed their previous competition.

Table 2: Results of the multivariable model for multi-loop starts for the Elimination outcome.

Risk Factor	Cases: Eliminated Total n=73 n per category (%)	Controls: Passed ride Total n=151 n per category (%)	OR	95% C.I.	P value
Ride					
1	2 (66.7)	1 (33.3)	1.71	0.02-194.69	0.823
2	8 (33.3)	16 (66.7)	0.32	0.07-1.43	0.136

3	22 (25.9)	63 (74.1)	0.17	0.05-0.57	0.005
4	9 (33.3)	18 (66.7)	0.34	0.08-1.45	0.146
5	5 (26.3)	14 (73.7)	0.13	0.03-0.66	0.014
6	16 (34.0)	31 (66.0)	0.28	0.07-1.21	0.088
7	11 (57.9)	8 (42.1)	Reference	-	0.117
Loops					
2 loops	25 (24.5)	77 (75.5)	Reference	-	0.043
>2loops	48 (39.3)	74 (60.7)	2.25	1.07-4.72	0.032
Loop 1 speed					
<12kmph	26 (31.0)	58 (69.0)	Reference	-	<0.001
12-14kmph	40 (40.8)	58 (59.2)	1.04	0.45-2.39	0.927
>14kmph	7 (16.7)	35 (83.3)	0.07	0.02-0.26	<0.001
Final Heart Rate					
<55	38 (24.7)	116 (75.3)	Reference	-	<0.001
55+	35 (50.0)	35 (50.0)	4.23	2.03-8.81	<0.001
Average speed					
<12kmph	25 (26.9)	68 (73.1)	Reference	-	0.033
>12kmph	48 (36.6)	83 (63.4)	2.88	1.15-7.24	0.025
Years competing					
1-5	41 (28.3)	104 (71.7)			Ref
6+	32 (40.5)	47 (59.5)	2.39	1.19-4.80	0.015
Result previous ride					
Completed	53 (29.4)	127 (70.6)	Reference	-	0.202
Eliminated	20 (45.5)	24 (54.5)	2.26	1.01-5.04	0.046

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.001, Hosmer and Lemeshow 0.78, ROC: 0.79
Final multivariable model showing elimination risk factors for horses competing in Endurance GB multi-loop rides (64-174km) from June-October 2019 at seven different venues.

Elimination due to lameness: Multi- loop rides

Following univariate analysis 9 risk factors were taken forward to multivariable analysis.

The results of the final multivariable analysis are shown in Table 3. Final heart rate and the number of loops were not statistically significant but were retained in the model as they improved the model fit. Speed had the most significant association with lameness eliminations with horses that averaged a speed of >12kmph over the total distance being more than three times as likely (OR 3.09, CI 1.32-7.26) to show lameness compared with horses that completed at less than 12kmph. Horses completing the first loop at >14kmph were at a slightly reduced risk of lameness elimination (OR 0.13, CI 0.03-0.53). Horses who completed their first loop after 11:30am were identified as having a small, but significant reduction in risk of lameness elimination, compared to those who completed the first loop before 11:30am (OR-0.04, CI 0.15-0.95).

Table 3: Results of the multivariable model for multi-loop starts for the Elimination due to lameness outcome.

Risk Factor	Cases: Lame Total n=44 n per category (%)	Controls: Not Lame Total n=180 n per category (%)	OR	95% C.I.	P value
Loops					
2 loops	12 (11.8)	90 (88.2)	0.45	0.18-1.15	0.094
>2loops	32 (26.2)	90 (73.8)	Reference	-	0.073
Loop 1 speed					
<12kmph	13 (15.5)	71 (84.5)	Reference	-	<0.001
12-14kmph	27 (27.6)	71 (72.4)	1.30	0.54-3.09	0.557
>14kmph	4 (9.5)	38 (90.5)	-0.13	0.03-0.53	0.004
Final Heart Rate					
<55	26 (16.9)	128 (83.1)	Reference	-	0.132
55+	18 (25.7)	52 (74.3)	4.23	2.03-8.81	0.097
Average speed					
<12kmph	12 (12.9)	81 (87.1)	Reference	-	0.013
>12kmph	32 (24.4)	99 (75.6)	3.09	1.32-7.26	0.010
Loop 1 finish time					
Before 11:30am	31 (27.7)	81 (72.3)	Reference	-	0.054
After 11:30am	13 (11.6)	99 (88.4)	-0.04	0.15-0.95	0.013

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.
Model fit was good: Omnibus p=0.001, Hosmer and Lemeshow 0.32, ROC: 0.75
Final multivariable model showing elimination due to lameness risk factors for horses competing in Endurance GB multi-loop rides (64-174km) from June-October 2019 at seven different venues.

Discussion:

The results of this study demonstrate that hindlimb eliminations are more prevalent in multi-loop rides when compared to single loop rides. High inter-rater reliability between the VP was identified, which should provide confidence in their decision making for the horses' welfare. This study demonstrates that risk factors for elimination and lameness eliminations in single loop rides and multi-loop rides differ.

Identification of which limb(s) are most predominantly classified as lame has not been possible previously as these data are not routinely recorded in endurance veterinary inspections. The high frequency of hindlimb lameness identified supports the findings of the veterinary examinations of endurance horses presenting for investigation at the animal health trust where the tarsus was identified as the most common location for injury in endurance horses.[22] Additionally, a small study of 22 horses who were examined during competition with a portable inertial sensor-based system identified the highest percentage (41.7%) of lameness's were attributed to hindlimb lameness.[23] The reasons behind the higher prevalence of hindlimb lameness observed is likely to be multifactorial.

It has been documented that back pain and hindlimb lameness often co-exist.[24-26] Nagy *et al.* (2017) found that, after lameness, the second most common veterinary issue reported by owners of horses registered with EGB was thoracolumbar pain. The impact of rider asymmetry on thoracolumbar movement of the horse has been identified previously,[27,28] with common causes of back pain in horses linked to poor saddle fit and rider position.[27,28] In endurance, saddles marketed specifically for the sport tend to focus on light weight and rider comfort, rather than the fit on the horse. However, there is no requirement to have a specific endurance saddle, and it is down to rider preference as to what type of saddle they ride in. In addition, endurance riders adopt different positions within the saddle, such as a two-point seat, where the weight of the rider is through the stirrups and there is no contact on the seat of the saddle, or a three-point seat, where the rider spends most of their time seated in the saddle. Additionally, an adapted 3-point seat is sometimes seen where the rider sits within the seat of the saddle, with longer stirrups and the upper body slightly further back.[29] The impact of these different riding styles, may of course differ depending on rider experience and it is not clear which style may be the most sympathetic to the horse, with each having positive and negative implications.[29] Horse riders frequently ride asymmetrically, which will impact on the horse biomechanics and ultimately performance, this is likely to increase as riders fatigue.[30] Although this has not been specifically studied within endurance riders, it is worth considering, given the higher prevalence of lameness eliminations in multi-loop rides compared to single loop rides. Given the number of hours that endurance riders spend in the saddle in comparison to other sports (minimum of 2, maximum of 13 hours)

, it is possible that equine back pain may be a contributing factor to increased hindlimb lameness and this warrants further investigation.

This study demonstrates that the veterinary panel at EGB competitive events have strong agreement with regards to which limb is identified as lame, which should go some way to reassuring riders and associates that the veterinary decision, despite being a subjective analysis, is likely to be the correct one. This information would be of benefit to share with riders, associates and stakeholders within the sport to reduce the confrontations or challenges faced by the VP as described by Mira *et al.* (2019). The inter-rater reliability of the grade of lameness was reduced for rides when three veterinarians observed the trot up, where agreement was only moderate. Participating VP members were sent information describing the AAEP scale prior to the study, however it was found that the majority of veterinarians were using the most widely used British lameness scale of 0-10, [31] and then dividing by 2. The AAEP scale was chosen due to its clear descriptions for each grade, however as some veterinarians used the AAEP scale as requested and others used the Wyn-Jones scale and halved it, the grading in this case cannot be considered reliable and could explain the variability observed between veterinarians.
Subjective evaluation of lameness has been found to be complex, with low inter-rater reliability of grading reported in previous studies.[15]However, particularly during competition, it remains the most practical and cost-effective approach and still protects horse welfare by removing lame horses from competition.[23]

Single loops:

Despite single loop rides being the entry level competitions for all horses and riders, there have been no studies to date looking at the risk factors surrounding elimination and more specifically lameness eliminations for these competitions. In single loop competitions there were insufficient lameness eliminations to construct a specific multivariable model for lameness and therefore all eliminations were considered as one model, some of the eliminations within that model are due to lameness. The findings of this study provide valuable insight to considerations of risk management in lower distance rides. Horses competing in single loop rides, who had attempted more than ten rides in their career were at a higher risk of an elimination outcome. Bennet and Parkin (2018) also reported that an increased number of competitive rides increased horses chances of elimination in international level endurance. The association between ride frequency and elimination may be due to accumulation of microtrauma or injury in musculoskeletal structures. Clinical symptoms may not present as injuries may be subclinical until horses are asked to increase their workload outside of their normal physiological parameters, such as during a competitive endurance ride [4,9,10,32-35] Additionally, horses who are competing more, may have less time between rides to recover from any microtrauma. Increasing rest periods at FEI level have been found to decrease deleterious outcomes and implementing a similar approach may be of benefit at a national level.[36] Appropriate return to training and competition post elimination has not been considered specifically in endurance, perhaps fundamentally because lameness within the sport is not fully understood. Whilst there is evidence supporting appropriate return to competition following specific injuries in other equestrian disciplines, diagnosis and veterinary follow up of the causality of lameness elimination in endurance is poor and therefore professional guidance on return to competition may be either absent entirely or is not tailored to the sport specific requirements, which may contribute to the multiple eliminations found within this study.[8,37]

Whilst the steepness of a ride has not been previously investigated within British endurance it was found that horses competing in single loop rides were more likely to be eliminated when the ride was steep. This may indicate a potential lack of training or ride preparation, possibly due to a lack of awareness of the demands on the endurance horse of the less experienced competitor or the technicality of the route, supported by the findings of this study that those competing for the first time were more likely to be eliminated. There is currently no objective evidence relating to the most appropriate methods of training the endurance horse specifically. Studies to determine optimum training and management strategies for the endurance horse and rider would be of benefit in order to provide guidance at all levels, but particularly for entry level competitors.[29]

This study found that horses competing in their first competition were more than three times more likely to be eliminated when compared with horses who successfully completed their previous competition. This may be associated with a lack of experience of the horse and/or the rider. These findings are supported by other studies in both endurance and thoroughbred racing which have found experienced horses are at a lower risk of a negative outcome, compared to those who are less experienced, although in endurance, this has again only been considered at FEI level.[6,38] This outcome is important for the sport, if the first experience a competitor has is a negative one (i.e. an elimination) they may be more likely to have a negative perception of the sport and may not return. It is therefore worth considering the information provided by EGB to newcomers within the sport and whether this can be improved to reduce the likelihood of a negative outcome for horses at their first competition and ensure that their welfare needs are met from the first experience within the sport. Additionally, when a negative first experience is combined alongside the findings that an increased number of rides results in an increased number of lameness eliminations, the wider public perception of the sport must be considered in order to safeguard the future of the sport and its social licence to operate.[39,40]

Multi-loops:

Speed was found to be a significant factor both for elimination and lameness, with horses competing at the higher speeds more likely to have a deleterious outcome, this has been found in previous studies identifying risk factors within endurance.[7,10,41] However, the speeds in which elimination and lameness are identified under EGB rules are much lower than those with deleterious outcomes at FEI level. This could indicate the greater experience and physiological capabilities of the international horses and riders being more capable of competing at higher speeds, or it could be an indication that the technicality of the courses may be different which may reduce the speeds in EGB rides. For example, the highest speeds are currently recorded in Middle Eastern countries, where the tracks are specifically made for competition, whereas in the U.K. tracks vary dependent on where in the country you compete and utilise natural terrain. In the Middle East competitors will not have to open or close any gates, whereas in the U.K. there are some rides which travel across fields containing livestock, which would necessitate the rider opening and closing gates, therefore significantly impacting on speed. Our results identified horses were likely to be eliminated at rides earlier in the competitive season. The weather was drier in the early part of the season, compared to the reference category ride which was the final ride of the season where the days immediately prior to and during the ride there was heavy rain. Although ground conditions were not documented, due to the impracticality of assessing the ground over the entire route, it is plausible that the weather impacted on the ground conditions and the wet weather at the final competition increased the likelihood of slippery going and possible muddy conditions. Muddy terrain has previously been found to be a significant factor in sweat fluid and electrolyte losses in endurance horses, which could be a consideration for fatigue-based injuries.[42]

The final heart rate of the horse was a significant factor in elimination (any reason), this is not surprising as the heart rate is deemed an important factor in evaluating the endurance horse during the veterinary inspection and therefore considered a relevant determinant of performance.[1,2,43] Foreman and Lawrence (1991) found a correlation between the degree of heart rate increase and the severity of lameness in horses at rest and when recovering from exercise. In addition to this, predictive modelling in multi-loop endurance rides outside of the UK has identified that slow heart rate recovery times, a potential sign of declining metabolic status, can be indicative of a higher chance of a deleterious outcome at the following veterinary inspection.[7,45] There were insufficient metabolic eliminations to construct a separate model for metabolic eliminations and therefore these are considered within the 'elimination for any reason' model.

The increased odds of elimination when the horse has competed for six years or more could be explained by an accumulation of subclinical musculoskeletal damage which may become more apparent during competition where increased demands are placed on the horse. Whilst typically these findings have been previously attributed to older horses in endurance and racing, the same principles of accumulative damage over a longer career would be considered likely.[4,9,32-34]

The increased likelihood of elimination when the outcome of the previous ride was elimination is also in line with previous studies.[9] It is thought this may be due to insufficient recovery from injury, as identified in racehorses.[38] Interestingly, due to the findings of Bennet and Parkin (2018a) the FEI imposed longer mandatory out of competition periods (MOOCP), with additional days added for elimination, lameness and elimination due to metabolic compromise and further days added if there is a subsequent deleterious outcome to allow horses a greater length of time to recover.[2] This was found to have had a positive impact in reducing the eliminations in FEI competitions.[36] Currently EGB has shorter MOOCP when a horse is eliminated for any reason compared to the FEI, with only eight additional days being added for lameness eliminations for EGB horses, regardless of the number of times the horse has been eliminated as lame, where as a horse with three consecutive lameness eliminations who is registered with the FEI would face an additional 180 days MOOCP and a veterinary examination prior to being allowed to compete at either national or FEI level.[1,2] The results of this study suggest the MOOCP duration should be extended at national level in order to align with the FEI approach to safeguard endurance horse welfare.

Limitations:

The relatively low numbers of deleterious outcomes in the lower distance single loop competitions and the lower number of ride entries in the higher distance, multi-loop rides may limit the wider extrapolation of these data, however it does give a clear indication that single loop rides have differing risk factors to multi-loop rides. The steepness of the ride was assessed very subjectively and whilst efforts have been made to quantify the steepness post analysis, a more robust, repeatable measurement would be of greater benefit. The AAEP lameness scale was used to ensure clearly defined categories to promote inter-rater reliability. However, it was found that some horses eliminated for lameness received scores of one or two, which would not have been noticeable on a straight-line trot as seen in endurance veterinary inspections. This has led to the assumption that veterinarians in some cases using a scale they were more use to in clinical practice, such as 0-10 scale and dividing by two. The scales are not interchangeable and therefore the results surrounding the grading of the lameness should not be over interpreted.

Conclusions:

The results of this study demonstrate that hindlimb lameness eliminations are more prevalent than forelimb lameness eliminations across all distances, but significantly more so in multi-loop rides compared with single loop rides in national level endurance. Additionally, this study demonstrates that single loop and multi-loop rides have differing risk factors for veterinary eliminations and for lameness eliminations. Education on the demands of the sport, appropriate pre, peri and post competition risk management needs to be tailored accordingly, dependent on the competitive level and experience of the competitor.

This study demonstrates that the veterinary panel at competitive events have strong inter-rater reliability when identifying a lame limb, which should go some way to reassuring stakeholders within the sport that the veterinary professionals working within endurance are skilful and aware of the welfare needs of the horses competing. Their decisions must be taken seriously and riders should consider professional veterinary follow up post elimination for appropriate diagnosis and management of injury to facilitate a successful return to competition.

Supplementary file 1: Possible outcomes of Endurance GB Rides
Supplementary file 2: Potential risk factors used to inform univariable models and the source of data
Supplementary file 3: Significant variables from univariable analysis for single loop starts for the Eliminated due to lameness outcome.
Figure 1: Flow chart showing the process of selecting the study cohort for multivariable analysis from horses that entered the competitions.

References:

1. Endurance GB (2020) Endurance GB Rule Book. Available at: https://egb.myclubhouse.co.uk/Cms/Spaces/RULES/01+General+and+FAQs (Accessed 08 November 2020)
2. Fédération Equestre Internationale (2020). FEI Endurance Rules 2020 Available at: https://inside.fei.org/fei/disc/endurance/rules (Accessed 06 December 2020)

3. Nagy, A, Murray, J and Dyson, S (2010) Elimination from elite endurance rides in nine countries: a preliminary study. *Equine Vet J.* **38**, 637-643 doi.org/ 10.1111.j.2042-3306.2010.00220.x
4. Fielding, C.L, Meier, C.A., Balch, O.K., and Kass, P.H. (2011) Risk factors for the elimination of endurance horses from competition. *J. Am. Vet. Med. Assoc*. **239,** (4) 493-498 doi.org/ 10.2460/javma.239.4.493
5. Nagy, A, Dyson, S.J. and Murray, J.K (2012) A veterinary review of endurance riding as an international competitive sport. *Vet J.* **194**, 288-293 doi.org/10.1016/j.tvjl.2012.06.022
6. Nagy, A, Murray, J.K. and Dyson, S.J. (2014) Descriptive epidemiology and risk factors for elimination from Federation Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). *Equine Vet J.* **46**, 38-44 doi.org/10.1111/evj.12069
7. Younes, M., Barrey, E., Cottin, F. and Robert, C. (2016) Elimination in long-distance endurance rides: insights from the analysis of 7032 starts in 80-160km competitions. *Comp. Exerc. Physiol.* **12** (4) 157-167 doi.org/10.3920/CEP160022
8. Nagy, A., Dyson, S.J. and Murray, J.K. (2017) Veterinary problems of endurance horses in England and Wales. *J. Prev. Vet. Mede.* **140,** 45-52 doi.org/10.1016/j.prevetmed.2017.02.018
9. Bennet, E.D, and Parkin, T.D.H. (2018a) Fédération Equestre Internationale endurance events: risk factors for failure to qualify outcomes at the level of the horse, ride, and rider (2010-2015) *Vet. J.* **236**, 44-48 doi.org/10.1016/j.tvjl.2018.04.011
10. Bennet, E.D, and Parkin, T.D.H. (2018b) Federation Equestre Internationale endurance events: riding speeds as a risk factor for elimination (2012-2015). *Vet. J.* **236**, 37-43 doi.org/10.1016/j.tvjl.2018.04.011
11. Fédération Equeste Internationale (2019). FEI Endurance Reports and Statistics Available at: https (Accessed 06 December 2020).
12. Mira, M., Santos, C., Lopes, M.A. and Marlin, D. (2019) Challenges encountered by Federation Equestre Internationale (FEI) veterinarians in gait evaluation during FEI endurance competitions: an international survey. *Comp. Ex Physiol.* **15** (5) 1-8 doi/org 10.3920/CEP180058
13. Jeffcott, L., Leung, W. and Riggs, C. (2009). Managing the effects of the weather on the Equestrian Events of the 2008 Beijing Olympic Games. *Vet. J.* **182** (3) 412-429 doi.org/10.1016/j.tvjl.2009.07.037
14. American Association of Equine Practitioners (2019). Lameness exams: evaluating the lame horse. Available at: https://aaep.org/horsehealth/lameness-exams-evaluating-lame-horse (Accessed 10 February 2019)
15. Keegan, K.G., Dent, E.V., Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Walsh, DM., Cassells, M.W., Esther, T.M., Schiltz, P., Frees, K.E., Wilhite, C.L., Clark, J.M., Pollitt, C.C., Shaw, R. and Norris, T. (2010) Repeatability of subjective lameness evaluation of lameness in horses. *Equine Vet. J.* **42** Suppl 2 92-97 doi.org/10.2746/042516409X479568
16. Di Eugenio, B. and Glass, M. (2004) Squibs and discussions: the kappa statistic: a second look. *Computational Linguistics* **30** Suppl 1 95-101 doi.org/10.1162/089120104773633402
17. Dohoo, I., Ducrot, C., Fouricho, C., Donald, A. and Hurnik, D. (1996). An overview of techniques for dealing with large numbers of independent variables in epidemiological studies. *J Prev. Vet. Mede.* **29** (3) 221-239 doi/org 10.1016/s0167-5877(96)01074-4
18. Hosmer, D.W. and Lemeshow, S., (2000) Applied logistic regression 2nd edition. John Wiley and Sons Inc., New York, USA
19. Gardner, I.A. and Greiner, M (2006). Receiver-operating characteristic curves and likelihood ratios: improvements over traditional methods for the evaluation and application of veterinary clinical pathology tests. *Vet. Clin. Path.* **35** (1) 8-17 doi.org:10.1111/j.1939-165x.2006.tb00082.x
20. Bandos, A.I., Rockette, H.E. and Gur, D. (2010) Use of likelihood ratios for comparisons of binary diagnostic tests: underlying ROC curves. *J Med. Phys.* **37** (11) 5821-30: doi.org/ 10.1118/1.3503849
21. Bloom, F., Draper, S., Bennet, E., Marlin, D. and Williams, J. (2022) A description of veterinary eliminations within British National Endurance rides in the competitive season of 2019. *Comp. Ex. Physiol.* **18** (4) 329-338: doi.org/10.3920/CEP220003
22. Murray, R.C., Dyson, S.J., Tranquille, C. and Adams, V. (2006). Association of type of sport and performance level with anatomical site of orthopaedic injury diagnosis. *Equine Exercise Physiology: Equine Vet. J Suppl.* **36** 411-416 doi.org/10.1111/j.2042-3306.2006.tb05578.x
23. Lopes, M.A., Eleuterio, A. and Mira, M.(2018). Objective detection and quantification of irregular gait with a portable inertial sensor-based system in horses during an endurance race- a preliminary assessment. *J Equine Vet. Sci.* **70**, 123-129: doi.org/10.1016/j.jevs.2018.08.008

24. Landman MA, de Blaauw JA, van Weeren PR, Hofland LJ. (2004) Field study of the prevalence of lameness in horses with back problems. *Vet. Record* **155** (6) 165-168 doi: 10.1136/vr.155.6.165
25. Gomez Alvarez CB, Bobbert MF, Lamers L, Johnston C, Back W, van Weeren PR. (2008) The effect of induced hindlimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Vet J.* **40** (2) 147-152 doi:10.2746/042516408X250184.
26. Greve, L. and Dyson, S.J. (2013). Saddle slip and lameness. *Equine Vet. J.* **45** 570-577 doi.org/10.1111/evj.12029
27. Gunst, S., Dittmann, M.T., Arpagaus, S., Roepstorff,C., Latif, S.N., Klaassen,B., Pauli,C.A., Bauer, C.M. and Weishaupt, M.A. (2019). Influence of functional rider and horse asymmetries on saddle force distribution during stance and in sitting trot. *J. Equine Vet. Sci.* **78**, 20-28 doi.org/10.1016/j.jevs.2019.03.215
28. Mackechnie-Guire, R., Mackechnie-Guire, E, Fairfax, V. Fisher, M., Hargreaves, S and Pfau, T. (2020) The effect that induced rider asymmetry has on equine locomotion and the range of motion of the thoracolumbar spine when ridden in rising trot. *Equine Vet. J.* **88** doi.org/10.1016/j.jevs.2020.102946
29. Williams, J.M., Douglas, J., Davies, E., Bloom, F. and Castejon-Riber, C. (2021) Performance demands in the Endurance Rider. *Comp. Exerc. Physiol,* **17** (3)199-217. doi.org/10.3920/cep200033
30. Symes D, Ellis R. A preliminary study into rider asymmetry within equitation. *Vet. J.* **181**(1) 34-7. doi: 10.1016/j.tvjl.2009.03.016
31. Wyn-Jones, G. (1988) Equine Lameness. Blackwell Scientific, Oxford.
32. Bailey, C.J., Reid, S.W.J., Hodgson, D.R., Suann, C.J. and Rose, R.J. (1997). Risk factors associated with musculoskeletal injuries in Australian thoroughbred racehorses. *J Prev. Vet. Mede.* **32**, 47-55 doi.org/10.1016/S0167-5877(97)00009-3
33. Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M.,Singer, E.R., Webbon, P.M. and Morgan, K.L. (2005) Risk factors for fatal lateral condylar fracture of the third metacarpus/ metatarsus in UK racing. *Equine Vet. J.* **37**, 192-199 doi/org:10.2746/0425164054530641
34. Henley.W.E., Rogers, K., Harkins, L. and Wood, J.L.N, (2006). A comparison of survival models for assessing risk of racehorse fatality. *J Prev. Vet. Mede.* **74** (1) 3-20 doi.org/10.1016/j.prevetmed.2006.01.003
35. Martig, S., Chen, W., Lee, P.V.S., Whitton, R.C. (2014) Bone fatigue and its implications for injuries in racehorses. *Equine Vet. J.* **46**, 408-415 doi.org/10.111/evj.12241
36. Bennet, E.D. and Parkin, T.D.H. (2020) The impact of the mandatory rest period in Fédération Equestre Internationle endurance events. *Equine Vet. J.***52** 268-272 doi.org/10.1111/evj.13148
37. Kaneps, A.J. (2016) Practical rehabilitation and physical therapy for the general equine practitioner. *Veterinary Clinics of North America: Equine Practice,* **32**(1)167-80 doi:10.1016/j.cveq.2015.12.001
38. Georgopoulos, S.P. and Parkin, T.D.H.(2016). Risk factors associated with fatal injuries in thoroughbred racehorses competing in flat racing in the United States and Canada. *J. Am. Vet. Med. Assoc.* **249** (8) 931-939 doi.org/10.2460/javma.249.8.931
39. Teixeira, P.J., Carraça, E.V., Markland, D and Ryan, R.M. (2012) Exercise, physical activity, and self-determination theory: A systematic review. *International Journal of Behavioural Nutrition and Physical Activity* **9** (78) doi.org/10.1186/1479-5868-9-78
40. Owers, R. (2017) Equestrian sport and the concept of a social licence: presentation to the 2017 FEI General Assembly.
Available from: https://inside.fei.org/system/files/GA17_World_Horse_Welfare_PPT.pdf Last accessed: 06/01/2022.
41. Coombs S.L., and Fisher, R.J. (2012) Endurance riding in 2012: too far too fast? *Vet. J.***194**, 270-271 doi.org/10.1016/j.tvjl.2012.10.037
42. Lindinger, M.I. and Ecker, G.L. (1995). Ion and water losses from body fluids during a 163km endurance ride. *Equine Vet J,* **27** 314-322 doi.org/10.1111/j.2042-3306.1995.tb04944.x
43. Adamu, L., Adzahan, N.M., Rasedee, A. and Ahmad, B. (2014). Physical parameters and risk factors associated with the elimination of Arabian and crossed Arabian endurance horses during a 120-km endurance race. *J. Equine Vet. Sci.* **34 (**4) 494-499 doi.org/10.1016/j.jevs.2013.10.175
44. Foreman, J.H. and Lawrence, L.M. (1991). Lameness and heart rate elevation in the exercising horse. *J.Equine Vet. Sci.* **11** (6) 353-356 doi.org/10.1016/S0737-0806(06)81268-2
45. Younes, M., Robert, C., Cottin, F. and Barrey, E. (2015) Speed and cardiac recovery variables predict the probability of elimination in equine endurance events. *Plos One*: [online] e0137013. doi.org/10.1371/journal.pone.0137013

Supplementary file 1: Possible outcomes of EGB rides

Outcome	Explanation	Veterinary examination
Completion (C)	The horse completes the course and passes all of the veterinary examinations	Metabolic: measurement of heart rate (objective assessment) and subjective assessment of muscular tone, mucus membrane colour, capillary refill, dehydration status and general demeanour of the horse. Gait: the horse is trotted in hand, without tack 30m away from and towards the veterinarian and is considered to have a 'normal' gait pattern. All horses undergo both metabolic and gait assessments every time they present to the veterinarians.
Elimination	The horse is eliminated from competition but the reason has not been clearly documented	The horse will have undergone both metabolic and gait assessment as described above and 'failed' one or both components, but the elimination reason was not clearly documented.
Eliminated due to lameness	The horse had an un-even gait pattern during the 30m trot.	The horse will have first been seen by one member of the veterinary panel (VP) and during the gait assessment the veterinarian may have seen a clear lameness or the horse may have trotted poorly. A second trot should be completed (unless the horse is clearly very lame and welfare would be compromised to request a second trot). During the second trot additional members of the VP will watch (one additional member for national graded rides with a maximum and minimum speed and two additional embers for competitive endurance rides which have only a minimum speed). Each member of the VP votes whether the horse is lame or fit to continue, without discussion and their decision is given to the ground jury who issues the majority vote to the rider.
Eliminated due to metabolic compromise	The horse has failed the metabolic assessment.	Most commonly this is the heart rate is above 64bpm in the allowed time frame (dictated by the level of competition, most commonly within 20 minutes during the ride, 30 minutes at the end at national level). However, can also be due to a lack of gut sounds, poor capillary refill, dehydration or a combination.
Retired on course (RET)	The horse has passed the veterinary inspection and has subsequently been withdrawn by the rider	The horse must pass the veterinary inspection in order for the outcome to be marked as ROC, if the horse does not pass, the outcome will be either eliminated for metabolic compromise or lameness.
Disqualification (DSQ)	The rider or accompanying grooms are in breach of a rule	The horse has passed the veterinary inspections but there has been a rule breach- this may be a course error, failure to compete within the time frame, or more serious offences such as using prohibited substances/ abuse of horse or personnel.

Supplementary file 2: Potential risk factors used to inform univariable models and the source of data

Potential risk factor	Categorisation	Description	Source of data
Horse gender	Binary	Male/ Female	Endurance GB database
Horse age	Categorical	Horse age on day of ride,	Endurance GB database
Horse breed	Binary	'Arabian bloodlines' and 'Non-Arabians	Endurance GB database
Returning combination	Binary	Had the horse and rider competed as a combination previously	Endurance GB database
Days since previous competition	Categorical	Number of days since previous competitive start	Endurance GB database
Career length of horse (years)	Categorical	How many years of competitive history did the horse have recorded on the database	Endurance GB database

Career rides attempted	Categorical	Number of rides attempted in the career of the horse	Endurance GB database
Career rides completed	Categorical	Number of rides completed in career of the horse	Endurance GB database
Rides attempted in 2019	Categorical	Number of previous rides attended in 2019	Endurance GB database
Rides completed in 2019	Categorical	Number of previous rides attended in 2019	Endurance GB database
Career distance attempted	Categorical	Distance (km) attempted in the career of the horse	Endurance GB database
Career distance completed	Categorical	Distance (km) attempted in the career of the horse	Endurance GB database
Distance attempted in 2019	Categorical	Distance (km) attempted previously in 2019	Endurance GB database
Distance completed in 2019	Categorical	Distance (km) previously completed in 2019	Endurance GB database
Outcome of previous ride	Binary	Completed, Did not complete	Endurance GB database
Distance of previous ride	Categorical	What distance was the previous ride that the horse entered	Endurance GB database
Reason for previous elimination	Categorical	For the last ride that the horse was eliminated: what was the given reason	Endurance GB database
Number of eliminations in career	Categorical	The total number of times the horse had been eliminated in its competitive career	Endurance GB database
Eliminated in 2019	Categorical/ Binary	How may or had the horse been eliminated in 2019 – differed between models	Endurance GB database
Number of lameness eliminations in career	Categorical	The total number of times the horse had been eliminated lame in its competitive career	Endurance GB database
Lameness eliminations in 2019	Binary	Had the horse been eliminated lame in 2019	Endurance GB database
Days since previous elimination	Categorical	The number of days since the previous elimination of the horse	Endurance GB database
Days since previous lameness elimination	Categorical	The number of days since the horse previously eliminated lame	Endurance GB database
Ride attended	Categorical	Which of the rides that data was collected at 1-7	Prospective: ride attended

Number of loops	Categorical	How many loops was the ride	Prospective: ride attended
Category (where applicable)	Categorical	Graded endurance ride or competitive endurance ride	Prospective: ride attended
Number of days	Binary	Was the competition a single or multi-day ride	Prospective: ride attended
Speed of loop (kmph)	Categorical	How fast was each loop completed	Prospective: ride attended
Average speed (kmph)	Categorical	Average speed of all loops completed	Prospective: ride attended
Recovery time	Categorical	Amount of time taken to present to the vet (multi-loop only)	Prospective: ride attended
Final HR	Binary	Heart rate below 56 or not at the last vetting that the horse was presented at	Prospective: ride attended
Pacing strategy	Categorical	Calculated per loop, was there an increase, decrease or continuous pace when compared to the first loop. Multi-loop rides only	Prospective: ride attended
Air temperature	Categorical	Calculated as an average per loop and for the entirety of the ride having taken the air temperature hourly	Prospective: ride attended
Relative humidity	Categorical	Calculated as an average per loop and for the entirety of the ride having taken the relative humidity hourly	Prospective: ride attended
Trot up surface	Binary	Hard (concrete/ tarmac) or grass	Prospective: ride attended
Steepness	Binary	Subjectively identified as Steep or minimal climbs	Prospective: ride attended

Supplementary file 3:

Significant variables from univariable analysis for single loop starts for the Eliminated due to lameness outcome.

Risk Factor	Cases: Eliminated Lame Total n=30 n per category (%)	Controls: Not Eliminated Lame Total n=479 n per category (%)	OR	95% C.I.	P value
Steepness					
Minimal climbs	15 (4.3)	332 (95.7)	Reference	-	0.038
Steep	15 (9.3)	147 (90.7)	2.26	1.08-4.74	0.031
Rides attempted career					
1-10	8 (3.8)	202 (96.2)	Reference	-	0.096
>10	19 (7.4)	237 (92.6)	2.57	1.09-6.14	0.031
No previous rides	3 (7.0)	40 (93.0)	1.89	0.48-7.45	0.361
Distance (Km) attempted 2019					
≤150	10 (4.5)	214 (95.5)	Reference	-	0.176
>150	16 (7.7)	193 (92.3)	2.06	0.91-4.66	0.082
None	4 (5.3)	72 (94.7)	1.08	0.33-3.52	0.905

OR Adjusted Odds Ratio; 95%C.I., 95 % Confidence Interval.

Univariable model showing lameness elimination risk factors for horses competing in Endurance GB single loop rides (22-48km) from June-October 2019 at seven different venues.

Appendix 7

Conference Abstract Study 3a

Bloom, F., Bennet, E., Draper, S., Tabor, G., Marlin, D. and Williams, J. (2022) Inter-rater reliability of grading soft tissue palpation of the thoracolumbar epaxial musculature of endurance horses during competition: *Proceedings of the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapists (IAVRPT).* University of Cambridge, Cambridge, 18-20 August 2022. Available from: http://iarvpt2022.org/speakers

Author Contributions: F. Bloom, S. Draper, E. Bennet and J. Williams contributed to study design, data analysis and interpretation, preparation of the abstract and final approval of the abstract. F. Bloom executed the study. G. Tabor and D. Marlin contributed to study design, preparation of the abstract and final approval of the abstract. F. Bloom had access to all of the data and is responsible for data integrity and analysis.

Inter-rater reliability of grading soft tissue palpation of the thoracolumbar epaxial musculature of endurance horses during competition

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Background

During an endurance competition horses must pass a series of veterinary inspections in order to complete the ride [1,2].Within these veterinary inspections the horse's epaxial musculature is palpated. There have been no studies to date looking at the inter-rater reliability of back palpation during any equestrian competition. The aim of this study was to test the inter-rater reliability of back palpation during an endurance competition, using a categorical grading scale [3].

Materials and Methods

Nineteen horses of mixed breeding entered into a pleasure ride (13-24km) run by Endurance GB, were included in the study. All horses, as per the rules were presented to a veterinary inspection consisting of a trot in hand, 30 meters away from and back towards one of two licenced veterinarians. Having been declared fit to start the competition, the horses had their thoracolumbar epaxial musculature palpated by the veterinarian and graded based on the scale described by Merrifield-Jones, Tabor and

Williams (2019). The veterinarian gave their palpation score for both left and right side of the epaxial musculature to a scribe. A fourth-year veterinary student blinded from the veterinary surgeon's scores then palpated the musculature and also gave their scores to the scribe. The horses completed their ride (13-34km) and the veterinary inspection, including epaxial palpation was repeated. Inter-rater reliability of palpation scores were tested with a series of Fleiss' kappa analysis.

Results

At the start of the competition inter-rater reliability between veterinarian 1 and the veterinary student was significant and 'moderate' K=0.60 (95% CI 0.59- 0.6) p=0.004). The agreement between veterinarian 2 and the student at the start was significant and 'good' K=0.72 (95% CI 0.71-0.73, p<0.001). At the end of the ride the veterinary student had total agreement with each of the veterinary surgeons K=1.00 (95% CI 0.99-1.01, p<0.001). Overall, the agreement between veterinarian 1 and the veterinary student was excellent K=0.89 (95% CI 0.88-0.89), p<0.001. The overall agreement between veterinarian 2 and the veterinary student was also excellent K=0.82 (95% CI 0.81-0.83), p<0.001.

Conclusions

This study identified that the categorical rating scale used for manual palpation of the equine epaxial musculature during endurance competition has excellent inter-rater reliability between veterinary surgeons and a veterinary student. In order to establish the validity of the scale during competition further information and testing is necessary.

Key words: endurance riding, equine back pain, manual palpation

References:

1. Endurance GB (2022) Endurance GB Rule Book. https://egb.myclubhouse.co.uk/Cms/Spaces/RULES/01+General+and+FAQs (Accessed 08 March 2022)
2. Fédération Equestre Internationale (2022). FEI Endurance Rules 2022 Available at: https://inside.fei.org/fei/disc/endurance/rules (Accessed 06 April 2022)
3. Merrifield-Jones M., Tabor G. and Williams J. Inter- and intra-rater reliability of soft tissue palpation scoring in the equine thoracic epaxial region. J Equine Vet Sci. 2019; 83;102812

Appendix 8

Conference Abstract Study 3b

Bloom, F., Bennet, E., Draper, S., Tabor, G., Marlin, D. and Williams, J. (2022) Back pain on epaxial muscle palpation as a risk factor for lameness elimination during endurance competitions: *Proceedings of the 11th Symposium of the International Association of Veterinary Rehabilitation and Physical Therapists (IAVRPT).* University of Cambridge, Cambridge, 18-20 August 2022. Available from: http://iarvpt2022.org/speakers

Author Contributions: F. Bloom, S. Draper, E. Bennet and J. Williams contributed to study design, data analysis and interpretation, preparation of the abstract and final approval of the abstract. F. Bloom executed the study. G. Tabor and D. Marlin contributed to study design, preparation of the abstract and final approval of the abstract. F. Bloom had access to all of the data and is responsible for data integrity and analysis.

Back Pain on epaxial muscle palpation as a risk factor for lameness elimination during endurance competitions

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Background

Lameness has been identified as the leading cause of elimination from endurance competitions [1-8] and within British national competitions hindlimb lameness is more common than forelimb lameness [9]. There is evidence to support the co-existence of thoracolumbar back pain and hindlimb lameness in horses [10]. The aim of this study was to identify if thoracolumbar back pain during endurance competition was a risk factor associated with elimination, more specifically lameness elimination, from competition.

Materials and Methods

The study took place across eight days of British national endurance competitions across five different venues in 2021. During the veterinary inspection, in addition to assessing lameness, when palpating the epaxial musculature, veterinarians were asked to grade the horses backs based on a categorical scale [11]. A series of Pearsons chi squared tests were used to identify significant differences between back palpation scores and successful or unsuccessful outcomes. Univariable models were constructed for risk factors for two outcomes a) eliminated vs not eliminated b) lame vs not lame. Risk factors were

considered significant to take forward to multivariable analysis with a P value of ≤ 0.1. Multi-variable logistic regression models were constructed using a backwards stepwise process with an omnibus test of model co-efficients applied at each step.

Results

Across all rides 44 horses started with an asymmetrical back palpation score, of those 29.5% (n=13) were subsequently eliminated for lameness. In comparison, 8.5% (n=32) of the horses which started with a symmetrical back palpation score (n=377) were eliminated lame. A significant difference was found (p<0.001) between horses who palpated a score of 0-2/5 and horses who palpated a higher score of >3/5, whether they were eliminated or not and whether they were lame or not. Horses who presented with an asymmetrical back palpation score throughout the ride were at increased odds of elimination from the competition (Odds ratio 2.31, 95% CI 1.15-4.62, P= 0.018) and increased odds of lameness (Odds ratio 4.16, 95% CI 1.92-9.01, P <0.001).

Conclusions

Asymmetrical back palpation scores during endurance competitions are a significant risk factor for elimination and specifically lameness elimination during British national endurance competitions. Higher palpation scores, associated with a pain response, were found to be significantly different in terms of elimination and lameness when compared to palpation scores considered normal or slightly hypertonic. This indicates back pain in endurance horses during competition should be further investigated in order to minimise risk of lameness eliminations and optimise welfare.

Key words: endurance riding, equine back pain, risk factor, lameness, equine welfare

References:

1. Nagy A, Murray J and Dyson S. Elimination from elite endurance rides in nine countries: a preliminary study. Equine Veterinary Journal 2010; 38:637-643
2. Fielding C.L, Meier C.A., Balch O.K. and Kass P.H. Risk factors for the elimination of endurance horses from competition. Journal of the American Veterinary Medical Association 2011; 239 (4) 493-498.
3. Nagy A, Dyson S.J. and Murray J.K. A veterinary review of endurance riding as an international competitive sport. The Veterinary Journal 2012, 194: 288-293.
4. Nagy A, Murray J.K. and Dyson S.J. Descriptive epidemiology and risk factors for elimination from Fédération Equestre Internationale endurance rides due to lameness and metabolic reasons (2008-2011). Equine Veterinary Journal 2014*;* 46:38-44
5. Younes M, Barrey E, Cottin, F and Robert, C. Elimination in long-distance endurance rides: insights from the analysis of 7032 starts in 80-160km competitions. Comparative Exercise Physiology 2016; 12 (4): 157-167
6. Nagy A, Dyson S.J and Murray J.K. Veterinary problems of endurance horses in England and Wales. Preventative Veterinary Medicine 2017; 140: 45-52.
7. Bennet E.D and Parkin T.D.H. Fédération Equestre Internationale endurance events: risk factors for failure to qualify outcomes at the level of the horse, ride, and rider (2010-2015). The Veterinary Journal 2018a; 236: 44-48.
8. Bennet E.D, and Parkin T.D.H. Fédération Equestre Internationale endurance events: riding speeds as a risk factor for elimination (2012-2015). The Veterinary Journal 2018b; 236:37-43:
9. Bloom F, Draper, S, Bennet E, Marlin D and Williams J. A description of veterinary eliminations within British national endurance rides in the competitive season of 2019. Comparative Exercise Physiology (2022) [online] 1-10.
10. Landman MA, de Blaauw JA, van Weeren PR, Hofland LJ. Field study of the prevalence of lameness in horses with back problems. Veterinary Record 2004; 155(6): 165-168.
11. Merrifield-Jones M., Tabor G. and Williams J. Inter- and intra-rater reliability of soft tissue palpation scoring in the equine thoracic epaxial region. J Equine Veterinary Science 2019; 83;102812

Appendix 9

Doctoral criteria as listed by University of West England and how they are fulfilled by the studies within the thesis.

(i) Have conducted enquiry leading to the creation and interpretation of new knowledge through original research, shown by satisfying scholarly review by accomplished and recognised scholars in the field.

Study 1: conducted retrospective analysis in order to allow original research to take place. Accepted and published after double blind peer review.
Study 2a: used knowledge gained from study 1 to build and undertake original research. Accepted and published after double blind peer review.
Study 2b: used knowledge gained from study 1 to build and undertake original research. Undergoing double blind peer review.
Study 3a: used knowledge gained from studies 1 and 2, combined with previous research in order to undertake original research of palpation scoring within competition which has not previously been completed. Abstract accepted and presented at International Association of Veterinary Rehabilitation and Physical Therapy Symposium.
Study 3b: used knowledge gained from studies 1, 2 and 3a, combined with previous research in order to undertake original research of considering palpation scoring within competition as a risk factor for elimination/ lameness elimination which has not previously been completed. Abstract accepted and presented at International Association of Veterinary Rehabilitation and Physical Therapy Symposium.

(ii) Can demonstrate a critical understanding of the current state of knowledge in the field of theory and/or practice.
Demonstrated throughout the literature review and within the introductions and discussions of each of the studies within the thesis. The critique of the literature established the areas of knowledge that are lacking within the field. This formed the development of the series of sequential studies, each informing the next.

(iii) Show the ability to conceptualise, design and implement a project for the generation of new knowledge at the forefront of the discipline or field of practice including the capacity to adjust the project design in light of emergent issues and understandings.
Study 1: Background study to identify gaps in current knowledge
Study 2a & b: New knowledge gained regarding risk factors in National level sport and that they differ between competitive levels. Also, identification of hindlimb lameness being more prominent than forelimb lameness, changed the direction of the third study.
Study 3a & b: Project designed and implemented based on the generation of knowledge from the first and second studies. Study 3a had to be implemented to ensure the palpation scale used in study 3b was reliable and valid.

(iv) Can demonstrate a critical understanding of the methodology of enquiry
Each study has different methodology explained in Chapter 4 of the thesis where the rationale for each methodology is confirmed.

(v) Have developed independent judgement of issues and ideas in the field of research and/ or practice and are able to communicate and justify that judgement to appropriate audiences.
The series of sequential studies demonstrates independent judgement of issues and ideas as each study informs the next. The reasoning and rationale is discussed within each chapter. Communication to appropriate audiences can be demonstrated by publication of two papers, one paper under review and two studies presented at the IAVRPT Symposium 2022. The presentation of the outcomes of the studies have also been adapted to different audiences, including the Board of Directors of Endurance GB and competitors within the sport.

(vi) Can critically reflect on their work and evaluate its strengths and weaknesses including validation procedures.
The limitations of each study are acknowledged and discussed within each of the study chapters. The strengths are also shown by the implications and impact of each study. Validation procedures such as ensuring the methods used are appropriate by means of critical analysis of the methods, implementing procedures such as inter-rater reliability of veterinary surgeons and checking collinearity/ interactions within multivariable models.

Relationship of each study to thesis objectives and doctoral criteria

The list of objectives of the thesis and how they link to each study and satisfy the doctoral criteria and taken from the UWE Postgraduate handbook

Objective Number	Objective Description	Study	Doctoral Criteria I	II	III	IV	V	VI
1	To identify risk factors associated with elimination and specifically lameness eliminations of horses registered with the governing body of British endurance, Endurance GB from information recorded and identify gaps within the data.	1	X	X		X		X
2	To record the risk factors considered missing in the previous data set and consider whether these impact on lameness and lameness eliminations.	2a 2b 3b	X	X	X	X	X	X
3	To establish which limb(s) are most frequently identified as lame at the point of elimination from competition and whether risk factors change depending on the level of competition	2a 2b 3b		X	X	X	X	X
4	To consider whether an additional component of the veterinary inspection, thoracolumbar epaxial muscular palpation could identify an additional risk factor for eliminations and specifically lameness eliminations.	3b	X	X	X	X	X	X
5	To assess the inter-rater reliability of lameness evaluations and thoracolumbar epaxial muscular palpation during the veterinary inspections at competitions	2b 3a	X	X	X	X	X	X